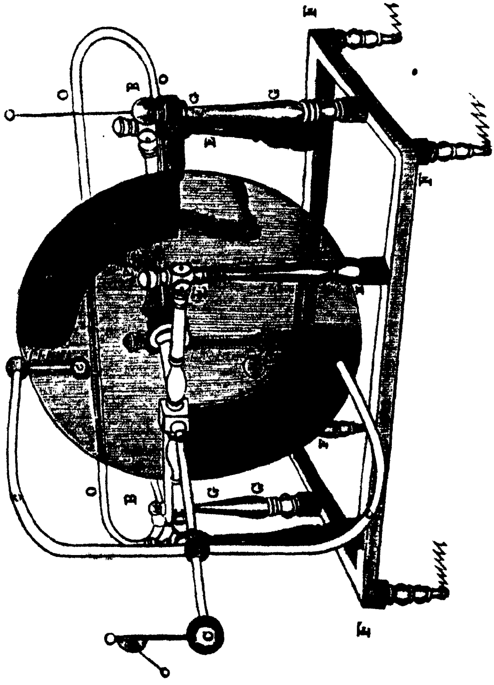
LECTURES ON ELECTRICITY.



LECTURES

ON

ELECTRICITY,

DELIVERED IN

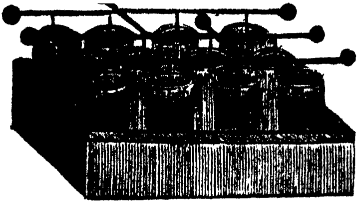
THE ROYAL VICTORIA GALLERY,

MANCHESTER,

DURING THE SESSION OF

BY WILLIAM STURGEON,

SUPERINTENDENT AND LECTURER OF THE ROYAL VICTORIA GALLERY
OF PRACTICAL SCIENCE, MANCHESTER; FORMERLY LECTURER
ON EXPERIMENTAL PHILOSOPHY AT THE HON. EAST
INDIA COMPANY'S MILITARY ACADEMY,
ADDISCOMBE; &c., &c., &c.



LONDON:
PUBLISHED BY SHERWOOD, GILBERT, AND PIPER.

MDCCCXLII.

DEDICATION.

TO THE PROPRIETORS AND ANNUAL MEMBERS OF THE ROYAL VICTORIA GALLERY OF PRACTICAL SCIENCE, MANCHESTER.

LADIES AND GENTLEMEN,

In dedicating this small volume I am actuated by the liveliest feelings of gratitude and respect for the honour with which you have favoured my humble labours in this Institution by your constant attention, not only to this individual course of lectures, but throughout the whole of two long seasons, during each of which more than fifty lectures on various branches of physical science have been delivered before you.

It has been particularly gratifying to me, also, that although each lecture was delivered twice in the same day, your attendance both morning and evening was unremitting, and with increasing numbers from the commencement to the termination of my labours amongst you.

To the Annual Members of this Institution I am particularly indebted, for unitedly manifesting their appreciation of my services by an unanimous vote of thanks at their last meeting in the Lecture Room: which mark of respect I with pleasure avail myself of this opportunity of acknowledging.

For these and other marks of your favour, both individually and collectively, I beg to subscribe myself,

Ladies and Gentlemen,

Your most humble and

Obliged Servant,

WILLIAM STURGEON.

CONTENTS :

PAGE.

PAGE.

ELEMENTARY

LECTURES ON ELECTRICITY,

In introducing these lectures to the Members of the Royal Victoria Gallery, as they are intended for instruction rather than display, it will be necessary to avoid, as much as possible, all those phrases and technicalities which not only puzzle, but absolutely mislead, even those who have, in their own estimation, much higher pretensions to a knowledge of such fashionable appendages to scientific literature, than the persons for whose instruction these lectures are intended; and to whom, therefore, I shall address myself with freedom, and in the plainest language that the present state of these subjects appear to me to be capable of admitting. I do not, however, wish to enter into any engagement that would limit my labours to the humble task of a mere detail and exhibition of facts, without linking them together in some theoretical system or systems of physical laws; because one of my objects is to trace to the same operations of nature, those facts, and those only, which are easily, and not otherwise, explained, by that code of laws which governs the display of one peculiar class of phenomena: and not to encumber any theoretical system with those phenomena to which they do not appear to belong; but to explain each class of phenomena by its own peculiar code of laws; or if you please, by its own peculiar theory. Hence it is that, I shall be expected to be explicit on every point on which I touch, both experimental and theoretical, and either undertake to explain all those experimental facts which I may consider necessary to bring forward, or candidly acknowledge that they are inexplicable upon the theoretical principles which I advance.

It will here be necessary to enter into certain conditions with my readers, respecting some of those theoretical points, which to many philosophers, even of the present day, appear to be somewhat doubtful: though I believe the opinions of many others are favourable to those theoretical views by which I propose to be guided.

I wish to be understood then, before I proceed any farther, that, besides those recognised portions of matter which appear to be the principal part of the materials which constitute the earth and its atmosphere, such as the various kinds of solids and fluids which usually receive these general appellations, there are, at least, *three* others, whose reciprocal actions on each other, and whose peculiar operations on the former classes of bodies, are productive of the most surprising, and, in our present state of physical knowledge, the most interesting phenomena that nature has revealed to man. These are the *electric matter*;—the *magnetic matter*;—and the *calorific matter*; each of which I shall consider as a distinct element, possessing peculiarities of force and modes of action, and exhibiting phenomena which no other kind of matter has the power of displaying. They, however, operate on one another in a very remarkable manner, by their peculiar reciprocal excitations, and are thus productive of phenomena which have led some philosophers to the belief of their complete identity.

The fineness and subtilty of the *electric*, the *magnetic* and the *calorific* particles, lead us to infer that they insinuate themselves into the pores of all other kinds o terrestrial matter; and their inactivity, when unmolested in these their natural habitations, is obviously a consequence of the equilibrium of their respective forces when in an undisturbed state. So long, therefore, as these natural equilibriums remain unmolested, all of these material agents are perfectly inactive,* and exhibit no phenomenon whatever. Hence it is, that some exciting process becomes absolutely necessary before any of their respective phenomena can be produced. The processes of excitation which may be employed for bringing these agencies into a state of activity are exceedingly various, as I shall have occasion to show in many parts of these lectures; but, for the present, it will be sufficient that I describe one simple mode only, of exciting each individual agent, by means of which certain phenomena, of each class, may very easily be brought into existence.

If you take a stick of sealing-wax, and, without any preparation, present it to any very light article, such as small feathers, bits of thin paper, &c., placed either on a table, book, dish, &c., you will not perceive any action whatever exercised by the wax on these light bodies. In this case you may easily imagine, that there is a complete electrical equilibrium in the body and on the surface of the sealing-wax; and also in the light articles to which it was presented: and that it is in consequence of this equilibrium that the electric matter is perfectly inert, and will not act upon the light bodies which you had prepared. I wish it to be understood, however, that, although the electric forces of the wax had not a sufficient degree of intensity to cause a disturbance in the light bodies, it is still possible, that there might not be an absolute uniformity in the distribution of the electric matter, either on the wax or on the other bodies.

* I am aware that, to the mathematician, the term *inactive* may appear to convey a doubtful meaning; because forces holding one another in equilibrio do so by means of their *activity*, though perfectly *inactive* on other forces, and on surrounding matter. It is the *inactivity* on surrounding matter that is here to be understood.

Now warm the stick of sealing-wax, taking care not to heat it too much; and then rub it on the sleeve of your coat.

By this simple process you have disturbed the previous electric equilibrium of the sealing-wax, and caused the electric forces to become sufficiently active to produce motion in the light bodies to which you now may present the stick. They will rise up and cling to the wax, often changing their positions on its surface, and sometimes they will be suddenly thrown off again to a neighbouring body, to which they will attach themselves for a short time, and again jump back to the sealing-wax; again leave it, and again return; and so on for several times before the action ceases. These motions of the light bodies are electric phenomena; and may be repeated many times by renewing the activity of the electric forces: by again rubbing the dry and warm sealing-wax on the sleeve of your coat.

If you prefer a piece of dry woollen cloth to the sleeve of your coat, you may rub the sealing-wax against it with the same effect. Or you may use a piece of dry and warm flannel to rub your wax against; or the fur side of a hare-skin, or a rabbit-skin, which is, perhaps, better than any of the previously named substances. But whatever you may choose to rub the sealing-wax with, let me advise you to have it *warm* and *dry*, because much of your success in the experiment will depend on those conditions of both the *rubbing substance* and the sealing-wax.

It will now be proper to inform you that the motions which the light bodies make *towards* the sealing-wax are considered to be the effect of an electrical *attraction*, exerted between them and the wax; and their motions *from* the wax are considered to be due to an electrical attraction exerted between them and the body to which they fly, and for a while attach themselves. Beside the force of electrical *attraction*, there is also a force of electrical *repulsion*, which played a certain part in these motions, and to which I shall solicit your attention more particularly in due course as we proceed.

There are many other bodies which exhibit this class of electrical phenomena, by treating them in the manner I have described for sealing-wax. Such is the case with amber, sulphur, &c. If you use a glass tube for the exhibition of these electrical phenomena, it will also require to be warm and dry, not only on the outer surface, but on the inner surface also; and the rubbing substance may be soft silk, or other flexible matter. A piece of old black silk answers as well as any thing. The rubbing process, in all these cases, whatever may be the nature of the articles employed, is called *excitation*.

When your sealing-wax, or glass tube, is well excited, and held at a short distance above the light bodies, the latter may be made to produce rapid motions to and fro, and dance on the table as if animated, by the active electric forces to which they are exposed. If you place your light bodies on a pewter or a silver plate, or on any metallic flat surface, their dancing motions will be more lively than when placed on any other kind of material; and if you touch the metallic plate with one of your fingers, the activity of the motions will be considerably improved.

I will now solicit your attention to a simple mode of producing *magnetic* phenomena, which I consider to emanate from the energies of an agent perfectly distinct from the electric. You must allow me to suppose that you are already acquainted with an instrument called the magnetic needle: it is sometimes called the compass needle; and when supported on a finely-pointed pivot, so as to rest on a horizontal plane, one of its ends, in these latitudes, points towards the north, inclining a little towards the west of that point; and its other extremity, consequently, points a little to the east of the true south.* In many other parts on the earth's surface, the direction in which the magnetic needle places itself when at rest, relatively to the geographical meridian, is very different to that in which it reposes in this country. But in every part of the world it is subject to certain influences which are capable of communicating to it peculiar motions, and

* The mean magnetic variation at Greenwich Observatory, for March, 1842, was 23° 10′ 39″ west. Mean dip of the needle, 68° 29·33′.

placing it stedfastly in other positions than those which it assumes when no such local influences are present.

If, after the magnetic needle has come to rest, you were to turn it on its pivot with your finger, so as to point to some other quarter of the world, and then take your finger away from it, the needle would commence a series of movements which would terminate by its settling again in its former position; showing that, by the operation of some hidden force or agency, the needle had a greater tendency to repose in one direction than in another; which, in England, and in many other countries, is more near to the meridian than to a line placed east and west, or to a circle of latitude at that place. With respect to the cause of this peculiar tendency of the needle to place itself in a north and south direction, I can only say, in this place, that it is so completely under the control of the magnetic forces of the earth, that they alone are supposed to constrain it to assume that particular direction; but why the earth is magnetic, and why its magnetic forces should be so situated as to operate on the needle in that peculiar manner, are matters which philosophers have not yet determined. There are, however, certain laws of magnetic action which are well known, and which I will explain in a future lecture, my object, at present, being that of showing the simplest and most easily produced specimens of the three grand classes of phenomena which are so eminently conspicuous in nature, and so easily distinguished from each other.

Perhaps the simplest process for bringing the calorific matter from a state of inactive repose to a state of such activity as to produce ignition and fire, would be that of striking flint against hardened steel, and thus igniting detached particles of the metal, which, in their turn, would ignite gunpowder, tinder, &c. In this case the calorific matter, which, previous to the collision of the flint and steel, was perfectly inactive, has, by the operation, become suddenly compressed into a smaller compass than that which it previously occupied, and become active fire in the condensed state it is made to assume by the blow that is given to it by the flint and the steel.

The blacksmith makes a nail red hot, by giving to it a a few smart blows with a hammer; and the Indian obtains his fire by rubbing two blocks of wood against each other. These, and many other mechanical processes, are productive of fire, by calling into action the calorific matter which, previously, was so perfectly inert as to be incapable of igniting the most inflammable substance. In some chemical compounds this latent calorific matter is so susceptible of activity by mechanical operations, that it requires extreme caution to prevent their ignition, even during the necessary processes of preparing them, and transferring them from one vessel to another.*

In the course of these lectures I shall have occasion to show that an *active* portion of the electric matter has the power of disturbing an inactive portion, and thus causing it to become active also. Active portions of the electric matter will also disturb other active portions of it, and become productive of very interesting phenomena. Active magnetic matter is also productive of its own class of phenomena, by the operation of its peculiar forces on other portions of matter of its own kind: such, also, is the case with the calorific matter; for one portion will disturb another portion, and thus become the exciting cause for the display of other calorific phenomena. Moreover, these distinct kinds of matter have the power of reciprocally operating on one another, in such a manner as to become the exciting agents for the display of each others phenomena. Hence it is that, we employ the terms *electro-magnetism,—magnetic-electricity,—thermo-electricity,* &c., the adjective in each expression implying the exciting agent, and the noun the character of the phenomena produced. I shall also have to employ the terms *galvanic-electricity* and *voltaic-electricity:* all of which terms I shall endeavour to explain in their places as I proceed.

* Some fatal accidents have lately occurred in London by the tremendous explosions of large quantities of the composition for filling percussion caps.

LECTURE II.

Having in the first lecture given specimens of the electric, the magnetic, and the calorific classes of phenomena, I will now proceed to offer to your notice a few other preliminaries which will be necessary to be understood before we can enter very far into the illustration of electricity. In the first place, then, I must present to your notice a very well established fact respecting a property of atmospheric air, which is applicable to all the gases, and also to the electric matter. When the air within the receiver of an air-pump has become attenuated by the action of the pump, it still occupies the whole capacity of the receiver, and does not settle, as water would do, into the lower part of the receiver, so as to occupy that part only. Let us, for example, suppose that the receiver originally contained a quantity of air, which we will call 100. If, now, by the action of the pump, 50 parts were to be withdrawn, the receiver would retain the other 50 parts only, or just one-half of the original quantity. But these 50 remaining parts of the air would still occupy the whole capacity of the receiver. Suppose, now, that the pump is again set to work, and it withdraws from the receiver just one-half of the 50 parts that were left by the first operation; it is easy to understand that, since the half of the 50 parts has left the receiver, there can be only 25 parts remaining. But these 25 parts, which are only a quarter of the original quantity, do not subsist in their original dimensions, and so occupy one quarter only of the receiver; nor do they subsist in one-half of the capacity of the receiver, in their dimensions previous to the last operation of the pump; but absolutely fill the whole capacity of the receiver as decidedly as the 100 original parts filled it. And in the same manner the whole capacity of the receiver would be occupied by any remaining portion of air, even after that portion had become too small for the pump to effect it any longer. Now, in all these cases, it is obvious that the air has expanded by virtue of some inherent power with which it is naturally endued. This power is usually called *repulsion*: and it is admitted by all philosophers that the particles of air have a natural inherent repulsive force, by means of which they are continually endeavouring to recede from one another. Hence it is that air becomes expansible to an amazing degree, and any portion of it may be made to occupy a space immensely greater than that which it occupies naturally at the surface of the earth.

On the other hand, any portion of the air at the earth's surface may be condensed into a smaller and smaller compass than that which it naturally occupies. If, for instance, an inverted glass tumbler were to be held just over the surface of the water contained in a glass jar, it would contain a certain quantity of air, which would occupy the whole capacity of the tumbler; but if this tumbler with its contained air, were to be pressed down into the water, the air would no longer occupy the whole capacity, but would be compressed into a less space, and a portion of water would enter the lower part of the inverted vessel: and the deeper in the water the confined air was taken, the less space would it occupy. This is a very decisive experiment, and the simplest I can think of for showing the compressibility of air. A small piece of cork may be placed on the surface of the water beneath the tumbler, which will always indicate the height to which the water ascends inside, at different depths, and consequently show the space occupied by the air. Having now become acquainted with these two facts, the expansibility and the condensibility of air, we learn that air has the quality of being *elastic*. But it must not be forgotten that this *quality of elasticity* which air possesses is a mere consequence of the natural *inherent repulsion* of its particles.

By keeping in view the consequences of the attribute of repulsion which air possesses, whilst contemplating electrical phenomena, we shall be enabled to account for a great variety of facts which would otherwise appear inexplicable. The electric matter, or, the electric fluid, as it is more frequently called, is much more highly elastic than common air, and therefore can be condensed and attenuated, by employing proper means, to a very great extent; but its motions, when in the act of expanding, are performed with such an immense degree of activity that, although several philosophers have attempted to ascertain its velocity, their efforts have hitherto been unavailing: and its force, under some circumstances is beyond all calculation.

Besides the quality of elasticity in common with air, and other kinds of gaseous matter, the electric fluid possesses others peculiar to itself. Its activity is superior to that of any other known kind of matter; it enters into the pores of the most compact solids, and is to be found in every kind of tangible matter. It constitutes a portion of the atmosphere, and frequently accumulates to an amazing extent in the clouds, gradually increasing in density, till its elasticity becomes sufficiently great to enable it to burst from its aerial prison in a compact form, and exhibit itself in all the majesty and splendour of lightning.

It is a remarkable fact that the motions of the electric fluid are much more facilitated by some classes of bodies than by others. The metals are considered to facilitate the progress of the electric fluid to a greater extent than any other class of bodies whatever; but the metals themselves, as individual bodies, vary very considerably in the degree of facility which they respectively offer to the motions of the electric fluid: copper offering the greatest facility of any known body, and lead, or iron, perhaps, the least of any of the metals. But it would be impossible, in the present condition of the science, to give a correct table of the various degrees of facility which different bodies offer to the motions of the electric fluid: for, although much has been attempted to be done, and much more pretended to have been done, in determining so important a particular in electricity, it is lamentable in the extreme to have to acknowledge that but very little has absolutely been accomplished in this interesting inquiry.

Those bodies which offer comparatively great facilities for the motion of the electric fluid, are usually called *conductors*; and those which offer the least facility, being supposed to present an absolute *resistance* to the motions of the fluid, and in some cases to arrest them altogether, have been called *non-conductors*. Now, as the terms *conductors* and *non-conductors* of electricity, are well known from their long use, and as I am not disposed to attempt to supplant, by others, any familiar technicalities, such as these, which have been of considerable benefit in the promotion of the science, I can find no objection to place before my readers the following tables of what has been considered *conductors* and *non-conductors* of electricity, which I find in Mr. Singer's excellent "Elements of Electricity:"—

CONDUCTORS.	NON-CONDUCTORS.
All the known metals,	Shell-lac, amber, resins,
Well burnt charcoal,	Sulphur, wax, jet,
Plumbago,	Glass, and all vitrifications; talc,
Concentrated acids,	The diamond, and all transparent gems,
Powdered charcoal,	Raw silk, bleached silk, dyed silk,
Diluted acids and saline fluids,	Wool, hair, feathers,
Metallic ores,	Dry paper, parchment, and leather,
Animal fluids,	Air, and all dry gases,
Sea water,	Baked wood, dry vegetable substances,
Spring water,	Porcelain, dry marble,
River water,	Some silicious and argillaceous stones,
Ice and snow,	Camphor, elastic gum, lycopodium,
Living vegetables,	Native carbonate of barytes,
Flame,	Dry chalk, lime, phosphorus,
Smoke,	Ice at — 13° of Fah.,
Steam,	Many transparent crystals, when perfectly dry,
Most saline substances,	The ashes of animal and vegetable substances,
Rarified air,	Oils (the heaviest appear the best),
Vapour of alcohol and æther,	Dry metallic oxides.
Most earths and stones.	

Mr. Stephen Gray, a pensioner of the Charter House, was the first person who discovered the conducting power of metals, and to ascertain the great difference, in this respect, between a metallic wire and a cord of hemp or silk. This discovery was made on the 3rd of July, 1729; it was perfectly accidental, and occurred from the circumstance of substituting a metallic wire for the suspension of an electrized body, in lieu of a silken cord which had broken. Dr. Priestley, at the suggestion of Dr. Franklin, seems to have been the first philosopher who undertook a series of experiments, for the purpose of ascertaining the different degrees of conducting power possessed by different bodies. Several other philosophers have also paid considerable attention to this subject, though, as I have before stated, little more has been accomplished than the ascertaining of a few general facts; for there still remains much difference in the tables given by different authors. The following table is taken from Cavallo's "Complete Treatise of Electricity," second edition, published in 1782:—

CONDUCTORS.	NON-CONDUCTORS.
Gold,	Glass, and all vitrifications, even those of metals,
Silver,	All precious stones: the most transparent the best,
Copper,	All resins and resinous compounds,
Brass,	Amber,
Iron,	Sulphur,
Tin,	Baked Wood,
Quicksilver,	All bituminous substances,
Lead,	Wax,
Semi-metals,	Silk,
Animal and vegetable charcoal,	Cotton,
The fluids of the human body	All dry animal substances, as feathers, wool, hair, &c.,
All fluids, excepting air and oils,	
The effluvia of flaming bodies	
Ice,*	

* According to Achard, ice conducts the electric fluid whilst it remains above a certain temperature, but is not a conductor below that temperature.

CONDUCTORS.	NON-CONDUCTORS.
Snow,	Paper,
Most saline substances, the best being metallic salts,	White sugar,
Soft stoney substances,	Sugar candy,
Smoke,	Air,
The vapours of hot water,	Oils,
Highly attenuated air.	Calces of metals,
	The ashes of animal and vegetable substances,
	All dry vegetable substances,
	All hard stones, the hardest the best.

Professor Cumming, in his translation of Demonferrand's "Manual of Electro-Dynamics," gives the following table of the conducting powers of metals:—

Silver,	Tin,
Copper,	Platina,
Lead,	Palladium,
Gold,	Iron.*
Brass, zinc,	

It would be useless to give any more tables of the conducting and non-conducting powers of different kinds of matter, as there are no two that agree in every particular. For my own part, I am of an opinion that all bodies are conductors more or less, metals being the best class of conductors, and vitrious and resinous substances being about the worst. Much, however, will depend upon the extent of the electric force employed, and much again upon the space over which that force has to operate.

When any body in a state of electrization is supported on a non-conductor, as by a glass stem, or suspended by silk or other non-conductor, it is said to be *insulated*. There are many other technicalities which I shall have to notice as I proceed, but it will not be necessary in this place to introduce any more than those already mentioned.

* In all these tables, those bodies which are first in the list are considered the best of their kind, and take precedence of all those below them.

The motions of light bodies by the action of sealing-wax, glass, &c., already noticed in the last lecture, are phenomena of a highly interesting character, and are a portion of those which must necessarily be regarded as of an elementary character, independently of a knowledge of which, no plausible hypothesis of electricity could possibly be formed: on which account it will be necessary to recur to them again, and to point out other experiments from which similar results may be obtained. But it must not be expected that because the results, by various modes of experimenting, are similar or of precisely the same character, that they should be of precisely the same extent, or degree of power. The light emanating from two burning candles of different dimensions, may be, and generally is, of precisely the same character, but the *intensity* of the light, from the two sources may be very different: or, we may say, the *quantity* of light proceeding from one of the candles is very different to the *quantity* of light proceeding from the other. If similar reasoning be applied to the display of electrical phenomena, we may easily understand that, notwithstanding the identity of the *character* of the motions produceable from different sources of electric action, the quantity, or intensity, of those motions may be very different. And as some sources are sufficiently vigorous to put into motion bodies of a considerable magnitude, and others so exceedingly feeble as to require the employment of the most delicate apparatus for their detection, it will be necessary, before proceeding to other experiments, to describe such instruments or pieces of apparatus as may be wanted for carrying on those experiments with which we ought to be made familiar as soon as possible.

The instruments which are usually employed for the detection of feeble electric action, are called *electroscopes*, of which we have several forms. The simplest electroscope, and one which may be frequently employed, is merely a single fibre of flax, silk, or any other such flexible article as will bend to slight electric forces. The fibre may be supported in any manner you please, so that it be permitted to hang freely in a vertical direction.

Fig. 1.

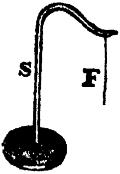


Fig. 1 is an electroscope of this kind, where the fibre F is supported by, and hangs freely from, the brass stem S. Having rubbed a stick of sealing-wax against the sleeve of your coat, present it to the lower end of the suspended fibre, and you will see that it bends towards the sealing-wax; and if you bring them sufficiently near to each other, the fibre will adhere to the wax for some considerable time. In this experiment you have an electric *attraction* exhibited as decidedly as by the motions of the pieces of paper in the former experiments: but if the fibre be not very dry and warm, you have not that jumping to and fro, as with the pieces of paper, for the fibre of the electroscope clings to the wax without leaving it, till the electric force is so far exhausted as to be no longer able to hold the fibre to the surface of the wax. The action will, in many instances, continue a long time, and by paying attention you will observe the fibre to change places on the surface of the wax, and this very frequently, if you accomodate the wax to the motions of the fibre, by moving the former so as to facilitate the motions of the latter. If, however, the fibre be very dry and somewhat warm, it will sometimes recede from the surface of the wax, in the same manner as the pieces of paper, and will lean towards the stem S, if very near to it, and even strike against it; and after remaining attached to it a short time, will again return to the wax, and repeat these motions several times, till the electric force is too far exhausted to produce them any longer.

I will not detain you, in this place, with an explanation of the cause of the electroscopic fibre continuing to be attached to the surface of the excited wax under some circumstances, and not under others; because I am desirous of first making you acquainted with the structure and method of using another simple electroscope, which will exhibit the principles upon which they are founded in better perfection, than by that made of a single fibre.

Fig. 2.

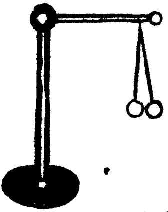
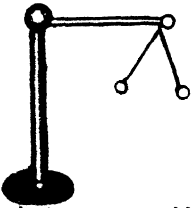


Fig. 2 will represent the form of a very simple electroscope which may be used to great advantage in some electric inquiries. It consists of a glass stem fixed in a wooden foot, and a projecting horizontal brass wire arm, terminated with a small brass ball. When the foot of this instrument is made of nicely turned and well polished mahogany, and the brass arm and its ball well polished and lacquered, the instrument assumes a very pretty appearance. Over the farther end of the horizontal arm is hung a flaxen fibre, to each end of which is attached a very small ball of the pith of the elder. As the glass stem of this instrument is a non-conductor, it is incapable of carrying off any of the electric action of the horizontal arm, or of the fibres and their balls; and as the atmospheric air is also a non-conductor, all that part of the instrument which is supported by the glass stem is insulated. As, however, glass has a great tendency to collect moisture on its surface, the stem of this instrument must be kept warm, and occasionally wiped with dry cloth, to preserve insulation as far as possible. If the surface of the glass be covered with a good coating of lac-varnish, the insulation may be maintained for a long time without much trouble.

Let us now again excite the stick of sealing wax, and afterwards present it to the upper side of the horizontal arm of the electroscope, Fig. 2. The pith balls will diverge from each other, as represented in Fig. 3, before the wax comes into contact with the metallic arm. But if the wax be withdrawn without touching the metallic arm, the balls will again collapse, and show no electric action.

Fig. 3.



Excite the wax again, and bring it into contact with the arm of the electroscope, drawing its surface over the arm. The pith balls will diverge as before, and will remain divergent, even when the wax is withdrawn. And if the room in which the experiment is made, be dry and warm, and the air perfectly still, the balls will remain divergent for a long time: even several hours. But in all cases the divergency will gradually lessen from the first moment that the excited sealing wax is withdrawn from the electroscope, and, eventually, the divergency entirely disappears. Precisely the same kind of phenomena are displayed by the application of any excited body whatever, provided its electric forces be sufficiently powerful.

Hence you may employ excited glass, amber, sulphur, paper, &c., in your experiments with this instrument, and the pith balls will diverge with each excited body. Dry writing paper rubbed with indian-rubber, becomes highly electric; and so does coarse brown paper, when drawn quickly between the coat sleeve and a woollen table cloth; or between the coat sleeve and the trousers. When the paper is made pretty warm before the friction is given to it, and the knuckle presented afterwards to its surface, a crackling noise will be heard, and sometimes sparks will be seen between the knuckle and the paper. This experiment answers best during frosty weather. Similar phenomena may be produced by stroking the back of a cat. Puss often becomes uneasy at this treatment, and the hairs of her back and tail brush out in a very strange manner.

I must now bring forward an experiment the results of which are something different to any I have yet offered to your notice. Excite the sealing-wax as before, and draw it over the arm of the electroscope Fig. 2, and when taken away the balls will remain divergent, as in Fig. 3. Again excite the wax, and again make it approach the arm, on the upper side, but without touching it; you will observe the balls separated further than before, but as you withdraw the wax again, the balls will fall again to their former position. The balls may be made to separate further from, or approach nearer to, each other, for several times by alternately advancing the excited wax to the arm of the instrument, and withdrawing it from it. If, after the balls have been divergent by the first application of the wax, the latter be again excited and then presented toward the balls, you will observe them to recede from it: and with a little practice, you may deflect the balls from the wax in any direction you please.

LECTURE III.

Having already made you acquainted with the modes of deflecting the pith balls by one and the 'same excited body, as sealing-wax, glass, amber, &c., it will now be necessary to inform you of the character of those phenomena which are displayed by the employment of two or more distinct excited bodies: whose electric forces are brought into play upon the electroscope, Fig. 2, at one and the same time; and in order to familiarize the experimental operations, we will employ two of those bodies with which we have already experimented, viz., a stick of sealing-wax and a tube of glass.

Excite the sealing-wax by some of the processes already described, and communicate its electric forces to the brass arm of the electroscope Fig 2, whose pith balls will remain divergent, as in Fig. 3, after the excited wax is withdrawn. Now excite your glass tube by rubbing it in the hand covered with warm black silk; and present this excited tube to the upper side of the metallic arm of the instrument, and parallel to it, and you find that the balls collapse by the approach of the glass tube, but separate from one another again as you withdraw the tube from them. These motions of the pith balls are the very opposite to those which are displayed by the operations of the sealing-wax alone; for in that case, the pith balls diverged further from one another by the approach of the sealing-wax, but by the excited glass they collapse.

Let us now reverse this experiment, by first exciting the glass tube and communicating its electric forces to the arm and balls of the electroscope, by drawing the tube over the metallic arm of the instrument, and afterwards approaching the upper side of the arm with an excited stick of sealing-wax. You will now observe that the phenomena displayed by this mode of experimenting is of precisely the same character as those observed by the former, or converse method; for the pith balls will as decidedly collapse by the approach of the excited wax, as they did before by the approach of the excited glass tube. These are exceedingly beautiful facts, and cannot be too soon implanted on the mind; for although they appear simple in themselves, they are the foundation stones upon which much reasoning in electricity is based: and by which alone many of the grandest operations of nature find an easy solution.

In those of the preceding experiments in which the electroscope was not touched, we have held the excited body, whether sealing-wax, glass, amber, &c., directly over, and parallel to, the horizontal arm of the instrument; but there are other modes of experimenting with these pieces of apparatus, which are productive of some variation in the phenomena, with which it will be necessary to become acquainted before we shall be enabled to explain several of those already noticed.

Let us now again excite the sealing-wax, and again communicate its electric action to the electroscope by drawing it along the arm. The pith balls will diverge as usual. Now touch the metallic arm with your finger, and immediately the pith balls will fall close to each other, and all electric action entirely disappears. Now perform the same experiment with the excited glass tube, and you find the same results to appear. You may try excited amber, sulphur, or any other body in place of the glass, or the wax, and in all cases you will observe that, by touching the metallic arm of the electroscope, you deprive the instrument of all its electrical action. The same thing would occur were you to touch the metallic arm with any of those bodies which have the faculty of conducting the electric fluid with a considerable degree of facility, such as metallic bodies, charcoal, &c.

Another method of abstracting the electric action from the electroscope, is by presenting the finger, or other good conductor, to the divergent pith balls. You will first observe that the balls approach the finger, and after being in contact with it for a few moments they will fall off again, having lost all their electric force. The electroscope may also have its electric action neutralized by the fine point of a needle, or a pin, presented to the brass arm without touching it. In this case the pith balls will gradually collapse until the electric action entirely disappears.

Let us now again excite the sealing-wax, and afterwards draw it over the arm of the electroscope as in previous experiments, leaving the pith balls divergent. Now excite the glass tube and draw it also over the metallic arm. The result of this experiment is very equivocal, and depends upon the proportional electric forces of the two excited bodies. If the force communicated to the instrument by the wax be exactly of the same extent as that communicated by the glass tube, they will balance each other, and the pith balls will collapse, and remain close together after the glass tube is withdrawn. But, as is more frequently the case, when the two forces do not balance one another, the balls will diverge, and remain divergent, after the glass tube is taken away from the electroscope.

Let us now reverse this experiment, by first exciting the glass tube, and communicating a part of its electric action to the electroscope, by drawing it over the metallic arm; and afterwards exciting the sealing-wax, and drawing it, also, over the arm of the instrument. In this case the behaviour of the pith balls will be similar to that exhibited by the preceding experiment. They will remain close together after the wax is withdrawn, if the action communicated by the wax be equal to that communicated by the glass, but in all other cases they will remain divergent. Moreover, the remaining divergency may be due either to the action of the electricity of the wax, or to that emanating from the glass tube, accordingly as their respective forces predominate; and the angle of divergency will, in all cases, depend upon the degree of the remaining force.

Now, to understand whether the remaining electric action in the electroscope be due to the electricity of the wax, or to that communicated by the glass tube, we have only to excite either the one or the other again, say the glass, and present it to the upper side of the arm of the electroscope. If the balls diverge farther, their previous divergency was due to the action of the glass tube, but if they collapse, that divergency was due to the action of the wax. But if, instead of the excited glass tube, we employ the excited wax, for the purpose of discovering the residuum electric action in the electroscope, then should the balls diverge farther by its approach, the residuum of electric action is due to the electricity of the wax, and if they collapse, it is due to the glass.

From several of the results of the preceding experiments, we have obvious instances of the electric powers of sealing-wax, and those of glass, by the hitherto described modes of excitation, counteracting one another; and when the experiments are made with great care, the electric forces which emanate from the two excited bodies are found to neutralize each other very exactly. Hence we learn, that those forces are of opposite kinds, and must necessarily originate from different electric conditions, which the exciting processes have occasioned in the sealing-wax and the glass tube.

In consequence of the electric forces emanating from glass and sealing-wax, by the methods of excitation hitherto described, being found to neutralize each other, some philosophers have been of opinion that there are two kinds of electric matter, one belonging to the glass, and the other to the sealing-wax; and as the electric action of all *vitrious* bodies has been found to correspond with that emanating from glass; and the electric action of amber and all *resinous* bodies to correspond with that of sealing-wax; the former has obtained the name of *vitrious* electricity, and the latter that of *resinous* electricity. These technicalities were brought forward in a very early period of the science, and answered the purpose of illustrating the principles of a certain hypothesis, now nearly exploded by subsequent discoveries which show that, at least, the terms *vitrious* and *resinous* are decidedly incorrect, as the *character* of the electric force emanating from either class of bodies, can be varied at pleasure: an instance of which I will now place before you.

Let us excite a stick of sealing-wax by rubbing it against the sleeve of the coat, or against fur, &c., as hitherto described, and then draw it over the metallic arm of the electroscope, Fig. 2, and leave the pith balls divergent. Now change the fur, &c., for a piece of tin-foil, and rub the surface of the wax a few times, very briskly, with the foil held in the hand. Present the newly excited sealing-wax towards the upper side of the arm of the instrument, and the pith balls will collapse in the same manner as by the approach of an excited glass tube. And if the sealing-wax be drawn over the metallic arm, the balls will remain together even after it is taken away from the instrument. And, indeed, all those phenomena which the excited glass tube has shown in the preceding experiments, can also be shown by a stick of sealing-wax when excited by tin foil: which show that there is no peculiarity of action in the wax, but that its electric character depends upon the nature of the substance against which it is rubbed; or, if you please, with which it is excited: and as this is the case with all resinous bodies, hence the absurdity of the term *resinous electricity*. The term *vitrious electricity* is also incompatible with experimental facts, because by varying some of the circumstances in the process of excitation, the character of the electric action proceeding from glass and other vitrious bodies, will vary accordingly. This fact is very easily shown by employing a tube of glass whose surface is made asperous, either by means of acid, or mechanically, by means of emery powder, or by a common grinding stone. When a glass tube, thus prepared, is excited by a piece of silk in the manner already described, its electric action corresponds with that emanating from sealing-wax, and the resinous bodies which have been excited by woollen cloth, or by fur, &c., and is consequently opposite to that displayed by a smooth glass tube, similarly excited. It is not necessary, even to employ a rough glass tube for this purpose; for by using the fur of a rabbit skin instead of silk, the smooth glass tube changes its electric character; and becomes possessed of the same kind of electric action as the rough glass and silk.

The difference in the electric action of excited smooth glass by dry silk, and that of sealing-wax, &c., by fur, woollen cloth, &c., was discovered by M. Du Fay, intendant of the French king's gardens, about the year 1733: who, in consequence, introduced the terms *vitrious* and *resinous* electricity. After describing some other of his discoveries, Du Fay proceeds to describe the one in question in the following manner:—

"Chance has thrown in my way another principle more universal and remarkable than the preceding one; and which casts a new light upon the subject of electricity. The principle is, that there are *two kinds of electricity*, very different from one another; one of which I call *vitrious*, and the other *resinous* electricity. The first is that of glass, rock-crystal, precious stones, hairs of animals, wool, and many other bodies. The second is that of amber, copal, gum lac, silk, thread, paper, and a vast number of other substances. The characteristics of these two electricities are, that they repel themselves, and attract each other. Thus a body of the vitrious electricity repels all other bodies possessed of the vitrious; and on the contrary, attracts all those of the resinous electricity. The resinous, also, repels the resinous, and attracts the vitrious. From this principle, one may easily deduce the explanation of a great number of the phenomena; and it is probable, that this truth will lead us to the discovery of many other things."

As this discovery formed an important epoch in the history of electricity, by furnishing materials for, what was then considered, an essential part, at least, of a complete theory of the science, which met with little or no opposition for about twenty years afterwards, and even to the present day, is adhered to by certain philosophers, the above passage of the author's will always be an interesting document to refer to. But, as I have already shown, by experiments, as the glass or the sealing-wax can be made to display either the one or the other kind of electric action, by varying the circumstances of the excitation, Du Fay's hypothesis of *vitrious* and *resinous* electricity is perfectly untenable. The discovery of varying the character of electric action of excited bodies, was first shown by Mr. Canton, by some experiments which that philosopher made in December, 1753, about twenty years after those made by Du Fay. Some of Mr. Canton's experiments were those I have already described with tin-foil and sealing-wax, and with rough glass and silk. Till this discovery by Mr. Canton, the friction of sealing-wax had always been supposed to produce one kind of electricity, and the friction of glass another kind; which "were thought to be essential and unchangeable properties of those substances."

Notwithstanding the prevailing idea which philosophers entertained respecting the difference in the electric actions of vitrious and resinous substances, Dr. Watson in this country, and Dr. Franklin in America, had explained electrical phenomena upon very different principles to those set forth in the hypothesis of Du Fay, about some six years previously to the discoveries of Mr. Canton, which I have already mentioned: and although Dr. Franklin has had the credit of the theory which is now generally adopted, it is certain that Dr. Watson has a prior claim to it, at least so far as the dates of their respective views were made public. "Dr. Watson showed a series of experiments to confirm the doctrine of *plus* and *minus* electricity to Martin Folkes, Esq., then president, and to a great number of Fellows of the Royal Society, so early as the beginning of the year 1747, before it was known, in England, that Dr. Franklin had discovered the same thing America. See the "Philosophical Transactions," vol. xliv, p. 739; and vol. xiv, p. 93—101. Dr. Franklin's paper, containing the same discovery, was dated at Philadelphia, June 1st, 1747.*

The principles of the Franklinean theory of electricity are similar to those which I have advanced at the commencement of these lectures: viz., that all electric phenomena emanate from the operations of a peculiar kind of matter. The following outline of this theory is copied from "Priestley's History."

* "Priestley's History."—The original papers of our old indefatigable electricians are extremely interesting to every cultivator of the science, on which account, they are occasionally introduced to the pages of the "Annals of Electricity."

"According to this theory, all the operations of electricity depend upon one fluid *sui generis*, extremely subtle and elastic, dispersed through the pores of all bodies; by which the particles of it are as strongly attracted, as they are repelled by one another.

"When the equilibrium of this fluid in any body is not disturbed, that is, when there is in any body neither more nor less of it than its natural share, or than that quantity which it is capable of retaining by its own attraction, it does not discover itself to our senses by any effect. The action of the rubber upon an electric* disturbs this equilibrium, occasioning a deficiency of the fluid in one place, and a redundancy in the other.

"This equilibrium being forcibly disturbed, the mutual repulsion of the particles of the fluid is necessarily exerted to restore it. If two bodies be both of them overcharged, the electric atmospheres† repel each other, and both the bodies recede from one another to places where the fluid is less dense. For, as there is supposed to be a mutual attraction between all bodies and the electric fluid, electrified bodies go along with their atmospheres. If both the bodies be exhausted of their natural share of this fluid, they are both attracted by the denser fluid, existing either in the atmosphere contiguous to them, or in other neighbouring bodies; which occasions them still to recede from one another, as much as when they were overcharged.

"Lastly, If one of the bodies have an overplus of the fluid, and the other a deficiency of it, the equilibrium is restored with great violence, and all electrical appearances between them are more striking."

* Those bodies which were *excited* by rubbing, such as glass, amber, sealing-wax, &c., were formerly called *electrics*; and the rubbing substances employed, were called non-electrics; from the idea that the former class alone could be excited, and, that the latter could not be excited, which is contrary to fact; as we shall see as we proceed.

† Electric atmospheres are supposed to surround all bodies that are in a state of electric action, and are more or less extensive as the body is more or less electrically active. I shall have occasion to illustrate the doctrine of electric atmospheres at some considerable length, in subsequent lectures.

If we admit that the Franklinean theory embraces the true principles of electric action, we shall be enabled to understand the cause of many phenomena, which otherwise would appear to be exceedingly intricate.

The attraction of light bodies by an excited stick of sealing-wax, or by a glass tube, and the jumping motions produced in bits of paper, &c., described in the first lecture, may now be easily explained. When a smooth glass tube is excited by silk, it is supposed to derive its electric action from a redundancy of fluid which it has obtained from the silk; hence it is said to be electrized *plus*, or positively. But when the sealing-wax is excited by fur, woollen cloth, &c., it is considered to have lost a portion of its natural share of the electric fluid; and is therefore said to be electrized *minus*, or negatively. Hence you will easily understand that, in the former instance, the redundant fluid which the glass tube was charged with, after excitation, must necessarily have been obtained from the silk with which it was rubbed; and, in the second case, some of the fluid naturally belonging to the sealing-wax, must have been carried off by the fur, or the cloth which formed the rubbing substance. Therefore, if these rubbing substances were to be insulated, they ought to exhibit electric action of an opposite character to the bodies which they respectively rubbed, and, consequently, of an opposite character to each other, which is absolutely the case; for the electric action communicated to the electroscope by the excited glass tube, is as decidedly neutralized by the electric action of the rubbing silk, as by that of an excited stick of sealing-wax. And the electric action of the sealing-wax is also neutralized by that of the fur, or woollen cloth with which it is rubbed. It can also be shown that the electric action exhibited by the silk, is of the opposite character to that of the fur, when these substances are rubbed against smooth glass and against sealing-wax, respectively; and that these actions will neutralize each other.

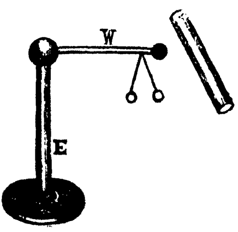
When the excited sealing-wax was held over the bits of paper, in the first experiment, being negatively electrical, it was disposed to abstract fluid from the nearest bodies that were capable of furnishing it, which in this case were the bits of paper and the table on which they were placed; but as neither of these were in contact with the wax, and as the light bodies were easily moved by a moderate attractive force, they were thus lifted to the wax, to which they gave off a part of their natural share of fluid, and became as decidedly negatively electrical as the surface of the wax itself. In this condition they were attracted by the table or the plate on which they were first placed, and where they were soon replenished with fluid; and now being in the same electrical condition as at first, were again attracted by the sealing-wax, giving to it another portion of fluid; and by a series of journeys between the table and the wax, the latter became so far supplied with fluid as to diminish the attractive force too far to continue the motions of the paper any longer. The wax, however, was still left in a minus condition, as might be easily shown by the employment of very delicate electroscopes, such as will be described by and by.

When the excited glass tube is used to produce motions in light bodies, the latter carry the fluid from the tube to the table, until it is deprived of nearly all its redundant quantity: the forces then become too feeble to continue the motions. We must not forget, however, that the electrical fluid is highly elastic, and that like all other elastic fluids it makes its way or expands to the greatest extent in that direction where the resistance is the least. Hence, in the case of sealing-wax, which was rendered negative by excitation, and, consequently, its attenuated fluid presenting a less resistance to that in the paper and table than was presented on any other side, the latter portion expanded in that direction, and urged or carried the light bodies along with it to the surface of the wax, or at least assisted materially in producing their motions.

LECTURE IV.

BESIDES the phenomena hitherto pointed out, the pith ball electroscope is capable of displaying many others of a highly interesting character, some of which I will now offer to your notice: but for these purposes it will be better to have a longer brass wire arm than that we have hitherto used; and, indeed, in some cases, we shall require two or more pith ball electroscopes to assist in our experiments. Let us now again excite our smooth glass tube, by rubbing its surface with a piece of old black silk, observing, as before, that both the tube and the silk are dry and warm. Let the now positive electric tube be held obliquely over the end of the brass arm of the electroscope, as shown in Fig. 4. The balls will diverge from one another as decidedly as in any of our former experiments; but there are several facts now to be exhibited to which I have not before alluded. Whilst the excited glass tube is in the position shown in the figure, let another similarly excited tube be held obliquely over the other end of the brass arm of the electroscope. The balls, instead of diverging farther from one another, as in our former experiments, will now come closer together; and by dexterous management of the two tubes, they may be made to collapse and hang as close together as if under no electrical influence whatever; but if, instead of another excited glass tube, a negatively excited stick of sealing-wax be held over the opposite end of the metallic arm, the pith balls will diverge farther from one another than when they were under the electric influence of the first glass tube alone.

Fig. 4.



These curious facts are very different to those exhibited in our former experiments, although, to a certain extent, we have employed the same means for their production. When we before presented the positively excited glass tube, and the negatively excited sealing-wax, to the arm of the electroscope, we found that their electric forces tended to destroy each others action, as was shown by the collapsion of the pith balls; but in this case the forces of these two differently electrized bodies are seen to operate in concert, and thus assist each other in maintaining the divergency of the balls. We also observe, in this experiment, that when the electroscope is under the influence of the electric forces of both of the positively excited glass tubes, at one and the same time, those forces tend to neutralize each others action, whereas by the former experiments two similar electric forces assisted each other in keeping the pith balls asunder.

The mystery that may probably appear to envelope these experimental facts, will partly become dispelled, when we notice the very different positions in which the excited bodies were held, with respect to the metallic arm of the instrument, in the two sets of experiments; although that observation alone will not satisfy the whole of your curiosity. You will, very naturally, want to know something about the *cause* of these apparent inconsistencies in the operations of the same species of electric force: and as it is here that we enter the inner portals of electric science, we must dwell awhile on these matters, in order to explain them somewhat minutely; and it is here that we must call into requisition the force of *electric repulsion*, and avail ourselves of its powers to a greater extent than we have hitherto had need for. It is in the production of these phenomena, also, that this formidable electric force is most beautifully displayed, and conveys to the mind the surest and most satisfactory indications of its existence.

When the excited glass tube is in an electro-positive condition, the redundant fluid on its surface, by virtue of its repulsive force, has a tendency to *displace* the fluid belonging to all surrounding bodies within the sphere of its action, even the electric fluid contained in the atmospheric air; and as the best conductors afford the greatest facilities for the motion of the fluid which they contain, that portion naturally belonging to the metallic arm of the electroscope became easily disturbed by the approach of the glass tube, whose electric forces repelled the greater part of it to the farther end of the metallic rod, where it accumulated and caused that end of the rod to be *positively* electrical, at the expense of the other end, which, in consequence, became defective, or *negatively* electrical. Hence you will understand, that in consequence of a displacement of a portion of its electric fluid, by the approach of the glass tube, the metallic arm of the electroscope was made to assume *oppositely electric conditions* at its two extremities: *negative* at the end nearest to the tube, and *positive* at the other. When bodies are thus electrized, or in this electric condition, they are said to be *electro-polar*. If, instead of being insulated by the glass support, the metallic arm had been in metallic connection with the table, the displacement of its fluid would have been more extensive, as would have been indicated by a greater divergency of the pith balls; for in that case it would not have been confined to the metallic rod, for a portion of it would have found its way to the table, or, perhaps, to the floor, where it would have been diffused in the general mass amongst the surrounding bodies.

If we now approach the metallic arm of the electroscope by an excited stick of sealing-wax, negatively electrical, in place of the glass tube, the electro-polarization of that part of the instrument will take place as decidedly as before; but we shall find, by the methods before described, that the divergent pith balls are now in an electro-positive condition, which is contrary to their electrical state when the glass tube was used: hence the electro-polarization of the metallic arm is now in the reverse order to that which it assumed when under the influence of the electric forces of the electro-positive glass. To understand how this occurs, it will be necessary to bear in mind that, by virtue of its repulsive force amongst its own particles, the electric fluid, like all other elastic fluids, moves with the greatest facility in the *direction of least resistance*. Now, as the sealing-wax has lost a portion of its fluid by this means of excitation, it has a disposition to recover a similar quantity from those vicinal bodies which are within the sphere of its attractive forces: so that when presented to the metallic arm of the electroscope the wax not only draws towards it a portion of the electric fluid in that end of the arm to which it approaches, but at the same time, causes the *electric resistance* to become much less in that direction than in any other: and therefore the fluid naturally belonging to the metal is constrained to accumulate in that end next to the wax, by the joint action of both the attractive and repulsive forces. Hence it is that the end of the metal arm next to the sealing-wax is electro-positive, and the other end electro-negative.

We are now prepared to explain the reason of the pith balls diverging more when the farther end of the metallic arm of the electroscope was approached by an excited stick of sealing-wax, than whilst under the electric influence of the glass tube only. The negative wax, in that case, tended to draw the electric fluid of the metallic arm towards it, and consequently afforded a less degree of resistance in that direction, than was offered in any other: and by thus diminishing the electric resistance at that end of the rod, the electric influence of the glass tube became assisted in displacing the fluid belonging to the vicinal end of the metal, and pressing it towards the end nearest to the negative wax. Hence you will readily perceive, that the metallic connection with the table in the one experiment, and the approach of the negative sealing-wax in the other, are but two different modes of accomplishing the same thing; both serving to facilitate the departure of the electric fluid from that extremity of the metallic arm of the electroscope which was under the influence of the repulsive electric forces of the glass tube.

We might explain these phenomena very satisfactorily, without taking into consideration the *attractive* forces of the excited wax; as the *repulsive* force alone, of the electric fluid in the brass arm of the instrument, would be productive of a greater accumulation by the presence of the sealing-wax, by the latter merely *lessening* the *resistance* in that direction. Indeed, so far am I from seeing an absolute necessity for that power called *electric attraction*, that I have some reason to believe it may be dispensed with altogether in the theory of electricity: the whole of the motions being traceable to a repulsive force only. At present, I use the term attraction as a convenience, and because it is used by all electricians. I have however, instituted an enquiry into this part of the theory, and as far as I have proceeded, the views which I have taken appear to be very satisfactory. Other theorists have taken the opposite view, and seem disposed to dispense with electrical repulsion.

Now, when another excited glass tube was presented to the opposite extremity of the metallic arm, its electric forces tended to prevent the fluid coming in that direction; and when its powers are equal to those of the first tube, they exactly balance each other, which was the cause of the pith balls collapsing on its approach to the electroscope. To manage this experiment, however, requires some dexterity: for if the metallic arm of the electroscope be of considerable length, say ten or twelve inches, and the two tubes be highly electric and brought near to its two extremities, they will polarize the metal in such a manner as to be *negative* at the extremities, and positive in the centre. And if you were to employ two sticks of sealing-wax in a negative electric condition, instead of the glass tubes, the metallic arm would become electro-positive at the two extremities, and electro-negative at the centre. I will presently show you a slight modification of the electroscope, by means of which these interesting facts may very easily be shown: but it will first be proper to make you acquainted with a few more particulars necessary to be attended to in the employment of this peculiar kind of electroscope, otherwise we might seem to meet with anomalies which would be inexplicable by the theoretical principles we have adopted.

We will now excite the glass tube by means of the silk, and electrize the electroscope, by permitting the pith balls to touch its surface, On withdrawing the tube, the balls, you observe, are left in a divergent state, as in all other cases of their electrization. See Fig. 3.

You have already seen by former experiments, that when the excited body which gave the electric action to the balls, was held over the brass arm of the instrument, the divergency increased. Moreover, you have hitherto been made to understand that, *repulsion* always takes place between bodies *similarly* electrized. This principle of electric action is the very cause of the fact I am about to bring before you, although the phenomenon itself, to a casual observer, and left unexplained, would seem to militate against it.

I have electrized the balls of the electroscope, and no doubt can rest on your minds of their being in the same electrical condition as the tube which electrized them. I now bring the tube to beneath the balls, approach them with it, and they collapse. Here then is the apparent anomaly. Why do the balls collapse by the approach of a body in the same electric state as themselves? If I hold the tube on one side of the balls, they shun it, but do not diverge further from one another. If I hold the tube directly over the balls, the divergency increases; and it increases still more if I present the tube to that end of the brass arm of the electroscope most remote from the balls. In this experiment, thus varied, we have the whole doctrine, which should ever be kept in view in electroscopic investigations.

When the glass tube was brought to beneath the divergent balls, its accumulated electric fluid repelled that accumulated by communication in the balls to the other extremity of the brass arm of the instrument, and rendered them neutral; in which condition they hung close together. When the tube was held nearly in the same horizontal plane with that of the balls, they shunned the tube without much change in their relative positions; because the electric action of the tube upon them was nearly equal both above and below. When the tube was held over the brass arm, and nearly parallel to it, a disturbance of the fluid in the whole arm took place, and nearly in every part of it alike, and a greater portion thus driven to the balls than that which they before possessed. Hence the divergency became greater. But when the tube approached the opposite extremity of the brass arm, a still greater quantity of fluid was driven towards the pith balls; and, consequently, under these circumstances, the divergency became greater than when the disturbing tube was placed in any other position.

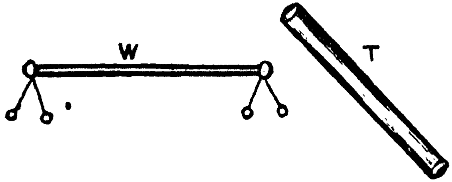
We will now make another experiment in which both the positively electric glass tube, and the negatively electric sealing-wax shall be employed. The pith balls shall receive their electric action from the glass tube as before; but instead of proceeding with that tube any farther, I will take the negative sealing-wax to present to the balls; and, in this case, you will observe the precisely reverse phenomena to those exhibited by the last experiment. On approaching the *positive* balls from beneath, with the *negative* wax, you observe that the divergency is considerably increased. On presenting the sealing-wax sideways, the balls lean towards it; and when it is held over the brass arm, the balls come closer together. On presenting the negative body to the remote extremity of the arm, the balls become neutral.

To apply the principles of the theory to these phenomena, we have only to understand that the resistance of the electric fluid in the instrument is lessened on that side approached by the negative body; and, consequently, it presses forward in that direction. When the negative body approached the balls from beneath, the balls became more positively electric than before, in consequence of the fluid pressing in that direction: and when the wax approached the remote extremity of the metallic arm, the fluid again pressed in that direction, and became more positively electric than before, at the expense of the fluid in the other end, and of that in the balls attached to it, and the divergency lessened accordingly.

By the phénomena displayed in these two experiments you will readily understand that, the divergency of two *similarly electrized* bodies—the pith balls, for instance, will be variously affected by the approach of another electrized body, *not only accordingly with the electric state of that body, but also accordingly with the direction of its approach.* And, if this rule be not understood and attended to, much error is likely to proceed from the generality of electroscopic investigations.

We must now employ a brass rod w, about ten or twelve inches long, suspended by two dry and clean silk lines, or threads of sewing silk; or it may be supported by a thin glass stem at its centre. For a trial in private, the brass rod may be supported on a clean and warm champagne glass. Two pairs of pith balls must also be used, one at each end of the rod, as seen in Fig. 5. If

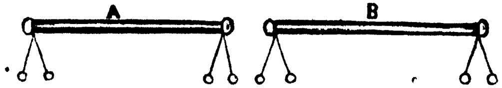
Fig. 5.



an excited glass tube T, be presented to this simple piece of apparatus, in the manner shown in the figure, the metal rod will become electro-polar, upon the principles I have just before described. The pith balls diverge at both ends of the rod; and by examining them either by an excited tube of smooth glass, or by a negatively excited stick of sealing-wax, it is found that those next to the polarizing tube T, are in an electro-negative condition, and the other pair in an electro-positive condition. If we were to hang a similar pair of pith balls to the centre of the brass rod, they would remain together, after a moment's slight agitation, which would be caused on the first approach of the glass tube T. Hence we learn that there is a zone of the rod's surface, about the middle part, which, during the time that it is electro-polar under these circumstances, which is perfectly neutral: being neither positively nor negatively electric. The position of this zone, however, varies accordingly with the degree of electric force, and with the distance of the tube from the metal rod. When the electric force is constant, the distance of the neutral zone from the approached end of the rod will be greater or less accordingly as the tube is brought nearer, or farther off respectively.

When the electsic force is sufficiently powerful, its polarizing influence may be extended through a series of metallic rods, placed end to end, having a plate of air, of about an inch in thickness, between them. If, for instance, we employ two of these rods, and place their axes in the same right line, at about an inch asunder, as represented by Fig. 6, and furnished with pith balls, we shall have them ready for the experiments.

Fig. 6.



Let us now excite the glass tube, and you will see that, when it is presented to the outside extremity of the rod B, in the manner shown in Fig. 5, page 35, the whole of the four pairs of pith balls will diverge, showing that both the rod B and the rod A are electrical. You will observe, also, that those two next to the excited tube, will not only diverge from one another, but they will also have a tendency to approach the tube; and by paying attention to the other balls, it will be seen that those belonging to the rods A and B, have also a tendency to come together; that is, although the balls of each pair will diverge from one another, those belonging to the different rods *lean* towards each other; and, indeed, very frequently come in contact.

Now, from the facts which I have before brought to your notice, respecting the conditions under which bodies attract one another by the influence of electric forces, you will easily understand that the outer balls of the rod B, which have a tendency to approach the glass tube, must necessarily be in an opposite electric state to that of the tube, otherwise they would have no tendency to move in that direction. Hence, they are negatively electrical; and as they are in the same condition as that end of the rod to which they are attached, that part of the metal is also negative. This is also the case with the balls attached to the inner extremity of the rod A, and consequently with that end of the rod itself: and as the balls attached to the inner extremity of the rod B, are attracted towards those belonging to the inner extremity of A, those extremities of the two rods are differently electrical, and consequently the inner extremity of the rod B is positive.

The balls attached to the outer extremity of the rod A, and consequently that end of the rod itself, may be shown to be positively electrical by the usual means already noticed; either by the application of a negatively excited stick of sealing-wax, or by a positively excited glass tube. And the same tests may also be applied to the two pairs of balls attached to the inner ends of the rods A and B. The outer pair of balls belonging to the rod B, may also be tested by a negatively electric stick of sealing-wax, or by the glass tube excited by the rabbit skin, which also renders it negative.

If, instead of employing two rods only, as in the last experiments, we were to place three or four in a row, every rod would become electro-polar, upon the principle above described. For instance: by the presence of a positively electrized glass tube, the nearest extremity of every conductor would become electro-negative, and their further extremities electro-positive. In such cases, the brass rods polarize one another after the polarizing of the first one by the excited glass tube; for the accumulated electric fluid at the remote extremity of the first rod displaces the fluid belonging to the second one; and the accumulated fluid at the remote extremity of the second rod exercises a similar action on the fluid of the third rod; and so on throughout the whole series. But as the polarizing action decreases with every additional rod, the series of rods which can be polarized by these means is limited to a very few. In all cases, however, the polarizing effects are exalted by connecting the rod most remote from the glass tube with the ground, by means of some good conductor; the reason of which is, that the resistance to the disturbance of the fluid in the other rods is lessened by giving free access to the ground to the fluid in the most remote one.

This last fact will lead us to another, merely by a trifling variation in the experiment. Let us now employ one insulated brass rod only, and polarize it by the approach of a positively excited glass tube: its pith balls at both extremities will diverge as usual. Now place a finger on the remote end of the metallic rod, and the balls at the nearest end will diverge more than before.

Take away the fingers whilst the rod is still under the influence of the electric tube, and then gradually draw the tube away also. You will now observe that both pairs of pith balls first collapse, and when the tube is entirely removed from the vicinity of the rod, they again open, and remain divergent for some considerable time afterwards. Now test the electric state of the rod, and it is found that the whole of it is negatively electrical. The reason of this is very obvious, when we consider some of the particulars of the previous experiments: for the application of the finger to the rod, whilst under the influence of the excited glass tube, gave an opportunity for a portion of the electric fluid to depart from the rod; and by taking away the finger whilst the rod was still under that influence, the latter was left insulated with less fluid than it previously possessed.

I must now point out another fact which very frequently attends many of the experiments I have hitherto offered to your notice, because if you were not acquainted with it you might probably, on many occasions, arrive at wrong conclusions respecting the electric characters of any electrized body presented to the electroscope. When the excited glass tube is kept presented to the brass arm of the electroscope for a minute or two, a portion of the fluid naturally belonging to the brass arm is driven out, through the medium of the asperities on the surfaces of the balls, and the fibres of the threads by which they are suspended; and, although the polarization of the brass rod holds good whilst under the electric force of the tube when you withdraw the latter slowly, the polarization gradually subsides; and at a certain distance the force on the tube permits the balls of each pair to collapse and hang together; but when the tube is still further removed from the brass rod, its electric influence is no longer in operation, and the balls again diverge; being left in a negative condition in common with the rod to which they are attached. It is exceedingly important that this fact should be well understood, because there is a strong probability that from a want of this information, many errors have arisen by the experiments of those who only occasionally employ an electroscope.

I shall very shortly have to describe electroscopes of much greater delicacy than that we have hitherto operated with; but they are all susceptible of similar electro-polarization and loss of fluid; which, if not taken into consideration, would necessarily lead to mistaken conclusions.

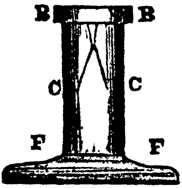
The employment of negatively electric bodies, such as excited sealing-wax against fur, also reverses the electric condition of the pith balls; for, in such cases, the remote extremities of the electroscope being negative by the polarizing influence of the wax, they draw in an additional quantity of the electric fluid from the surrounding air, which, when the wax is withdrawn, leaves them in an overcharged or positive condition, as may be understood by the usual tests with which you have now become familiar.

The reversal of the electric condition of asperous bodies, or those with sharp points or sharp edges, is a very common circumstance in the employment of those delicate electroscopes which I shall next offer to your notice, whose moveable indicators are narrow strips of leaf gold; the first of which was introduced to the notice of electricians by the Rev. Abraham Bennet, M.A., who, in the year 1786, gave the following description of it:—

"This electrometer consists of two slips of gold leaf, suspended in a glass. The foot may be made of wood or metal: the cap of metal. The cap is made flat on the top, that plates, books, evaporating water, or other things to be electrified, may be conveniently placed upon it. The cap is about an inch wider in diameter than the glass; and its rim about three-quarters of an inch broad, which hangs parallel to the glass to turn off the rain, and keep it sufficiently insulated. Within this is another circular rim, about half as broad as the other, which is lined with silk velvet, and fits close on the outside of the glass: thus the cap fits well, and may easily be taken off to repair any accident happening to the leaf gold. Within this is a tin tube, hanging from the centre of the cap, somewhat longer than the depth of the inner rim. In the tube a small peg is placed, and may be occasionally taken out. To the peg which is made round at one end and flat at the other, two slips of gold leaf are fastened with paste, gum-water, or varnish. These slips, suspended by the peg, and that in the tube fast to the centre of the cap, hang in the middle of the glass, about three inches long, and a quarter of an inch broad. In one side of the cap there is a small tube, to place wires in. It is evident that without the glass the gold leaf would be so agitated by the least motion of the air, that it would be useless: and if the electricity should be communicated to the surface of the glass it would interfere with the repulsion of the gold leaf: therefore two long pieces of tin foil are fastened with varnish to the two opposite sides of the internal surface of the glass, where the gold leaf may be expected to strike, and in connexion with the foot. The upper end of the glass is covered and lined with sealing-wax as low as the outermost rim, to make its insulation the more perfect."

Figure 7 is a representation of Bennet's electroscope, c c being the glass cylinder, F F the wooden foot, and B B the cap. The gold leaves are represented divergent, as when under an electric influence. A short brass wire is usually screwed into the hole in the cap of the instrument, having its upper extremity finely pointed. A brass ball also screws on the top of the wire to conceal the point, when necessary for particular enquiries.

Fig. 7.

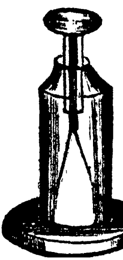


The way to use Bennet's gold leaf electroscope is similar to that we have pursued with the other: but it is better on all occasions, when we want to communicate an electric action of some duration to the instrument, to unscrew the ball from the vertical wire rising from the cap, and expose the point with which the wire terminates upwards. The point, in this case, receives the fluid from an electro-positive body presented to it, and gives off fluid to an electro-negative body. For instance: excite a tube of smooth glass by warm silk, and afterwards hold it over the point of the wire of the electroscope; the gold leaves will immediately diverge, and will remain divergent after the tube is taken away; and by testing the electric action left in the instrument it is found to be positive. Now discharge this electric force by touching the point with a finger. It is very likely that the first touch of the finger is not sufficient to remove all the electric action from the electroscope, because it often happens that a portion of the glass near to the cap becomes electrical; and when this is the case, the glass being a bad conductor, it prevents any rapid movements of the electric fluid over its surface; so that whether positively or negatively electrical, *time* is required to equilibre its electric powers.

When the gold leaves no longer open after the finger is removed from the point of the wire, screw on the brass ball: the point will again be concealed, and its functions in facilitating the ingress and egress of the electric fluid entirely annihilated. Now present an excited glass tube to the ball of the electroscope; and you will observe that the gold leaves diverge as before: but if you immediately remove the tube from the instrument the gold leaves will collapse, and will hang together in as neutral a condition as if they had never been under an electrical influence. But if you permit the excited glass tube to remain for some time near to the ball of the electroscope, then on withdrawing it the gold leaves will first collapse and afterwards open with a negative electric action, which is of an opposite character to that of the tube which was presented to the cap of the electroscope. Hence you will perceive that the electric fluid can be driven out of the lower extremities of the gold leaves by the repulsive action of the fluid, superinduced on the surface of the glass tube, as decidedly as it was driven out of the asperities on the surface of the pith balls, in the former described electroscope. The fine edges of the gold leaves also admit of the ingress of the electric fluid when the instrument becomes electro-polarized by the approximation of a negative stick of sealing-wax, or any negatively electrized body, to the ball, or to the cap of it.

The late Mr. Singer, who was a very clever electrician, made a great improvement in Bennet's electroscope, which in its original condition was somewhat difficult to keep in order. Mr. Singer's improvement consists in passing the wire to which the gold leaves are appended, through a glass tube about four inches long, and much wider than the diameter of the wire, which is held fast in the axis of the tube by two bosses or coils of sewing silk, wound round the wire at the distance of about three inches from one another. These coils of silk not only hold the wire steadily in the tube, but assist in insulating it from the brass cap of the instrument. The insulation is still farther perfected by covering both the inner and outer surface of the tube with a good coat of lac varnish.* The axial wire is screwed into the top of a brass ferule, something wider than the glass tube, and by surrounding it prevents deposition of dust and moisture. The wire of this instrument is generally surmounted with a brass disc, the plane of which is perpendicular to the axis of the wire. The electroscope thus fitted up is represented by Fig. 8.†

Fig. 8.



The management of this electroscope is precisely the same as that I have already shown you with the rude instruments hither employed: but in consequence of the

* Lac varnish is made by dissolving shell-lac, or seed-lac, in spirit of wine, in a phial, which is better for being wide-necked, to admit the brush freely.

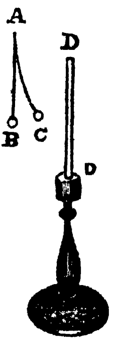
† It is frequently exceedingly difficult, without extensive reading, to confer the merit that is due to invention on the right party; and even then we sometimes err for want of proper information. Mr. Singer has hitherto, with most writers, had the exclusive merit of insulating the axial wire of the electroscope from the brass cap, by a glass tube; and it would appear from the description he gives of this improvement, in his excellent treatise on electricity, that he was not aware of any thing of the kind being previously done. It appears, however, by an article of Mr. Erman's in the Journal de Physique, vol. 59, p. 98, and Nicholson's Journal, vol. 10, published in 1805, that a Mr. Weiss had applied the glass tube for the purpose of insulating the axial wire of Bennet's electroscope. The account runs thus: "The electrometer he (Mr. Erman) used was that

extreme flexibility of the gold leaves, this instrument is much more delicate than those are, and must never be employed where the electric force is considerable; its principle use being to detect, and ascertain the character of minute electric actions.

There is another appendage to the gold leaf electroscope, which renders it still more sensitive to feeble electric forces. This is the *condenser*: an invention of the celebrated Volta, of Como. But before I can communicate to you the theory of its action, it will be necessary to illustrate, by experiment, the electro-polarization of thin metallic discs.

There are several methods of exhibiting the polarization of the flat surfaces of thin metallic discs, one of which I will now select for our present illustration. For this purpose I employ a thin disc of tin (tinned iron), about ten inches in diameter, and well rounded and polished at its edge by the introduction of a stout marginal wire. This disc I place upon an insulating pillar of glass, with its plane vertical, as represented by D D, Fig. 9, which is an edge view of the disc. B, is a pith ball, suspended by an uninsulated fibre A B. I first excite the glass tube by the tin-foil, and afterwards communicate a portion of this electro-positive action to the insulated disc. Immediately the ball B is drawn to the position C towards the disc, which shows electric

Fig. 9.



distinguished in Germany as the electrometer of Weiss." From this it would appear to have been long known. "The length of its leaves of gold is half an inch, and the diameter of the glass cylinder which encloses them is three quarters of an inch in diameter, the height being an inch and a half. Its cover of ivory does not project above the glass, and is perforated in the middle with a hole in which a *smaller glass tube is fixed, and through this last tube passes the metallic rod that serves to suspend the gold leaves.*" Singer's improvement, first published in 1814, would, therefore, consist in adding the brass ferrule, which covers the glass tube first introduced by Weiss.

action in the latter. Now, in this state of things the disc is surrounded by an equable electric pressure, with the exception of the trifling difference occasioned by the wooden ferrule on which the disc rests, and which we will not permit to interfere with our present illustration. This equability of electric pressure, permits of an equable distribution of the electric fluid on the two sides of the disc, by which I mean that at the *centre* of the disc the electrization is equal on the two opposite surfaces; and although, in consequence of the repulsion amongst its own particles, the electric fluid is distributed more and more abundantly from the centre to the margin, the absolute quantity superinduced on each individual concentric ring on one side of the disc, is equal to the quantity superinduced on each *opposite* ring on the other side: therefore, the sum total of all the concentric rings of electric fluid on one side is equal to the sum total of all the concentric rings of it on the other side. Moreover, the *distribution* of the electric fluid on one side of the disc is precisely the same as the *distribution* on the other side of it.

To give you an experimental illustration of this beautiful fact, I will first dismiss the electric action of the disc, and whilst it is in this neutral condition, I will suspend another pith ball on the other side of it, in such a manner that the two balls shall hang at the same height, and the plane of the disc shall be placed between them, at an equal distance from each, and at right angles to the horizontal line joining them. I now again communicate electric action to the disc from the *electro-positive* excited tube, and immediately neutralize the latter, and remove it to some distance. You now observe that both of the pith balls are drawn towards the disc by the electric forces on its two sides; and by close attention, you can form a pretty good idea of the quantity of their respective approaches towards the disc, which you will find to be nearly, perhaps exactly, equal. They have, indeed, advanced so nearly alike, that it would be difficult, from mere inspection alone, to ascertain which ball is nearest to the disc: which shows that the electric forces on the two opposite sides of it are equal to each other. By removing the pith balls towards the edge of the disc, we shall find that they are drawn further from their original *neutral* distance, than when placed opposite to the disc's centre; but still both balls advance alike.

There is yet one other point to decide respecting the electric character of the disc; for although the electric forces appear to be equal on its opposite surfaces, you have not yet been shown that, in this condition, it is not electro-polar; or, in other words, that one side is not *electro-positive*, and the other side *electro-negative*; under which circumstances, the pith balls might be drawn towards those surfaces as decidedly as if both were in the same electric condition. This point is easily decided by the employment of two gilt pith balls, suspended by silken fibres. Thus insulated, I bring the pith balls into contact with the electrized disc; one on each side of its central part. On removing them, I bring them to within the spheres of each others action; and you observe that they shun one another: or, in electric language, they repel each other. Hence we understand that the balls are similarly electric, and, consequently, that the two surfaces of the disc whence they derived their electric actions, are also in one and the same electric condition.

Our next business is to show the manner of rendering thin metallic discs electro-polar, which is the principal illustration we have in view prior to introducing the condenser. I now remove one of the uninsulated pith balls last used, permitting one only to hang opposite to the face of the disc, as represented by Fig. 9. I again communicate electric action to the disc by means of the *electro-positive* glass tube. The pith ball is drawn towards the disc, in the manner shown by A C. I now approach the opposite side of the disc with another disc of the same kind, holding the latter in my hand by a metallic handle attached to its centre. The face of the approaching disc is kept parallel and opposite to the face of the electrized one; and as it advances upon it, you perceive the pith ball recedes from its advanced position, and when the two discs are within about an inch off each other, the pith ball falls to its first neutral post, showing that it is not affected by the electrized disc. But we are not to suppose that, because the pith ball is not affected under these circumstances, the electrization of the disc is annihilated: for if I withdraw the uninsulated plate gently, the pith ball gradually advances again upon the *insulated* one; and by withdrawing the plate held by the hand entirely away from the other, the pith ball advances into its former position c, indicating the same degree of electric action in the insulated disc as at first. Any uninsulated body, however small, presented to any part of the disc, monopolizes a portion of its electric action, and causes a recession of the pith ball.

Now, since by the recession of the pith ball during the presence of the uninsulated disc, we can easily understand that, on that side of the electrized one next to the ball, the electric action was neutralized: and since we also understand, from the re-advance of the pith ball, that the electric action was restored by the removal of the uninsulated plate, it is obvious that all, or nearly all, the electric fluid first communicated to the insulated disc, had accumulated on that side of it which was appoached by the uninsulated one: and, consequently, by the two sides of the electrized disc being in different electric conditions, the disc itself was electro-polar; having *relative* positive and negative surfaces as decidedly as in any other shaped body whatever.

Being now acquainted with the nature of the electro-polarity of thin discs of metal, the operations of the condenser will be easily understood.

Fig. 10.

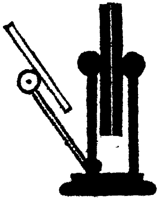


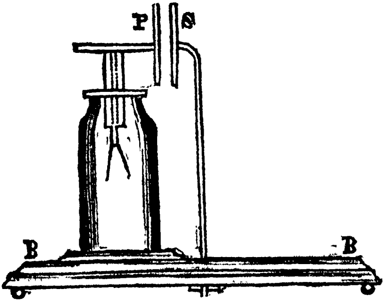
Fig. 10 is an edge view of the condenser. It consists of two metallic plates similar to those we have been using in our last experiments. One of these plates is supported on a glass pillar, and is consequently, insulated. The other is supported by a metallic pillar, moveable on a joint at its lower extremity; by which means it can be made to approach the other plate, as represented by its vertical position; or withdrawn from that plate, as in the position shown by the dotted part of the figure. The whole is attached to a neat mahogany base-board.

When the insulated plate of the condenser is connected, by means of a metallic wire, with the cap of Bennet's gold-leaf electroscope, and the uninsulated plate brought parallel and close to it, without touching, any feeble electric action communicated to the cap of the instrument would principally be collected on that surface of the attached wire nearest to the uninsulated one, and no divergency of the pendant leaves would take place. But on taking back the uninsulated plate, the electric fluid spreads itself over every part of the insulated metal of the electroscope; and if the action be sufficiently powerful, the gold leaves will diverge by the repulsive force thus communicated to them; the condenser, however, can be but of very little use in those cases where a *single contact* of the body under examination will communicate to the electroscope a sufficiency of electric force to deflect the gold leaves; because, in such cases, they would be deflected independently of the condenser, and indeed, to a greater extent, because of the less extent of metallic surface to electrize.

The important services of the condenser, are limited to those cases in which the electric action, by one single contact of the body under examination, is not sufficiently powerful to deflect the gold leaves of the most delicate electroscope. There are many cases of this kind which come under the notice of the investigating electrician;. who, by a judicious management of the condenser, combined with his electroscope, is enabled to detect those minute electric actions, so extensively and variously ramifying throughout the multitudinous associations of nature's productions; and which, independantly of some such exquisite implements of research, he could never have known of their existence.

The condenser, although considered as a distinct piece of apparatus, is now generally attached to the electroscope, as a suitable appendage to improve its delicacy and usefulness. In this capacity the two discs are each of about six inches diameter; one of them receiving its insulation from being supported by the glass cylinder of the electroscope; being attached to its brass cap, as represented by P in Fig. 11. The insulated plate S is sup-

Fig. 11



ported by a brass stem, which slides to and fro in the base-board B B: by means of which movement it can be made to approach the insulated disc, or to recede from it at pleasure.

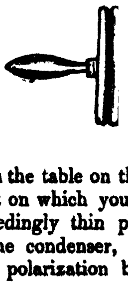
When employing this instrument, we first bring the moveable plate S into close contact with the plate P; and if the instrument be properly made, the two plates will just cover each others inner surfaces, which ought to be perfectly vertical. Now separate the plates a little, by withdrawing the moveable one S, until only an exceedingly thin plate of air lies between them. It is now obvious, from what you have before observed, that any electric action communicated to the cap of the electroscope would be partly transferred to the plate P, even if the plate S were not present. But now as the plate S is close to the plate P, which, by being connected with the ground, reduces the pressure on that side, and thus gives a greater facility for the polarization of the latter plate, so that when a feeble positive electric action is communicated to the cap of the electroscope, an accumulation of the electric fluid will take place in the plate P, without its affecting the gold leaves, which would remain nearly neutral. But if we now withdraw the plate S from the vicinity of the plate P, the polarization ceases; and the fluid which rested principally in the plate P, now becomes almost equally distributed over every metallic part of the electroscope; and, if the force be sufficiently powerful, the gold leaves will diverge. In many cases, however, and indeed in all those in which the condenser can be used to much advantage, it requires several communications between the body under examination and the cap of the electroscope, to convey a sufficient degree of electric force to diverge the gold leaves, even in the least appreciable degree.

It may now be necessary to say something further with respect to the terms *positively electrical*, and *negatively electrical* bodies. These terms ought, in all cases, to be understood as implying the electrical condition of bodies *relatively* to the electric condition of other bodies, and in no other manner whatever. Let me endeavour to give you an illustration of what I mean by the term *relative*. I will suppose that three metallic spheres, A, B, and C, of precisely the same diameter, uniformity of polish, &c., are insulated, and placed on different parts of the table. I will communicate ten particles of the electric fluid to A, seven particles to B, and five particles to C. Now, although the whole of these three bodies are positively electrical with regard to the surrounding group of bodies in the room, they are, in reality, in different electric conditions with respect to each other. A, which has the quantity ten, is positively electric with respect to the other two; and C, which has only the quantity of five, is negatively electrical with respect to both A and B. And for the same reason, the body B is either positively or negatively electrical, accordingly as it is compared with C or A respectively. This is obviously a prominent case, and may very easily be comprehended. But there are others, which I shall shortly have to notice, wherein the difference of the electrical condition of bodies is not so easily illustrated independently of direct experiment. I shall presently have to show you that two distinct metallic bodies, in their *natural electrical condition*, are very far from being in *one and the same electrical condition*: and I will further observe, in this place, that not only are the various substances constituting the body of the earth in different *relative* electrical conditions, but that different parts of the *same body* are also *differently electrical.*

I have long entertained this view of the electrical condition of bodies when surrounded by equable electrical pressures, or when they are in, what Franklin called, their natural electric states: and I will lead you through a series of experiments, as we proceed in these lectures, that will prove to you that this view is a correct one, as far, at least, as those bodies on which we operate are capable of rendering us the necessary information.

We will now proceed to an experiment which will not produce very satisfactory results, unless we avail ourselves of the advantages afforded by the condenser. We will take two metallic discs, one of which is copper and the other zinc; they are about six inches in diameter, and each furnished with a glass handle in the manner represented by Fig. 12: their opposite sides should be perfectly flat, so that when placed together, as shown in the figure, those surfaces may be in contact throughout. Let us now bring the moveable plate s, of the condenser, Fig. 11, into contact with the fixed plate P, and afterwards separate them a little, so that we can just see between them, and no more: which is best done by having a sheet of white paper lying on the table on the opposite side of the electroscope to that on which you are standing. We have now an exceedingly thin plate of air between the two plates of the condenser, which will afford great facility for their polarization by a feeble electric force.

Fig. 12.



The electroscope with its condenser, and the zinc and copper plates with their dry and warm handles, being now ready, we will proceed to the experiment; which is to show that the zinc and copper, though each in its natural electric condition, are not in *one and the same* electric condition: but that the copper is positively electrical with respect to the zinc, and that by their simple contact alone, the copper will communicate to the zinc a portion of its natural share of the electric fluid, so that the zinc shall become positively electrical and the copper negatively electrical; not only with regard to each other, but also with regard to all surrounding bodies which are in their natural electric states.

I now place the copper plate upon the palm of my left hand, with its smooth flat face upwards; and with my right I take up the zinc plate by its glass handle, and place it on the face of the copper one. I now separate the plates suddenly, and touch the cap of the electroscope with the zinc one, by which means I communicate a feeble electric force to the instrument. I bring the zinc plate into contact with the copper one as before, and again separate them suddenly and communicate another portion of electric force to the electroscope: and by proceeding in this manner for about half-a-dozen times, I lay down the two discs and withdraw the plate s of the condenser, and the gold leaves immediately diverge, in consequence of the electric fluid which was condensed in the plate P, whilst the plate s was close to it, being now nearly equally distributed over the whole of the metal in connexion with P: and as the gold leaves are portions of that metal, they receive their portion of the electric action and are repelled from each other accordingly.

Our next business is to ascertain what kind of electric action is possessed by the electroscope, and it is found to be positive, whether we test it by a *negatively* or by a *positively* electrized body. I am very anxious that the facts which this experiment develope should be very well understood; because I am well aware that many persons fail in producing any electric action whatever by these means, and others doubt the fact altogether. It was first shown by the celebrated M. Volta, and was the foundation of all that sound philosophical train of reasoning which led that eminent electrician to the invention and formation of the most formidable source of electric action that has hitherto been placed in the hands of philosophers, viz., the Voltaic battery: an implement of research which so justly bears his name, and by which the most important discoveries in this branch of science have been made.

We will now vary the experiment by placing the zinc disc on the hand, and with the other hand taking hold of the glass handle of the copper disc. But we must first adjust the plate s of the condenser to its proper distance from the plate P. Having now brought the face of the copper disc into contact with the face of the zinc one, I again separate them quickly, and afterwards touch the cap of the electroscope with the copper disc. After repeating this operation a few times as before, we shall find that the gold leaves diverge as soon as the plate s is withdrawn from the plate P; and by testing in the usual way, we find that the gold leaves are negatively electric; proving all that I said before we performed the experiment, respecting the development of electricity by the simple contact of metals, and that they are naturally in different electric states. It is in the investigation of these beautiful electrical niceties that we discover the superior penetrating genius of the genuine electrician, and distinguish the philosopher from the mere iterant experimenter. The name of VOLTA, will ever remain associated with the electrophorus (an instrument presently to be noticed), the condenser, and the famous battery which bears his illustrious name: and will be venerated by the electrician whilst this beautiful branch of science shall continue to be cultivated by man.

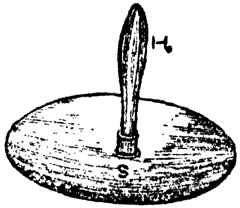
When an electroscope is not furnished with a permanent condenser, the open hand held near the cap of the instrument will answer very well for many purposes. In this position the hand becomes a substitute for the uninsulated plate, and the flat horizontal disc which is insulated by the glass tube in Singer's improved electroscope, forms the other. I will now show you an experiment which will convince you of the usefulness of the hand in this capacity.

I will take one of Volta's plates by its glass handle, and give the face of it a gentle rub on the table cloth or on the sleeve of my coat; and whilst the other hand is held over the insulated disc of the electroscope, I will touch that disc with the excited one, and immediately take it away again. The communicated electric action is very feeble, and the gold leaves will scarcely diverge: but now, that I take away my hand, you will observe that they separate to a considerable extent. This is precisely the result that we should obtain were we to use the metallic condenser: and in those delicate cases where the electric action is 'too feeble to deflect the gold leaves by one single contact of the excited body, we have only to repeat these feeble units of electric force for a few times, as in the experiment with Volta's copper and zinc discs, and the sum of the feeble electric increments of force, collected whilst the hand is present, will be sufficient to diverge the gold leaves when it is withdrawn from the vicinity of the insulated disc of the electroscope. If I stand on a stool with glass legs, or be insulated by any other means, my hand has still the same kind of influence, though in a less degree than when uninsulated.

There is another method of showing the influence of vicinal uninsulated bodies, which I will now point out to you. Let us communicate, in the usual way, either kind of electric action to the electroscope whilst unfurnished with a condenser. The gold leaves diverge, and remain divergent when the electrized body is withdrawn. I now bring my open hand over, and parallel to, the insulated disc of the electroscope. You will observe that the divergency lessens as my hand approaches the disc, and when it is sufficiently near, the gold leaves collapse and hang together. But on withdrawing my hand gently, the divergency again commences, and gradually becomes greater till the hand is removed from the sphere of action, when the divergency arrives at nearly the same degree as at first. Similar phenomena are produced by insulated plates of metal, though in a minor degree.

This is a beautiful experiment and conveys a great deal of information, which we ought to avail ourselves of in all those electroscopic inquiries in which the electric action is *to be tested*, and the electric action of the *testing body* are of different degrees of tension. Let me give you an experiment in illustration. I excite a feeble electric action in Volta's copper disc, by rubbing it against the sleeve of my coat, and I communicate a portion of this electric action to the electroscope, and the gold leaves are observed to diverge slightly. The electricity is negative. I now excite a round tin plate, insulated by its glass handle H, Fig. 13, to a considerable degree of power, by rubbing it on the fur side of a dry rabbit skin; and it will be observed, when I bring this tin disc over the cap of the electroscope, that the divergency of its gold leaves increases to a great extent.

Fig. 13

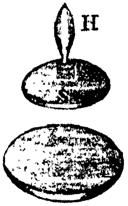


Being satisfied with this result, let us now reverse the process, by first communicating a powerful *electroscopic* action to the gold leaves, from the excited tin disc, and afterwards bringing the feebly excited copper plate over the face of the insulated disc of the electroscope. Now, although you are aware, by the former experiment, that both discs are in the same negative *electric* condition with reference to the uninsulated group of things about the table, yet, as they are positive and negative with regard to each other, the divergency of the gold leaves diminishes by the approach of the copper disc, which is the less formidable electrized body of the two. Hence experimenters unacquainted with this curious fact would be almost sure to be led into error from the indications afforded by the electroscope. As this, I believe, is the first time that such a circumstance has been announced, it is highly probable that wrong conclusions may have been drawn by some of those who have not studied these nice points of electric action. This interesting fact may be produced by one excited disc only: the tin disc for instance. First, excite it on the fur to a considerable degree, and afterwards communicate a portion of its electric action to the electroscope. Again excite it very feebly, and then bring it over and parallel to the disc of the electroscope.

The divergency of the gold leaves will diminish, and when the experiment is dexterously performed, the divergency will be completely annihilated, until the feebly electrized plate be withdrawn from the vicinity of the other.

Having now proceeded through a sufficient series of illustrations of the application of the electro-polarization of thin metallic discs in the capacity of the condenser, we will proceed to employ another beautiful piece of apparatus, whose operations essentially depend on the same laws of electric action. This apparatus, which is called the *electrophorus*, is also the invention of the celebrated Volta.

Fig. 14.



The electrophorus is represented by Fig. 14, and consists of three distinct parts: the sole, the resinous cake, and the cover s, with its glass handle H. The sole is simply a circular flat tin dish, having a rim of about half an inch in height. A mixture of about equal parts of pitch and resin, and a little linseed oil, well incorporated with each other whilst melted, form a good compound for the resinous cake. Some persons employ lac, resin, bees wax, &c., mixed together, for the resinous cake: but the simple compound first described is quite as good for this purpose. The power of the electrophorus will vary, of course, accordingly with its size, but one of about twelve or fifteen inches diameter answers very well for ordinary purposes. The cover s, is simply a metallic disc of about two inches less diameter than the sole, well polished and rounded at its edges. A well lacquered brass cover looks very neat, and gives the electrophorus a good appearance: though a tin cover, wired round the edge and japanned is often employed. A brass ball is occasionally attached to the cover by means of a bent brass wire.

The resinous cake of the electrophorus being warm and dry, I excite it by briskly rubbing its surface with the fur side of a dry and warm rabbit skin: whipping with a warm silk handkerchief excites the resinous cake very well. This process produces on its surface a negative electric action, and to the highest degree, when the *sole* rests on the hand, or is well connected by conductors with the ground. On the excited resinous cake I place the *cover*, or *scudo*,* as Volta termed it; taking care to touch the glass handle only. Now in consequence of the surface of the resinous cake presenting a multitude of asperites, scudo rests upon them, and is thus prevented from coming into general contact with the resinous surface. Under these circumstances the electric fluid naturally belonging to scudo, finding a less resistance on the lower surface than on its upper one, presses in that direction, and accumulates on that surface, leaving the upper surface in an *electro-negative* state. Scudo, therefore, whilst resting on the resinous cake, is electro-polar; and its upper surface being the *negative* pole, it is prepared to receive a fresh portion of fluid from any other body within its reach.

I present my finger to the upper surface, and immediately a portion of fluid, in the form of a spark, jumps from it to scudo; which, being insulated, has no opportunity of disposing of it until its removal from the resinous cake. I lift it up by the glass handle, and present the ball to the knuckles of my other hand: the spark which I before communicated to scudo now returns. I again place scudo on the resinous cake; he again becomes polar, and being ready to receive additional fluid, I again supply it from my finger; and by affording him an opportunity, as before, he returns it in a full brilliant spark to the knuckle of my other hand. By repeating these operations we find that the resinous cake retains its action for many hours, and even days, to a certain extent, when great care is taken to keep it clean and dry.

From this retention of its electric action, the electrophorus becomes a convenient instrument in chemical laboratories, where electric sparks are wanted for the explosion and combination of gaseous mixtures, in various investigations. Its inventor, Volta, applied it in a peculiar form for the purpose of obtaining an instan-

* Scudo, in the Italian language, means a *cover*, a crown, or *top-piece*. It is always a noun of the masculine gender.

taneous light in the night-time, or whenever a lighted lamp or candle was wanted. This was accomplished by igniting a small jet of hydrogen gas by the spark which passed through it from scudo to the nozzle of the jet pipe.

Our next business will be to examine more closely than hitherto, the electric characters of the two principal operating parts, the resinous cake and scudo, of the electrophorus. For this purpose, I again excite the cake with the rabbit skin, and afterwards bring it into contact with Bennet's electroscope. The gold leaves diverge: and by bringing the face of the cake a second time over the cap of the instrument, the divergency is increased. I now excite the glass tube with the same fur, and by its approaching the cap of the electroscope the divergency again increases; showing that the cake and tube are in the same electro-negative condition. But to satisfy ourselves still further, if possible, I excite the glass tube by tinfoil, which renders it electro-positive. By now bringing the tube over the cap of the electroscope the divergency of the gold leaves diminishes. Hence, by both tests, the resinous cake is proved to be in an electro-negative state.

We next examine scudo prior to his being placed on the cake, and find him neutral. We place him on the cake, leave him there for a short time, and by the glass handle, remove him to the previously neutralized electroscope, and find that he is slightly electro-positive; having collected a small quantity of fluid from the air, through the instrumentality of the asperities on his surface. We again place him on the resinous cake, touch him with the finger, experience a pungent sting from the spark, and then transport him again by the glass handle to the cap of the electroscope. The gold leaves exhibit a powerful repulsive force, which on examination by the two former tests, we find to be *positive*.

There are many other curious experiments to be made with the electrophorus, which in a theoretical point of view are very interesting: but as the whole of them are the results of electro-polarization, those hitherto offered to your notice will be sufficient to show the groundwork of all the rest.

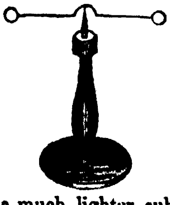
LECTURE V.

Besides the electroscopes hitherto described, there are others of no less importance yet to be noticed, before we proceed to employ other classes of electrical apparatus. The lever electroscope, Fig.15 , first employed by Dr. Gilbert, in the earliest electrical investigations on record, from its simplicity, and conspicuity of action, may be used with advantage, and without much dexterity of manipulation, on many occasions. It consists of a neat mahogany base, from the centre of which rises a brass stem, finely pointed at its upper extremity, as represented by Fig. 15, for the purpose of a pivot, on which the brass wire lever can move with freedom, by the application of a very slight electric force.

Fig. 1

The complete instrument, in its improved state, is represented by Fig. 16. The supporting stem of this electroscope is of glass, well varnished, and surmounted by a brass ferrule, and a steel point for the pivot. Each extremity of the brass arm is furnished with a small cork ball, neatly gilt. The delicacy of the instrument is somewhat improved by its having gilt balls of the pith of the elder-tree, which is a much lighter substance than cork. This instrument being very extensively employed by the Abbé Hauy, in his mineralogical enquiries, is now frequently called Hauy's electroscope.

Fig. 16.

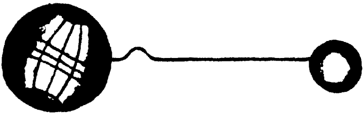


In illustration of the mode of using this instrument, I take a morsel of sealing-wax between my finger and thumb, rub it against the sleeve of my coat, and then present it to one of the pith balls. The electric force thus brought into play draws the lever to the wax. If I use a larger piece of sealing-wax, and excite it by the rabbit skin, the electric force is sufficiently powerful to draw the ball at the end of the lever at a considerable distance. The lever moves slowly at first, increases its speed gradually, and as it approaches closer to the excited wax, its velocity becomes considerable, and it strikes against the electrized body with some force.

When the wax is withdrawn, the insulated lever is left in the same electric condition as itself, and the next approach drives the lever off by the electro-repulsive forces of the two bodies. If, however, I force the electrized wax too closely to the lever, the latter will again attach itself to it by virtue of attraction: because, in this case, the wax polarizes the lever, rendering the vicinal end electro-positive, and the remote end electro-negative, with respect to itself. Hence with this electroscope, as with that with the two pith balls, Fig. 3, page 16, it is necessary for the experimenter to keep in view the laws of electro-polarization, otherwise the result of his experimental enquiries might lead to erroneous conclusions.

The principles upon which this electroscope operates are applicable in communicating motion to an orrery of the earth and moon. Fig. 17 represents a lever, with

Fig. 17.

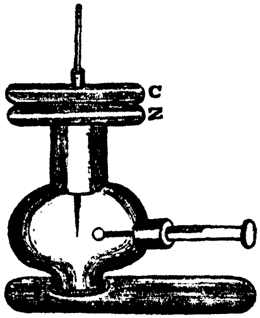


arms of unequal length. At the extremity of the short arm is a large cork ball, weighted if necessary, representing the earth; and at the other extremity is a small ball of the pith of the elder, to represent the moon. When this piece of apparatus is placed on the glass stem, Fig. 16, any electrized body, the excited glass tube for instance, presented to the moon, will draw that body towards it, and by keeping the tube before it, the whole system may be made to revolve round the centre of motion, highly imitative of the revolutions of the earth and moon round their common centre of gravity. When the electrized body has been carried round in front of the moon a few times, it may be taken away, and the momentum acquired by the system will keep it revolving for some considerable time afterwards.

If the insulated orrery be first electrized, by permitting it to touch the excited tube, it may afterwards be driven round by repulsion. It will be obvious from these illustrations, that many amusing and instructive variations of objects might be attached to the two arms of the lever, and put into motion by these means. There is an advantage to young persons by varying their experiments in every way they can think of, as by frequent repetitions they pass unconsciously through a train of practice which familiarizes them with the use of apparatus, ensures dexterity of manipulation, and stamps on the mind those lasting impressions by which the principles of the science are kept in unfading remembrance.

The most delicate electroscope hitherto brought into notice, is that invented by Dr. Robert Hare, professor of chemistry in the Pennsylvania University at Philadelphia. This electroscope is represented by Fig. 18, and consists of an oval wooden base board; a globular glass vessel, capped with brass; a zinc disc of six inches diameter, from which hangs a narrow strip of gold leaf, and a wire with a ball attached to its inner extremity, and a graduated head at the other. The zinc disc z is fixed to the brass socket c: one end of the gold leaf is attached to the centre of the zinc disc, and is suspended in the axis of the glass vessel. A brass socket is cemented round a hole to the side of the glass, and through the centre of the socket, passes the stout brass wire; the ball of which, by means of a screw, can be adjusted to any required distance from the lower point of the gold leaf. The precise distance in minute parts of an inch can easily be ascertained, by means of the micrometrical graduation on the head of the screw. The delicacy of this instrument is shown by placing a copper disc on the zinc one, as shown in the figure, and lifting it suddenly

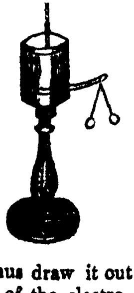
Fig. 18.



off again; the feeble electric action thus brought into play causes the gold leaf to strike the ball of the lateral wire.

Hitherto, I have applied the term *electroscope*, to all these instruments, which indicate electric action; but as all of them are capable of indicating *relative* differences of the electric forces communicated to them, they are frequently called *electrometers*. When, for instance, the angle of divergency of either the pith balls or the gold leaves is great, we know that the electric force is greater than when the divergent angle is small: and so far these instruments are measurers of *relative* electric forces; and, consequently, are *electrometers* in this individual capacity: that is, in showing the relative *intensity* of the forces applied to them; but they are very far from having the power of indicating the relative *quantity* of forces, or the relative *quantities* of electric fluid, in those bodies which communicate to them electric action. Nor have we, indeed, any instrument capable of affording this kind of information correctly.

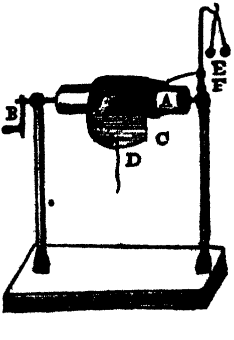
Fig. 19.



In order to give you a still better idea of the extent of information which our *indicators* of electric action are capable of communicating, I must solicit your attention to an experiment first made by Dr. Franklin. The apparatus employed by that philosopher is represented by Fig. 19, and consists, simply, of a metallic can and chain, insulated by standing on a glass pillar. A pair of pith balls, suspended by a flaxen fibre, hang from a wire projecting from the can. If now we electrize the metallic can, with its contained chain, by an excited glass tube, the pith balls diverge to a certain extent; but if we afterwards lift up one end of the coiled chain, by taking hold of the silken thread s, and thus draw it out gradually, we find that the divergency of the electroscopic balls gradually lessens; and when a great portion of the chain is lifted out of the can, the divergency is so far diminished as to be scarcely perceptible. We now drop the chain gradually into the can, and you will observe the pith balls begin to separate from each other again: and the more so as a greater portion of the chain returns to the can; and when the whole of it has returned the divergency is nearly, though not quite, as great as at first.

This is one of those experiments from which much information is to be obtained, and gives us a good idea of the true value of electroscopic indications: by showing us that one and the same *quantity* of the electric fluid will exert a greater, or a lesser degree of repulsive force, accordingly with circumstances. When the whole of the chain is within the can, the metallic surface exposed to the surrounding electric pressure is less than when the chain is drawn out: and, consequently, the electric force is more *condensed*, and has to operate against a *less extent* of pressing surface under the former than under the latter circumstances. But when the electric force has to operate against a *less extent* of pressing surface, it presses more *intensely* against each individual *point* of that surface. And as the divergency of the pith balls was *greatest* under those circumstances, we learn that the greatest degree of divergency indicates the greatest degree of *intensity*, without any reference whatever to the absolute quantity of fluid in operation.

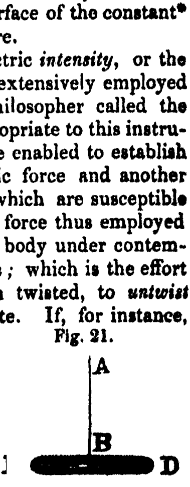
Fig. 20.



Another method of showing this fact, is by means of the instrument represented by Fig. 20, which consists, principally, of a metal windlass A, round which is wound a broad flexible metallic strap C, with its silken cord D, an electroscope E, and a glass handle B: the whole being supported by two glass pillars fixed into a mahogany base. We first electrize the insulated part of the apparatus by the application of the excited glass tube, on the withdrawal of which the electroscopic balls are left in a divergent state. We now take hold of the silken cord D, and by pulling at it, unwind the metallic strap, and thus expose to the surrounding air a more extended electrized surface. The pith balls fall closer together in proportion as this surface extends, until the electric force becomes so far attenuated that it is unable to cause any divergency whatever. On turning the glass handle, and thus winding up the metallic strap, the pith balls again indicate electric action, which becomes more and more powerful as the strap is more coiled on the windlass; and when it is wholly coiled up, the angle of divergency is nearly the same as at first; showing again that the communicated fluid was not *lost* by the unwinding of the strap, but that it was merely *attenuated* by exposure to a more extensive surface of the constant* surrounding statical electric pressure.

The most exact measurer of electric *intensity*, or the *intensity of electric forces*, is one extensively employed by M. Coulomb; and by that philosopher called the *electrical balance*: a term very appropriate to this instrument, because by its means we are enabled to establish an equilibrium between an electric force and another force, the minutest quantities of which are susceptible of very exact measurement. The force thus employed to measure the electric force of any body under contemplation, is called the *force of torsion*; which is the effort made by a thread which has been twisted, to *untwist* itself and return to its former state. If, for instance, A B, Fig. 21, represent a thread or thin metallic wire, carrying the horizontal lever E D, and the whole at rest, it is obvious that the lever will assume a certain direction; and for convenience of illustration, we will suppose that it hangs in the plane of the meridian, with D

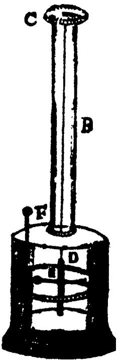
Fig. 21.



* The surrounding pressure may be considered as *constant*, or uniform, for the short time occupied by the
though its fluctuations are occasionally very great.

towards the north, and E towards the south. If, now, we move either end of the lever, whether eastward or westward, the thread being fixed at its upper end, would become twisted in proportion to the number of degrees of the horizontal circle through which each extremity E and D passed; and if we would retain the thread in this state of *torsion*, we must employ a *resisting* force to the lever, sufficient to balance the thread's effort to untwist itself; the counterbalancing force required would be less in proportion to its distance from the centre of motion; and, consequently, least of all, or at a minimum, when applied to the extremity E, or D, of the lever.

Fig. 22.



The operating principle of the *torsion balance electrometer* being now explained, the structure and employment of the instrument will be easily understood. It is represented by Fig. 22. The lower part A, is a wide cylindrical glass vessel, with its mouth downwards, and cemented to a wooden base. Over a perforation in the centre of the top of this vessel, rises a tall glass tube, surmounted by a brass cap and a horizontal plate, divided into 360°. Through the centre of the graduated plate passes a small cylindric brass pin, which can be turned freely in the hole: its upper end carries an index, and its lower end carries a small pincer, which holds the upper extremity of a thin silver wire, at whose bottom is suspended a little brass cylinder D, to keep it stretched. This cylinder is split in the direction of its length, and holds a little lever at right angles to its own axis. One arm of this lever is made of a piece of stout silken thread, covered by lac varnish, and terminated by a small circular plane E, of gilt paper. The other arm is of copper wire of a proper length to establish horizontality of the whole lever. The top of the large cylindrical glass vessel has another opening, through which passes, vertically, a brass wire F, terminated both at top and bottom with a small brass ball: the lower of which is in the same horizontal plane as that in which the lever moves, and at the same distance from the centre of motion as the gilt disc at the end of the lever.

When using this instrument, we first turn the brass cap c, at the top of the tube, until the gilt disc just touches the lower ball of the wire F. A slight electric force is communicated to that ball, and also to the gilt disk, by touching the upper ball F, with the electrized body under examination. The disc E, is immediately repelled from the fixed ball, and rests at some angular distance, the amount of which is ascertained by the graduated arch on the side of the large glass vessel. The silver wire is, consequently, twisted to the same extent: and the electric force of repulsion just balances the *torsion force* of the wire. If, now, we neutralize the electric action of the instrument, the gilt disc E, returns to the fixed ball again; and by applying another electrized body to the ball F, the disc is again repelled to a greater or a less distance than before, accordingly as the last communicated force was greater or less than the first one.

When two or more electric forces are to be accurately compared with each other, we choose a certain distance between the ball and the disc, at which all the forces under contemplation shall operate. This is effected by turning the index on the graduated brass circle, until the disc is at the standard distance from the fixed ball, and the numbers of degrees which the index has passed over, added to those between the moveable disc and the fixed ball, give the exact twist of the torsion wire; or, if you please, of the *force of torsion* which just balances the electro-repulsive force at that distance.

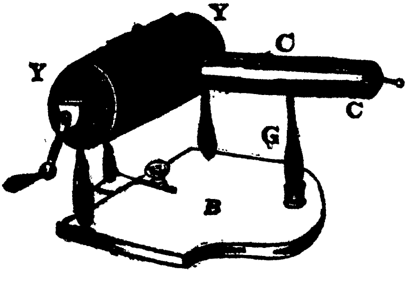
If, for instance, the standard distance between the fixed ball and the moveable disc be 10°, and that I find the repulsive force is such, in one case, as to require the index to pass over 90°, in order to bring the disc back to within 10° of the ball; and in another case the index has to pass over 190°, before the disc will stand at the the 10° from the ball; then as the number of degrees passed over by the index, added to the 10° in each case, is the measure of the force of torsion in the wire; and, as these torsion forces are exactly balanced by the respective electric forces at the standard distance of 10°, they are the exact measurers of those latter forces: and, therefore, the electro-repulsive forces were as 100 to 200; or, as 1 to 2.

LECTURE VI.

ALTHOUGH we are very far from having exhausted the electroscopic class of phenomena, it may be prudent, at this period of our illustrations, to direct your attention to the structure, management, and uses of other pieces of apparatus of a somewhat more formidable character, and by means of which we shall be enabled to pass through a great number of illustrative experiments, and show some of the principles of electric action to a much greater advantage than by the employment of those simple and delicate instruments which we have hitherto operated with.

I will first describe to you the electric machine, an instrument of general use amongst electricians whilst performing many of their favourite experiments. There are, however, at this time, two distinct forms of electrical machines, both of which are in general use. One of these is called the *cylindrical* machine, the other the *plate* machine. Some persons prefer one of these machines and some the other: but as the cylinder machine is more commonly used than the plate one, I will describe it first.

Fig. 23.



The principal operating parts of this machine consist of a cylinder of glass and a flexible cushion; which, by rubbing against each other, excite the electric fluid in precisely the same manner as it is excited on the surface of the glass tube, or on sealing-wax. Fig. 23 is a representation of a cylinder machine; in which B is a stout mahogany board, and, in some cases, well varnished also. Both are useful, inasmuch as, if the upper surface of this board were not so finished, the fibres of the wood would be apt to draw off some of the fluid which had been excited; and would, consequently, lessen the disposeable part which was intended for experiment. This board forms the basis of the instrument. Y, Y is a cylinder of glass, supported on two pillars, whose lower extremities are well fastened into the board B. The glass cylinder has an open neck at each end; and on each of these necks a cap of wood is firmly cemented. Each wooden cap has a projecting cylindrical pin, formed of the same piece of wood. When the caps are cemented to their respective necks of the glass, these pins ought to be situated in the axis of the cylinder continued; because they form the pivots on which the cylinder rotates when the machine is in action. Proper pivot holes in the upper ends of the two supporting pillars are provided for the reception of these pivots.

To one end of this axle is attached a handle, or winch, as seen in the figure, for the purpose of turning the cylinder. On the further side of the cylinder is a cushion, mounted on a glass stem, the lower end of which is fixed in a piece of wood that slides in a dovetailed groove in the base-board. There is also a set-screw attached to this piece of mechanism, all of which will be understood by looking at the figure. This sliding piece is for the purpose of pressing the cushion more or less against the surface of the cylinder, and the screw is to hold it fast at its place when the required pressure is obtained. The cushion is frequently called the *rubber*. It is furnished with a silken flap, one end of which is sewed to the upper side of the rubber, and the other part lies on the upper surface of the cylinder, in the manner shown in the figure. This piece of silk is intended to prevent the excited fluid from flying off into the atmosphere, until it arrives at the extreme edge, where it is attracted and taken from the cylinder by a row of metallic points, which are attached to one end of the prime conductor C C. The prime conductor, being supported on a pillar of glass, G, is insulated, and from it the fluid can be transmitted to other pieces of apparatus for experiment. The cushion is also insulated; and some experimenters think it necessary that the glass cylinder should be insulated, for which purpose they have its supports of glass. For my own part, I do not see the necessity of having the cylinder insulated.

There are many particulars to be attended to in order to make a machine work well. Every part of it ought to be quite free from dust and moisture; and the glass parts of it somewhat warm. The face of the cushion which rubs against the glass cylinder must be covered with an amalgam of zinc, of about the consistency of butter, and mixed up with a little tallow from a candle, in the manner already described. It must also be connected with the ground by means of a copper wire of about the diameter of bell-wire, or with a metallic chain. When these precautions are properly attended to, the machine usually works well, especially in a warm and dry room, which is better adapted for electrical experiments with the machine than in any other situation.

The machine being now in good order, we will take away the prime conductor, and put the cylinder into motion. You will now observe an immense quantity of the electric fluid darting from the edge of the silken flap into the air, and several bright sparks passing round the surface of the revolving cylinder. These appearances are exceedingly beautiful when the room is darkened; and they may be produced for a long time together by continuing the motion of the machine. If you hold the ends of your fingers towards the silken flap, the nails will be curiously tipped with luminous matter, and the whole of the fluid excited by the machine will lean towards them, and scarcely any sparks will be seen travelling round the glass cylinder. In this case your fingers attract the fluid, and draw it from the surface of the excited cylinder, and it is carried away to the ground by yourself, the floor, and other materials of the building; all of which are sufficiently good conductors for this purpose.

Let us now insulate the cushion by removing from it the copper wire. You will now find that the machine produces but a very small quantity of fluid; the reason of which is, that when it has parted with that which naturally belonged to the cushion, it can yield no more, excepting some small portion which it receives from the atmosphere. But when the cushion is in metallic connexion with the ground by means of the copper wire, or when the hand is placed on it, it gets an abundant supply from that source. Hence, whatever quantity of fluid is drawn off by your fingers when presented to the edge of the silken flap, a similar portion is immediately supplied to the cushion from the ground. In many experiments, as you will see in a future lecture, we dispense with the copper wire, and have the cushion purposely insulated.

Let us now turn the points of the prime conductor towards the cylinder, taking care that they do not touch it. Now turn the machine, and you will observe that these metallic points are all tipped with small luminous stars. They are receiving the electric fluid, and conveying it to the prime conductor.

You will see that there is a metallic ball and stem attached to that end of the prime conductor which is furthest from the cylinder. This ball is screwed to the stem, and may be removed from it at pleasure, for the purpose of exposing the sharp-pointed termination of the stem.

When this sharp point is uncovered, and the machine in good action, you will observe a beautiful brush of electric light proceeding from it; and if you present the back of your hand to this brush, a singular and rather pleasant sensation, something like a gentle stream of wind, is experienced. This stream of electric matter is usually called the electrical *aura*. When a smooth metallic ball is presented to the point, a series of exceedingly minute sparks are observed; but when another fine metallic point is presented to it, this latter is tipped with a spot of light. Now, as the point which is attached to the prime conductor is delivering the fluid and the other receiving it, we have these two distinct kinds of phenomena produced. The *delivering* point exhibits a brush, and the *receiving* one a star. These peculiarities of the *delivering* and *receiving* points are of high importance in some electrical contemplations, as by these indications alone we are enabled to ascertain the *relative* electric states of different bodies, and of the different parts of one and the same body, through which the electric fluid is transmitted; and to discover analogies not easily detected independently of these phenomena.

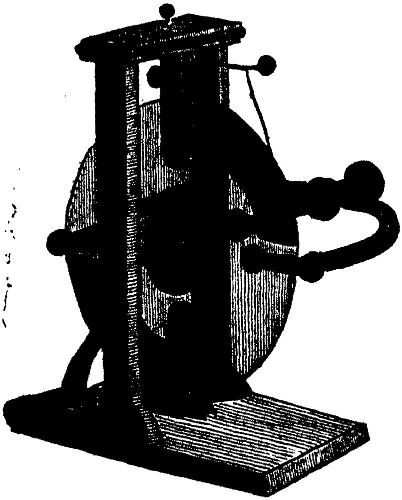
We will now screw on the ball, and thus cover the metallic point; you will now find that a series of beautiful sparks pass from the ball of the prime couductor to another ball presented to it. The snapping noise which these sparks make is occasioned by a sudden collapsion of the air, which becomes displaced by the electric fluid whilst jumping from one ball to the other. It is from a similar circumstance, only on a larger scale, that thunder is produced, by the lightning which darts from the clouds. In miniature, lightning is very beautifully imitated by the sparks which traverse the air from the prime conductor to the other ball; especially when the ball from which the sparks proceed is rather small. You will now perceive that the sparks which pass from the small ball in the end of the conductor, are ten or twelve inches in length, and that they travel through the air in zig-zag paths, in precisely the same manner as you may have observed lightning traversing the air. The crooked paths of the sparks are occasioned by the resistance which the electric fluid meets with in the air, and the same remark is applicable to lightning. When the fluid first sets out, it drives a portion of air before it, and thus suddenly condensing it in the direction of its path, causes a greater resistance in that direction than in any other. This being accomplished, the electric fluid finding an easier path sideways, becomes deflected from the original one; and as it performs the same operation on the air in the new path as in the old one, it is again suddenly deflected: and thus, by a rapid series of deflections, arising from the same cause, the fluid is compelled to move in a crooked path through the air, till it reaches its destination. There is also another cause which assists the resistance of the compressed air in producing these deflections of the electric fluid. The compressed air, in front of the spark, becomes highly charged with electric fluid, which thus operates repulsively on the approaching spark, and tends to drive it out of its direct course.

Approach the ball of the prime conductor with the back part of your hand, and you will receive a series of sparks which produce a sharp burning sensation. You may have on your glove, and still the sparks will arrive at your hand; and by presenting your arm to the ball, you will find that they pass through your coat sleeve. As we proceed, I shall have to show you that the electric fluid is capable of perforating, and even tearing to pieces, those bodies which are not good conductors.

If, instead of a ball, you present a sharp-pointed wire to the prime conductor, you no longer get any spark; but you will observe a pretty little luminous star on the point, which shows that it is receiving the fluid in a silent and almost imperceptible manner. Hold the point with one hand towards the prime conductor, and with the other hand present a ball to it. You get no sparks under these circumstances, although the machine is in good order; but if you take away the pointed wire, you immediately get a series of sparks. Now, these are exceedingly interesting facts, by teaching us that sharp metallic points have great influence in drawing off the electric fluid from those bodies which are charged with it. You may place the pointed wire at the distance of several inches from the prime conductor, and still it has the power of attracting the fluid from that apparatus to a great extent. You may try vegetable points, such as thorns, the points of green leaves, &c., and you will find that all of them have the same property as the metallic point, in drawing off the electric fluid. A bunch of grass held at a few inches distance from the prime conductor, robs it of all the fluid that is communicated to it by the machine. You will now see the necessity of keeping all kinds of sharp-pointed articles entirely away from the prime conductor, otherwise much of the fluid intended for experiment would be lost by means of them.

The plate machine, as usually constructed, is represented by Fig. 24; and consists of a stout disc of plate glass, supported in a wooden frame by means of a horizontal metal axle, which passes through its centre.

Fig. 24.



The glass plate is rotated on its axle by turning the handle attached to one end of it; and, by means of four rubbers, one on each face at its *lowest* side, and one on each face at its *upper* side, it brings into play a considerable quantity of the electric fluid. The prime conductor of this machine, is invariably of brass, consisting of two bent arms, which proceed from a centre-piece, as represented in the figure. The prime conductor is insulated by being supported on a stout, solid, horizontal glass cylinder; one end of which is attached to one of the upright cheeks of the wooden frame. To each rubber is attached a silken flap, which reaches to the horizontal diameter of the glass plate. At these remote edges of the silken flaps the prime conductor presents a series of sharp metallic points, which collect the excited electric fluid, and thus charge the conductor, and such other pieces of apparatus as may be placed in contact with it. There are certain contrivances by means of which the prime conductor, rubbers, &c., can easily be removed from their places, when such removals are required for cleaning, amalgamating, &c.

The plate electrical machine belonging to this institution, is somewhat differently constructed to that last described. Its vertical glass disc is four feet in diameter, which is excited by four rubbers in the same manner as by those in the last described machine. The rubbers of this machine,* however, are placed in the horizontal diameter of the glass plate, and are supported by the two glass pillars G G, G G, which rise from the ends of the mahogany frame F F, F F. From the two opposite sides of the frame F F, F F, rise four mahogany pillars E E, E E, E E, E E, two on each side: and each two is surmounted and joined by a cross piece, also of mahogany. One pair of these pillars, with their cross piece, is seen in front of the glass plate, and the other, which is behind the glass, is represented as seen partly through the glass and partly on one side of it. The axle of the disc rests on these two cross pieces, and with the disc revolves in brass bushes, by means of the hand applied to the winch, seen through the glass at the further extremity. In the centre of the cross piece on this side of the glass plate, is lodged one end of a stout cylindric glass bar G G, which projects horizontally, and carries the large curved brass conductor C C, C C, with its projecting horizontal brass cylinder terminating with the large sphere C. Each arm of the prime conductor terminates by a cylinder of brass, parallel to the plane of the glass plate; each of which is furnished with a series

* See Frontispiece.

of pointed wires, foi the purpose of collecting the excited fluid at the edges of the silken flaps s s, s s, which are attached to the two pairs of rubbers. Here is also a *negative* conductor o o, the principal part of which passes horizontally behind the glass plate: it is bent towards its ends for the purpose of adapting them to the tops of the glass pillars G G, G G, on which they are fixed, being screwed firmly down to them, by the brass balls B B. The central part of this negative conductor is supported by the glass pillar P. This is a superb piece of apparatus, and works exceedingly well. It was made to order, by Watkins and Hill, Charing Cross, London, expressly for the institution.

The particulars I have already pointed out respecting other electric machines, such as keeping them clean, warm, and dry, are applicable also to this magnificent instrument, and, indeed, to all kinds of electrical apparatus. Every particle of dust presents a virtual point to the surrounding air, and delivers to it a great quantity of fluid as decidedly as the metallic point at the extremity of the prime conductor delivered fluid to the air in one of our previous experiments. If you will now pay attention to the prime conductor, which was perfectly clean when the machine was first put into action, you will observe that it is completely covered with a film of the finest particles of dust, which looks almost like smoke. This covering has been formed by virtue of the prime conductor, whilst in an electric condition, attracting the dust from the contiguous air; and now, instead of presenting a smooth surface, it presents an asperous one; every point of which loses some portion of the electric fluid which passed to it from the machine, and consequently, under these circumstances, you have not so much *disposable* electric fluid from the prime conductor for experiment, as when that apparatus was perfectly free from dust; and as every other piece of apparatus, whilst in use, would loose the electric fluid into the air, from a similar cause, you will be sensible not only of the advantages, but even of the necessity, of keeping every part of an electric apparatus perfectly clean. Hence, also, every part of the surface of those instruments that are not intended to *dissipate* the electric fluid in the air, whether they may be constructed of wood, ivory, or metallic matter, ought to have their surfaces well polished, as convex as possible, and without sharp edges; even the operations of the milling tool should be carefully avoided. The loss of fluid from any piece of apparatus, from these or any other causes, may be very correctly called *dissipation*.

Now, it often happens that one or more of the collecting points of the prime conductor, dissipates the fluid whilst the others are collecting it; and especially when the prime conductor is well insulated. This fact may be ascertained by looking at the points whilst the machine is in motion; for the receiving points are tipped with a luminous star, and the delivering points exhibit pencils of electric light. This kind of dissipation occurs most frequently from the outermost points of the series.

There is also another source of loss of fluid which it may be well to mention in this place. If the rubber has been newly amalgamated, the surface of the revolving glass becomes partially covered with streaks of the amalgam after it has been in action for a short time; and as these streaks are of metallic constitution they are conductors, and carry a portion of the excited fluid entirely round to the rubber again, and thus prevent it from being taken up by the collecting points belonging to the prime conductor. When this happens, the prime conductor gives but very feeble sparks, or any other indication of electric action; indeed, the machine is out of order. Therefore these streaks and spots of amalgam, which stick to the surface of the glass plate, must be immediately removed as fast as they appear.

The distribution of electric fluid over the surface of bodies, is a topic of great importance in the study of this branch of physics, whether it be viewed in a theoretical or in a practical point of view. With non-conducting bodies a dissemination of the fluid over the whole surface is not easily attained within any moderate limit of time, whilst on the surface of good conductors, it is accomplished in a moment; and, therefore, the best conductors, the metals, for instance, are best adapted for contemplating the laws of electric distribution.

Let us suppose that we have two flat pieces of metal of equal surface insulated, and that I communicate to each piece a certain quantity of the electric fluid. Now as each piece has received the same quantity they will both be electric alike; and, because they have equal powers of dissemination, the distribution of the fluid in the one piece will be equal to the distribution in the other: for, although the distribution will not be *equable* over the whole of the surface of either of them, it will be similar in both pieces; so that the electric forces at the *centre* and at the *edge* of one plate, will, respectively, be equal to the electric forces at the centre and at the edge of the other.

The same reasoning holds good with metallic cylinders with convex ends, such as the prime conductor of the cylindrical machine. Similar portions of the electric fluid on each cylinder will render them similarly electric on corresponding parts of their surfaces, But in no instance can the distribution be *equable* unless the body be perfectly *spherical*, and surrounded on every side by equable electric forces. On this subject I shall have much more to say in a future lecture, my present object being only to show you that, with the same electric machine the electric forces exhibited by the prime conductor will vary with its size and figure.

If the prime conductor be spherical, as is sometimes the case, you may take a spark from any side of it you please, and you will find the pungency of that spark nearly alike from whichever side of the sphere it be taken; more especially if the sphere be not of large dimensions. But if the conductor be a long narrow cylinder with convex ends, the pungency of the sparks is greater from the end most remote from the machine, than from its sides.

Now, in order to become acquainted with the effects of prime conductors of different magnitudes, for the same machine, it will be necessary that we first make ourselves acquainted with the electric conditions of two unequal metallic bodies charged with similar quantities of the electric fluid. If, for instance, I were to employ two insulated metallic spheres, whose surfaces were as one to two (one a square foot, the other two square feet), and to each sphere I were to transmit a certain quantity of the electric fluid, say ten particles; it is very obvious that as these ten particles occupied only half the space on one of these spheres as on the other, the electric density on the small sphere would be twice the electric density on the large one: and as the *intensity* of the force depends upon, and is proportional to, the density of the fluid, the intensity of force on the smaller sphere is twice that on the larger.

Now, although, as I have before stated, the electric condition of a cylindrical conductor is not equable on every part of its surface, yet the *mean* intensity of force in the prime conductor with the same machine, will be in some inverse ratio of the size of the conductor: or, in other words, a small conductor becomes more intensely charged than a large one. On the other hand again, the *quantity* of fluid which a conductor can hold, at a *maximum intensity*, is in some direct ratio of its size; or, if you please, a large conductor will hold more fluid than a small one. But it must be observed, that a large conductor, by exposing a more extensive surface to the surrounding air than that exposed by a smaller one, has a better opportunity of dissipating the fluid; and would require a larger supply from the machine to keep up any certain degree of intensity. There is also another point to be taken into consideration. When two conductors of the same magnitude are charged to different degrees of intensity, that which has the highest intensity will have the greatest propelling force; and, consequently, will have the greatest dissipating power from the same extent of surface. But it is found by experience, that the dissipation from a large conductor is much greater than from a small one, when attached to a small machine. Therefore, from all these considerations, it appears, that with a glass cylinder of certain dimensions, say ten inches diameter and fifteen inches long, we may keep a tolerable sized prime conductor continually charged to a high degree of intensity: but that the same cylinder could not keep up the same degree of electric intensity in a very large conductor. Indeed, the surface of a conductor might be so large as to dissipate the greater portion of the whole fluid excited by the machine.

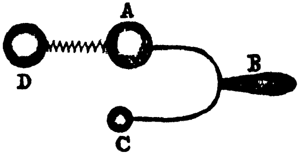
Again, the *striking distance* (or the thickness of the plate of air that the first spark from a conductor will penetrate), is proportional to the intensity of the fluid in that particular part of the conductor from which the spark is taken: therefore the higher the intensity the greater the length of the first spark. I here take into calculation the *first spark* only; because after the plate of air is once broken through, the succeeding sparks of a series will be regulated by the *quantity* as well as by the *intensity* of the fluid transmitted.

Let us now suppose that a spark taken from a conductor at a certain distance, is constituted of the whole quantity of fluid which the conductor contained at the precise time of its emission, and that the degree of intensity is constantly the same. It is very obvious that a spark from a large conductor would be more powerful than a spark taken from a small one: because there is more fluid in the spark from the large conductor than in that from the small one, and because the velocity is the same in both cases. Therefore, in order to obtain formidable sparks from the action of a machine of any given power, we must endeavour to regulate the size of the conductor to the power of the machine. If it be too small the sparks will be small, pungent, and rapid. They are small and rapidly produced because the quantity of fluid constituting each spark is small, and the supply is comparatively great: and they are pungent because they are discharged with great velocity, and impinge on a mere point on the skin. If the conductor be too large, the intensity of the fluid can never rise to a great height, when the sparks are rapidly delivered because the supply cannot be kept up by the machine. The sparks at a maximum intensity will be infrequent, and will produce a dull heavy blow to any person taking them. But when the conductor is of a proper size to be kept well supplied at a high intensity, the sparks are delivered rapidly, are extremely severe on any part of the body on which they impinge, give a brilliant white light, and produce a continuous loud rattling noise.

When the glass cylinder of a machine is of the dimensions already stated, the cylindrical prime conductor with convex ends may be three feet long and six inches diameter: and the supply of fluid will be sufficient for a discharge of sparks of great intensity and power. As the greatest degree of intensity of a prime conductor is invariably found at its remote end, and greater in proportion to the smallness of the ball which terminates the conductor, the striking distance is greater; and consequently the sparks are longer when taken from a small ball than from a large one. We will prove this fact by the following experiment with our large plate machine, represented in the frontispiece.

In the end C, of the prime conductor, I fix the apparatus A B C, Fig. 25, which is a bent brass wire with a

Fig. 25.



ball at each end, one of which is much larger than the other. To the bend of the wire is fastened a stem, A, to be introduced to the hole in the end of the conductor. I will now take sparks from the large ball A, to another ball D, which I hold in my hand, and you will observe that when the distance between them is small the sparks are very large and dense, and give a bright white light, with a great deal of noise; and if I stand on a chain, or any other metal which is in good connexion with the ground, I feel a dull, heavy, disagreeable blow on my shin and ancle bones. I will now withdraw my hand farther from the ball of the conductor, and you will perceive that sparks are not so frequent as before, but that they are more brilliant, and make a greater noise, and the shocks on my legs are much more severe. When I separate the two balls to about three inches, the sparks appear at very distant intervals, and a little further off they entirely disappear. Certainly none can pass through four inches of air.

Having now ascertained the maximum length of a spark from the large ball A, I will show you what will happen at the small ball C. You perceive that I can take a spark from this ball when the ball in my hand is five or six inches distant from it; and by increasing that distance gradually, I obtain a stream of sparks ten or twelve inches long; and in some cases they may be made to pass through a space of eighteen inches. In this case, the sparks have none of that brilliancy of white light as is developed by the sparks taken from the larger ball; they are of a reddish colour, inclining to purple, and travel in very crooked lines for reasons already explained. Whilst these long straggling sparks are passing between the two balls, there is a great dissipation of fluid into the surrounding medium, as you may see very clearly when the room is well darkened. The dissipating part of the fluid forms beautiful ramifications of purple light, which dart into the air from the angles of the zig-zag path described by the main body of the stream of sparks.

From these experimental facts, we learn that sparks, of different lengths are producible by the same machine, even when in one and the same state of action: therefore, the *relative* powers of two, or more machines, cannot be ascertained by the length of sparks delivered by their prime conductors, unless the balls from which their sparks are taken be of the same size and at the same distance from the remote end of every prime conductor; and even those conductors should also be of the same size, figure, polish, &c., and similarly insulated, to give an approximation to their relative powers by the criterion of sparks alone.

It is an universal law in electricity, though little noticed by the generality of writers on this subject, that whenever a body is delivering the electric fluid to another body, the former is *electro-positive* to the latter; and, as the terms *positive* and *negative* refer to the relative *intensities* only, without any reference whatever to the relative *quantities* of fluid that the bodies absolutely contain, it is obvious that in all cases where a transference of fluid takes place, the *delivering* body must be more intensely charged than the *receiving* one.

From this train of reasoning, and from the fact that the luminous star and brush of electric matter indicate *receiving* and *delivering* points respectively, we easily ascertain that the collecting points of the prime conductor is electro-negative to the revolving excited glass; and the remote point which exhibits the electric pencil or brush of light, is electro-positive to the surrounding air. Moreover, since the prime conductor experiences a greater electric pressure at that extremity presented to the revolving glass, than at the remote one, it is electro-polar: the remote extremity being *positive* to the one nearest the excited glass: therefore, the remote extremity of the prime conductor is not only electro-positive with regard to the surrounding air, but also with regard to the other parts of its own body.

If now we arrange a series of insulated pointed wires in the manner represented by Fig. 26, having one end of the

Fig. 26.

series directed to the pointed wire in the end of the prime conductor, and the remote extremity of the series in the opposite direction, the whole series of points will become luminous the moment that the machine is put to work. The point projecting from the prime conductor, and the *remote* point in every wire will throw out a brush of electric fluid into the vicinal air; and the nearest points will be tipped with electric stars, indicating that those points are occupied in receiving fluid at the same time. If a wire connected with the last in this series, have its remote extremity presented to another projecting from the insulated rubber of the machine, the latter wire will exhibit the star, and the presented point of the former will throw to it copious brushes of luminous electric matter. From these indications we have ocular demonstration of the electro-polarization of every wire in the series, as well as of that of the prime conductor itself: and as the rubber receives fluid on its *outer* surface, and delivers it from its *inner* surface to the surface of the revolving glass, it becomes evident that the rubber is also electro-polar, and that its inner surface is positive to the glass which it feeds with electric fluid.

Having thus ocularly ascertained the relative electric conditions of the different parts of all the metals in the series: we can easily, by analogy, determine the electric states of the plates of air which lie between them: for, since one side of each plate of air receives fluid from the pencilled point of a wire, and the other side delivers it again to the star-tipped point of the next wire, it follows that each plate of air is electro-polar: having its negative surface presented to the electric *pencil*, and its positive surface towards the electric *star*.

Let us next join the prime conductor with the negative conductor by means of a copper wire. Under these circumstances, the apparatus gives no signs of electric action, excepting at the collecting points of the prime conductor, which are all tipped with the usual stars; occasionally, however, we observe the electric fluid dancing between the rubber and the revolving glass plate. These indications are sufficient, of themselves, to assure us of the machine being in good action; which may at any time be farther proved, if necessary, by removing one end of the wire from the prime conductor, and, whilst still holding it, presenting the other hand to the conductor thus insulated: a series of powerful sparks will immediately strike the hand.

Being thus satisfied that the electric action of the machine proceeds with vigour when the two conductors are connected by means of a good conducting wire, and that the luminous stars still indicate their *collecting* occupation, we very naturally infer that the apparatus is exciting and keeping in motion *its own* electric fluid, working it over and over again, and thus driving it through the collecting points, and consequently through every other part of the apparatus, in a continuous *current* or *electric stream*.

If we cut open any part of the insulated *connecting* wire, and separate the points thus made to about an inch apart, the electrical star and pencil again appear, and indicate the *current* still flowing in its former direction; and if the series of wires, Fig. 26, be again introduced to the circuit, the previously shown phenomena re-appear in all their beauty, and in their usual instructive capacity; teaching us that the atmospheric air is polarizable and penetrable, and that electric currents can find channels through that medium as decidedly as through the best conducting bodies. The phenomena displayed by electric currents are amongst the most interesting in this branch of physics. I shall treat on these phenomena very extensively in my lectures on voltaic, thermo, and magnetic electricity; in which we shall have to employ various pieces of apparatus, better calculated than the glass machine for displaying them to advantage.

LECTURE VII.

The electrical light which was so brilliantly exhibited in some of our experiments in the last lecture, is capable of being moulded into a great variety of very beautiful experiments, some of which I will presently show you. You have already seen that a spark taken from the prime conductor is capable of penetrating and making its way through a stratum of air, of the usual density, more than twelve inches in thickness; and it will traverse a much thicker plate of air that is attenuated, because, when in the latter condition, the air is a much better conductor than when it is dense: but in proportion as we attenuate the air through which a current of electric sparks is passing, the light becomes more feeble, and that brilliancy which the electric fluid exhibits in air of the common density, is entirely lost in highly attenuated air.

There is an experiment, however, usually called the Falling Star experiment, and of which I shall speak more particularly in a future lecture, in which the light is very brilliant when the air is attenuated to a certain degree; but in that case we transmit a greater quantity of the electric fluid in one spark, than can be accumulated on the surface of the prime conductor, for which purpose we employ an instrument called the Leyden jar.

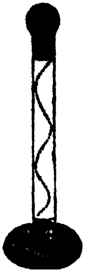
A very simple piece of apparatus for showing the electrical light in a pleasing manner, is made by a few leaden shot (duck-shot, for instance), strung on a thread of silk, keeping a space of about one-tenth of an inch between every two. Twenty or thirty, or even more, of these small globes, thus arranged, and the ends of the thread cut, or burnt, close to the extreme globes of the series, so that no loose ragged end may interfere with the experiment, are to be held by one of the extreme shot between the finger and thumb, and letting the rest hang down to the ball of the prime conductor, so that the lowest may not touch it, you will see a beautiful series of sparks traversing the silken thread from one end to the other.

In this experiment, it will be observed, the sparks appear between the leaden globes only, and no light is observable whilst the fluid traverses the balls; therefore, the lowest shot first receives the sparks from the prime conductor, and delivers them to the second, which again delivers them to the third, and so on, from one to the other, until they arrive at the hand, where they are lost.

This instrument, it is true, is but a very rude substitute for some of those elegant pieces of apparatus which are usually employed for the same purpose; but, at the same time, it answers all the purposes of explanation quite as efficiently. The apparatus generally employed are pieces of glass, either flat, or in the shape of tubes, partially spangled with discs of tin-foil. They are generally constructed very tastefully, and the spangles of foil suitably arranged, so as to diversify the route of the sparks in a variety of ways, which give to their display a more pleasing and interesting effect than could otherwise be produced.

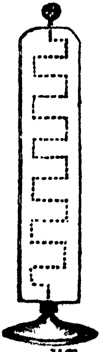
The glass tubes are capped at both extremities with hollow spheres of brass, well polished and lacquered,

Fig. 27.



and the spangles of tin-foil are arranged round and round the tube spirally, from one end to the other, taking care that they do not touch one another. See Fig. 27. The spangles are attached firmly to the glass, by means of strong gum-water, and the whole occasionally covered with a coating of lac varnish. The spangled tube, however, is sometimes placed inside of another glass tube, which, when capped by brass spheres at both ends, excludes all dirt and moisture in future. This method of fitting up these spangled tubes is, therefore, much preferable to that of using one tube with varnish only. When one end of this apparatus is held in the hand, and the other presented to the ball of the conductor, a series of sparks are seen traversing its surface between the spangles, and, consequently, in the same spiral line: rendering it beautifully luminous the whole of the way.

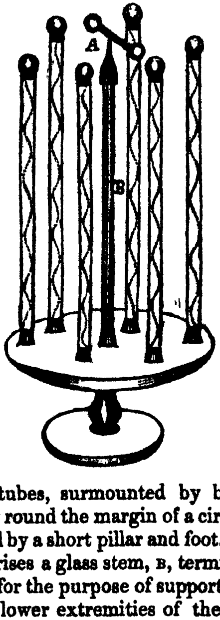
Fig. 28.



Another form of apparatus for this purpose, is that of a long strip of plate glass, on one side of which an arrangement of metal spangles, from one end to the other, is fastened by means of gum-water, and the line of electric light displayed by the sparks will vary with every variation in the arrangement of the spangles. See Fig. 28. The opposite side of the glass is usually varnished in transverse bands of different colours, which vary the colour of the sparks according to the colour of the medium through which they are seen. When a spiral arrangement of metallic spangles is placed on coloured glass tubes, such as blue, purple, violet, &c., the sparks will assume different colours as they proceed from one end to the other. They are perfectly white whilst passing along that side of the tube next to the spectator, but will assume the colour of the tube at those parts of its route which are behind it.

Perhaps the most pleasing of these electrical *devices* is that represented by Fig. 29. It consists of seven

Fig. 29.



spangled glass tubes, surmounted by brass balls, and placed vertically round the margin of a circular mahogany board, supported by a short pillar and foot. From the centre of the board rises a glass stem, B, terminating upwards in a steel pivot, for the purpose of supporting the rotating piece A. The lower extremities of the spangled tubes are inserted in brass ferrules, and the whole in connexion with a metallic ring which is let into the wood.

If I present the centre of the rotating piece A to the ball of the prime conductor of the machine in action, it immediately receives a series of sparks, and is drawn towards the ball of the nearest spangled tube; delivers a spark to it, and is carried on to the next, to which it also delivers a spark: and thus it visits the whole of the tubes in succession, illuminating each line of spiral spaces between the spangles as it proceeds, which in a dark room has a very splendid effect.

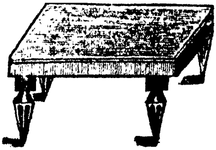
There are some curious circumstances connected with the electro-conduction of bodies which I did not mention whilst classifying them in our second lecture. They are these. Those solid bodies which have been called non-conductors, are considered to be such, only whilst in a state of solidity, or whilst their parts are in a certain state of aggregation. For instance: glass whilst solid and perfectly dry, is a non-conductor, but melted glass is a very good conductor. Crystals of several salts also possess the same faculties; for although non-conductors whilst solid, they become conductors when in a state of fusion by heat. Green wood is a conductor of electricity, but baked wood is an insulator. If the baked wood be converted into charcoal, it is again an excellent conductor, but burn it to ashes and it loses the conducting faculty.

I will now show you a very satisfactory experiment on this point. You are already aware that a solid stick of sealing wax is a non-conductor; but if we warm the same stick, so as to make it quite soft, and then apply it to the cap of Bennet's electroscope, whose leaves are already in a state of electro-divergency, you will soon find that the electric action disappears, and the gold leaves hang down close together. A tube of glass presents us with a similar fact, for although a non-conductor whilst cold, it becomes a conductor by being made to assume a high red heat, and better still when white hot.

By taking advantage of these facts, an illustrative experiment has been established, whose effect is called the electro-spinning of sealing-wax. I have a stout brass wire, which will just fit the hole in the end of the prime conductor of the machine. It is somewhat pointed at the other end, which is stuck into a short stick of soft sealing-wax. When the wax has become hard and cold it is a non-conductor; but, as we have already seen, when melted, or even softened considerably, it becomes a conductor. I place this wire in the end of the prime conductor, and afterwards soften the wax by the flame of a spirit lamp; and now, whilst the machine is in operation, I hold a blank card in front of the softened sealing-wax, and I find that a considerable quantity of the melted wax has been blown off from the wire, and is attached to the card in beautiful fine filaments, as soft and flexible as flocks of wool or silk. By repeating this experiment with several cards, we have an opportunity of varying the arrangement of the fibrous wax in many ways. A great quantity may be collected upon the surface of one card, and placed in a cabinet, as a curious production of this species of electric action.

I think it is pretty evident, from what you have already seen, that when any insulated body is connected with the prime conductor, it partakes of the same kind of electric action; and, in fact, becomes an appendage to that piece of apparatus. If, therefore, I were to stand on the *electrical stool*, Fig. 30, furnished with glass legs, and, while thus insulated, place my hand on the prime conductor; I should be electrized in common with that conductor; and if, whilst the machine is in good action, I present the knuckle of my other hand to any article on the table, a spark immediately passes from my hand to that body. If I take hold of one end of the spangled glass tube, Fig. 27, page 85, and present the other end to any uninsulated metallic body, a series of sparks pass from my hand, and the tube is illuminated the whole of its length. Should any one present their knuckle to any part of my body, whilst thus electrized, sparks would be drawn from me as decidedly as from the prime conductor itself.

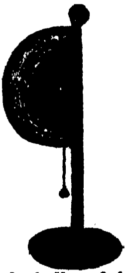
Fig. 30.



If with my finger and thumb, I take hold of the thread which joins two pendent light bodies, pith balls, or small feathers, for instance, these bodies diverge from one another: but if any one standing on the floor, touch any part of my person, the divergent bodies immediately collapse.

Here is a pretty little instrument, Fig. 31, called the *quadrant electrometer*. It is the invention of Mr. Henley, and is a most valuable instrument for ascertaining the intensity of electrization of any piece of apparatus to which it is attached. Its indications are the consequences of electrical repulsion. It consists of a stem, generally of wood; a semi-circular piece of ivory, and an index moveable on a joint-pin at one extremity, which is situated in the centre of the circle. Half of the semi-circle is graduated, showing degrees, from zero at the lower edge, to 90° in the horizontal line: hence the term *quadrant*. The index is an oaten straw, terminated by a pith ball. A hole in the upper part of the ball c of the prime conductor (see frontispiece), receives the lower end of the stem of the electrometer, and the angle formed by the repelled index and the fixed stem, indicates, though not exactly, the degree of electrization, both of the prime conductor and of every piece of apparatus connected with it.

Fig. 31.



If, now, whilst standing on the electric stool, and in connexion with the prime conductor, I hold the quadrant electrometer in my hand, the deflection of the index shows the intensity of electrization both of myself and the conductor with which I am in connection; which is not so great as that which the prime conductor alone would display, because of the greater extent of surface to be kept electrized; and, also, because of the loss of fluid from the asperities of my clothing, hair of my head, &c. The latter throws off an immense quantity of electric fluid into the surrounding air, whilst being repelled from one another. Whilst in this electric state, I experience a singular sensation about my head and face; something like that which would be produced by drawing over them some flimsy substance, such as the web of a spider, and you will see the hairs stand erect on every side, like radii from a centre.

We have an artificial head, well covered with long hair, by which this singular fact is shown to great advantage. The stem of the head, represented by Fig. 32,

Fig. 32.

is placed in the hole at the top of the prime conductor; and when the machine is in action the hairs stand aloof from one another in the ludicrous manner shown by the figure.

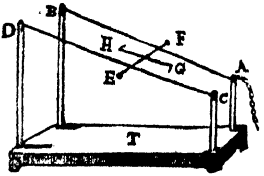
I have already shown you that an *electric aura* streams into the air from the point of an electrized wire. This aura, consequently, charges the vicinal air with the electric fluid, and renders it in nearly the same electric condition as the prime conductor and wire from which it proceeds. From the re-action thus produced, we are enabled to put bodies into motion as decidly as by the application of any other species of force.

Fig. 33.

The *electrical fly*, Fig. 33, consists of a stem pointed at its upper extremity, and a metallic cap, into the sides of which, and at 90° from each other, are screwed four brass wire arms, pointed at the outer extremities, and at about half an inch distant, bent at right angles, as seen in the figure. When the stem of this apparatus is placed in the hole at the top of the prime conductor, and the machine in action, the electric streams which rush out at the points, both electrise and condense the air; which, by re-action against the points, drives them back, and causes the whole system to retrograde and rotate on the vertical pivot.

The electro-mechanical force thus produced is somewhat considerable, when the machine is in good action; as may be understood by the following experiment with the apparatus represented by Fig. 34. T is a base board of mahogany, from one end of which rise two short glass stems A and C: and from the other end, two longer glass stems B and D. Between the top of A and B, is stretched a finely polished brass wire; and from C to D, is stretched a similar wire. The short wire E F, has a knob at each end, and at right angles to it, is attached the short wire G H. The latter wire is pointed, and, near to its extremities, it is bent at right angles to its general direction.

Fig. 34.

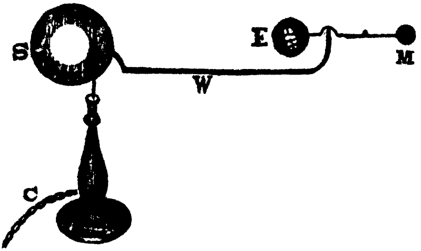


The chain proceeding from it we connect with the prime conductor of the machine, and the wire E F, is placed across the wires A B, and C D, near to the lower end of the inclined plane in which they are situated. Immediately the electrical machine is put into motion the fluid rushes out of the points G and H, and they spin round with an amazing velocity, and speedily arrive at the top of the inclined plane. Stop the machine, or, which is better, place a finger on the prime conductor, and the system rolls down by the force of gravitation: take away the finger, and the system rolls up again: replace the finger on the conductor, and the descent recommences; and by this means the moveable part of the apparatus may be made to make a series of alternate upward and downward trips for any length of time you please.

The electrical orrery, Fig. 17, page 59, may be kept in motion by availing ourselves of the influence of pointed wires. If a short point were to proceed from one side of the earth, and another from the opposite side of the moon, and the supporting pivot placed in connexion with the prime conductor, those points would discharge electric fluid into the air, and the system would revolve accordingly, on the principles already described.

The electrical orrery is still more complete by adding the sun to those parts hitherto employed. This orrery is represented by Fig. 35.

Fig. 35.

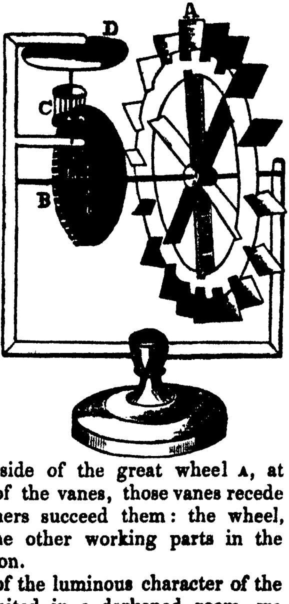


It consists of three balls, S, E, M, which respectively represent the sun, earth, and moon. The sun is a hollow ball of wood, neatly gilt, and weighted on the side S, to counterbalance the earth and moon at the extremity of the long arm of the lever. The earth and moon are united by a wire, moveable round a point at their common centre of gravity; and the whole system is supported on another point within the body of the sun, which is the centre of gravity of the whole system. A short wire, pointed outwards, projects from one side of the moon, and another similar wire, projects from the long arm of the lever which joins the sun and the other part of the system.

When this apparatus is insulated, by placing it on the electrical stool, and in connection with the prime conductor of the electrical machine, by means of the chain C prolonged, the electric streams which proceed from the points put the orrery in motion; the earth and moon revolve round their common centre of gravity, and these two bodies and the sun revolve round the centre of gravity of the whole system. This is a most interesting piece of apparatus, as it conveys a good idea of the revolutions of these three bodies as performed in nature, and also shews the influence of electrized points at the same time.

Mr. Ferguson, the self-taught mechanic and astronomer, invented several light pieces of machinery, which he took a delight in putting in motion by means of the electrical aura applied to the vanes of wheels.

Fig. 36.



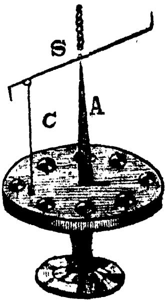
The model of a corn mill represented by Fi 36, will give you a idea of the character of the machinery employed in the electrical experiments of this ingenious man. A, is the water wheel, whose floats are made of thin card-paper; B is the cog wheel on its axis; C the trundle, turned by that wheel, and D the running millstone: the whole model is made as light as possible.

When a pointed wire from the prime conductor is made to project a stream of the electric fluid against the uppermost side of the great wheel A, at right angles to the face of the vanes, those vanes recede from the point, and others succeed them: the wheel, and consequently all the other working parts in the model, are put into motion.

By taking advantage of the luminous character of the electric aura when exhibited in a darkened room, we are enabled to produce a circular ring of electrical light, by the fluid which rushes from the four points of the fly, Fig. 33, whilst rotating on its pivot attached to the prime conductor. The light of this ring is very faint, unless the machine be in good order, and the points not very sharp.

Another application of the electrical aura, is that of ringing a chime of bells. Fig. 37, represents this piece of apparatus, which consists of a round mahogany table, supported by a pillar and foot. Round the upper side of the table are placed, on pillars, a series of eight bells, in the regular succession of their tones. From the centre of the table rises a glass stem A, having a sharp steel point, on which rotates the cross arm S. From this arm hangs a silken thread C, at the lower end of which is fixed a piece of brass for a clapper to the bells.

Fig. 37.

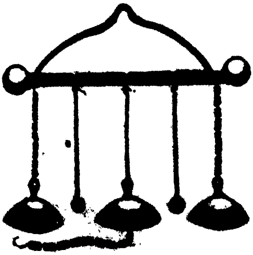


If now, a stream of electric fluid be poured on the centre of the moveable lever, from a pendant chain or wire, connected with the prime conductor: it rushes out of the points at both extremities into the air, and the wire rotates on the pivot as in the previous cases: and the clapper rings the bells in succession as it passes round with the wire to which it is attached.

The bells, when rung as in the last experiment, having nothing to do with the electrical action, although frequently called the *electrical bells*, have no legitimate claim to the dignity of any such title; but we have certain arrangements of bells for experiment, whose sounds are produced by a direct and important part which they themselves take in the process.

If, for instance, we hang the three bells of the apparatus represented by Fig. 38, to the prime conductor of the machine, by the bent wire of that part of the apparatus from which they are suspended, the two outside bells, which hang by metallic chains, will become electrical,

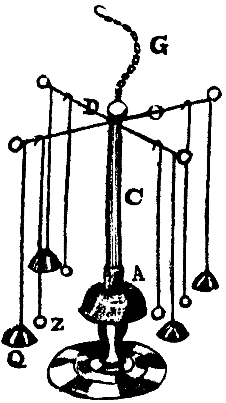
Fig. 38.



and will attract the two brass balls, insulated by silken lines, towards them. These balls strike the bells, and thus become electrical also. The electric action, thus acquired, carries them to the middle bell, on which they deposit their redundant portions of fluid, which is conducted to the table by the brass chain. The balls are now ready for another journey to the outer bells, where they again become charged, and are again repelled to the middle bell: and by a series of journeys to and fro, the bells are kept ringing. The middle bell is suspended by a silken line, and, consequently, is insulated from the cross metallic bar which supports it.

Another set of electrical bells is represented by Fig. 39. In this set we have five bells, a large bell A in the centre, and four smaller bells suspended by wires from two cross pieces, which stand at right angles to each other, upon the supporting glass pillar C. The clappers, Z, &c., are small balls of brass, suspended by silken lines. By these means the clappers are insulated from the bells Q, and four of the latter from the ground. The central bell A is supported by a brass pillar and foot. When the chain G connects this apparatus with the prime conductor, the bells commence ringing from the same cause as the former three were rung. But the middle bell never sounds musically, in consequence of being firmly fixed to the support.

Fig. 39.

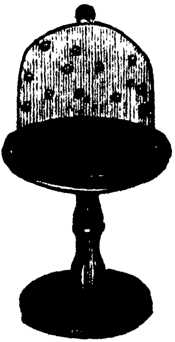


The bell-ringing, in the two last experiments, was obviously the effects of a series of attractions and repulsions, which gave motion to the pendent and insulated balls. Upon the same electrical principles we sometimes exhibit several very amusing experiments; a few of which

I will offer to your notice before concluding this lecture.

If we place a number of small pith balls on the metallic table, represented in Fig. 40, and afterwards cover them with a glass receiver, whose inner surface has been electrized by holding it over an electric aura, the balls immediately jump up from the table to the inner surface of the glass, and are projected back again to the table, where they discharge their acquired fluid; jump up again, and again return; and so on, with great rapidity; and thus exhibit their restlessness until they have robbed the glass receiver of nearly all its charge of electric fluid. When we have a cylindrical glass open at top, and covered with a brass plate, in connexion with the prime conductor, these volant motions may be kept up for any required period of time.

Fig. 40



The electric actions which produce motions in these light bodies, are very efficiently and amusingly displayed by the *electrical dancers*, represented in Fig. 41. The figures are made of the dry pith of elder, and are placed between two round brass plates, well rounded at the edges. The upper plate, which is smaller than the lower one, is attached to the prime conductor by a brass wire chain; and the lower plate, being supported by a metallic pillar, is uninsulated. The figures are put into a jumping motion upon the principles already explained; and by their exchange of places on the table, and the frequent turning on their heels, they perform their electric dance with much more

Fig. 41.

grace than is displayed, on many occasions, in the most fashionable ball-room: and the ludicrous anticks they sometimes pass through eclipse those of Harlequin himself.

The *electrical swing*, represented by Fig. 42, is another amusing piece of apparatus, which operates upon the principles of attraction and repulsion. The figure of a young lady is seen sitting in the bend of a silken cord, whose extremities are supported by two vertical glass pillars, fixed into a mahogany base-board B. An insulated brass ball A, is connected with the prime conductor; and another similar ball C, with the ground. The figure is first drawn towards A, where it receives an electric charge, and is then driven to C, where it discharges its acquired fluid; and by a repetition of these movements the figure is kept swinging between the two balls. A feeble electric action is most suitable for this and the next piece of apparatus, represented by Fig. 43, whose principal parts

Fig. 42.

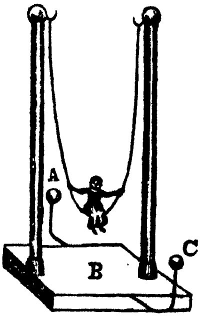
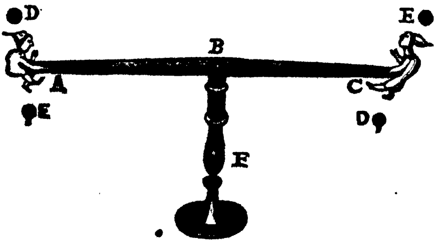


Fig. 43.



consist of a wooden foot with a glass stem F, and a lever A B C, which is moveable in a verticle plane on a joint at its centre B. On each end of the lever is placed a figure of a clown, and the two ascend and descend alternately between the electrized balls E E, connected with the prime conductor, and the uninsulated balls D D. The motion is accomplished by the same kind of electric action as in the previous cases.

I have no doubt of these ludicrous figures appearing to some persons too contemptible for a place in this work; but as the apparatus represented by Fig. 43, is the invention of the Italian philosopher Beccaria, one of the most indefatigable and skilful electricians the world ever yet produced, it will long remain an interesting *curiosity* at least, if nothing more, to all those who venerate the productions of the true cultivators of electrical science.

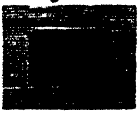
Our illustrations of *communicated* electric action have hitherto been limited to the employment of those bodies which display the most eminent electro-conducting qualities. Indeed, of all known bodies, the metals are best calculated for those elementary illustrations of the rudiments of electricity which ought to be firmly implanted on the mind in the earliest part of a course of instruction on this interesting subject. We will now, however, introduce a very different class of apparatus, by means of which we shall be enabled to extend our experimental illustrations: and bring forward a few specimens of the grandest phenomena that this branch of electricity has hitherto developed.

As a type of the formidable apparatus we are about to employ, we will re-introduce the electrical condenser, Fig. 10, page 46, and take into consideration another element in its operations, which we did not find necessary to notice till now. This element is the plate of atmospheric air which lies between the two metallic plates of the condenser. The atmospheric air is generally ranked amongst electro-nonconductors, and a thin stratum of it is, in fact, an insulator of feeble electric action, or in other words, of those bodies whose electric force is but of low intensity. And as all insulating matter is more capable of constraining electric forces as their radial dimensions from the electrized body, as a centre, is increased, an enveloping sphere of atmospheric air of great dimensions becomes an insulator even of tolerably powerful electric action: although a discharge of lightning from the clouds to the earth shows that a thick stratum can be transpierced when the electric intensity is very high.

With respect to the plate of air between the metallic discs of the condenser, the intensity being always feeble, the electric action communicated to the insulated disc never breaks through the air to the other which is in connexion with the ground: but although a discharge does not absolutely take place, the preliminary phenomenon to all electric discharges is really brought into existence. This preliminary is *polarization*, independently of which no electric discharge can in any case occur. The intervening plate of air becomes electro-polar, from a disturbance of its own fluid by the repulsive action of that acumulated on the insulated metallic plate: and if the accumulation were to rise to a sufficient degree of intensity, a rupture of the ærial plate would be effected by a portion of that fluid, which would transpierce the air in order to arrive at the uninsulated metallic disc.

Now since electro-polarization is effected the most easily in those bodies which offer the least resistance to the motion of the fluid, or in the best conductors, the metals are more easily polarized than atmospheric air; and the latter more easily than solid vitrious and resinous bodies; hence it is that these solids are not easily rendered electro-polar to a great extent unless in very thin sheets. When, however, a plate of glass is thin, it is not only susceptible of electro-polarization, but will absolutely receive a charge of the electric fluid as decidedly as any other species of matter: and by taking advantage of its insulating character, one of its surfaces may be rendered electro-positive, and the other electro-negative, to a degree of intensity far surpassing that obtainable by the employment of any other body.

Fig. 44.



If, for instance, a pane of glass, which Fig. 44 may represent, were partially covered with a sheet of metal, such as tinfoil, on each surface, as represented by the dark central part of the figure, it would be in a state of preparation suitable for receiving an electric charge of high intensity. A piece of glass thus prepared is said to be *coated.* The process of charging is simply that of forming a metallic connection between one of the coatings and the prime *conductor* of the machine, and a similar connection between the other metallic coating and the ground, or with the *rubber* of the machine. When the machine is put into motion a portion of the excited fluid is received by that surface of the coated glass pane which is in connection with the prime conductor; and the accumulation on that surface repels from the other a portion of the fluid naturally belonging to it: hence, in this condition the pane is electro-polar, having a redundancy of fluid on one surface and a deficiency on the other: which we can easily determine by employing an electroscope in the usual way.

If we again place the coated pane in connection with the prime conductor and the ground, or the rubber, as before, and again set the machine in motion, you will presently see a bright flash of light, passing over the edge of the pane, and accompanied with a loud snapping noise. These are the immediate consequences of a sudden discharge of the accumulated fluid from the positive to the negative side of the glass, arising from the charge on the former side arriving at a higher degree of intensity than the atmospheric air was capable of balancing.

Fig. 45.

By continuing the action of the machine, a great number of these *spontaneous* discharges are produced in rapid succession: which is one of the several indications of a machine being in good order. In experimental operations, however, we endeavour to avoid spontaneous discharges as much as possible, and in order to direct a discharge to any piece of apparatus, we employ an instrument called a discharging rod, which is represented by Fig. 45.

The discharging rod usually employed by electricians, consists of a glass handle and two metallic arms; the arms are of stout brass wire, each terminating in a ball of the same metal. The inner ends of the arms are screwed into the edges of two circular pieces of brass (one into each), which move freely on a brass pin that passes through their centres, and thus form a joint, similar to the joint of candle snuffers, or the joint of fire tongs. To this joint is fixed a brass socket, by which the whole of the metallic part of the apparatus is attached to the glass handle. The arms of the discharging rod are usually bent so as to form two similar bows, as represented by the figure; they are also pointed at the outer extremities, but the points are covered with the before-mentioned balls, which screw over them, and can be removed at pleasure when required for any particular experiment.

If, now, the coated glass be again charged as before, and one of the balls of the discharging rod be placed on one of its coatings, and the other ball be made to approach the opposite coating, the discharge takes place through the metallic arms of the discharging rod, without the operator being in its way; he being insulated from the fluid by means of the glass handle by which he holds the instrument.

Now, since the only part of the glass which receives the charge is limited, or nearly so, to that portion of the surface which is covered with the metal, it will be obvious that the quantity of fluid accumulated for a maximum charge will depend on the extent of coated surface, when the glass is of uniform thickness, and of the same quality, in all cases. Thus it is that, although we see a vivid light, and hear a much louder noise, by the discharge of the coated pane, than when a spark is taken from the prime conductor, these phenomena dwindle into complete insignificancy when compared with the light and noise which attend discharges from extensive coated surfaces of glass.

As it is a matter of indifference what may be the shape of the glass we employ in this capacity, provided it be thin and coated with metal on its opposite surfaces, leaving an uncovered marginal space for the purpose of insulating the coated surfaces from one another, the choice of shape is open to the taste of those who employ the apparatus. Convenience and elegance, however, appear to have given a decided preference to the general employment of glass *vessels* in the shape of jars, which, when properly prepared, have received the universal name of Leyden jars, in consequence of the electric powers of charged glass having been discovered in the city of Leyden. Fig. 46, will give an idea of one of the shapes of Leyden jars in common use, although many persons use those which are uniformly cylindrical from bottom to top.

Fig. 46.

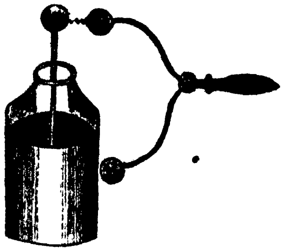
The Leyden jar is lined with tinfoil from the bottom to within about two inches and a half of the top. Some persons have three or even four inches of the upper part of the jar uncovered by the foil. Its outside is also covered with tinfoil to the same height as the lining. The foil may be stuck to the surface of the glass, either by means of gum water or by thin paste. The mouth of the jar is furnished with a wooden cover which fits into the inside, and rests on the jar by means of a narrow projecting rim, which forms a shoulder. A stout brass wire passes through the centre of the cover, having a brass chain hanging from its lower extremity to the bottom of the jar, which is also covered with tinfoil, and in contact with the other part of the metallic lining. The upper part of the wire projects two or three inches above the cover, and is surmounted with a brass ball.

If I present the ball of the jar to the ball of the prime conductor, having hold of the coated part of the jar with my hand, a series of sparks are seen to pass between the two balls, from the conductor to the inner surface of the glass jar; but their size and frequency very soon diminish, and eventually they entirely disappear. When this happens, the jar is incapable of receiving any more fluid from the conductor, and is in that condition which we call *charged*. If now, whilst the jar is charged, any person were to touch the outside coating with one hand, and approach the ball on the top of the wire with the other, he would immediately experience a smart blow, or shock, which would affect him more or less, accordingly with the size of the jar. This effect is known by the name of *electric shock*, and is one method of discharging the jar.

If instead of one person making the communication between the outside and inside of the jar, a number of persons were to join hands, so as to form a chain from the person at one end in connexion with the outside of the jar, to the person at the other end, who by his hand touched the ball at the top, the whole chain of persons would simultaneously receive the shock; but, in this case, the shock experienced by any individual would be much feebler than if the same person were to discharge the jar himself from one hand to the other. But if a chain of persons were to take hold of a long wire, which reached from the outer coating of a charged jar to the ball at its top, the glass would be more effectually discharged than by the chain of persons alone, and they would be entirely free from the shock; showing that the electric fluid prefers traversing the best conductors in the circuit, which, in this case, would be the metallic wire; for, although a portion of the fluid might pass through every person in the arrangement, the quantity would be so small as scarcely to be productive of any sensible effects. Hence it is, that we can discharge a jar with impunity through a metallic rod held in the hand, having one of its extremities in connection with the metallic coating, and bringing the other extremity close to the brass ball. Any metallic wire employed for that purpose is called a *discharging rod*, although that represented by Fig. 45, is the only one in general use, as a distinct piece of apparatus.

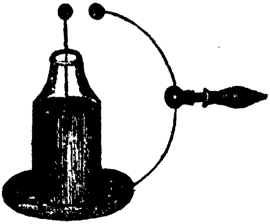
Having now described the Leyden jar and discharging rod, we are prepared to pass through a considerable number of experiments with these important pieces of electrical apparatus. Let us now charge the jar by holding its ball in contact with the prime conductor, whilst the machine is in motion. As the jar is but a small one, a short contact will be sufficient to accomplish the charge. I now take it away and apply the discharging rod in the manner represented by Fig. 47, and you see a brilliant flash of light between the upper ball of the discharging rod, and that of the jar, which is attended by a smart report. This process is usually called *discharging the jar.*

Fig. 47.



You will have observed that one of the balls of the discharging rod was placed against the side of the jar; which, with some persons, is a common practice, though frequently attended with consequences fatal to the jar; especially when made of very thin glass, which becomes broken by the discharge. Hence, you will readily understand that some other method of discharging our Leyden jars, especially when large, and consequently expensive, must be a desirable object. Several methods of discharging the Leyden jar, without the risk of breaking it, have been proposed; the principal of which are the two following. One of these is to place a long intervening wire between the outside of the jar and the lower ball of the discharging rod; and thus, by lengthening the circuit, the electric force is somewhat diminished, and the jar preserved. This plan has been frequently resorted to when the jar is somewhat large; or when several of them are connected together in the shape of a battery, of which I shall speak more particularly in another place; but as long circuits invariably lessen the electric force, a lower charge of the jar through a short circuit would answer quite as well. The other plan, which in my opinion, is much preferable to the former, is to place the jar, when charged, on a plate of metal considerably larger than the bottom of the jar, and then place the lower ball of the discharging rod upon the metallic plate, and bring the upper one quickly towards the ball of the jar, as in Fig. 48. By this process the fluid

Fig. 48.



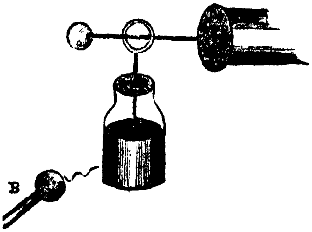
which passes through the discharging rod from the inside of the jar, becomes spread over the whole of the metal plate the moment it leaves the lower ball, and thus arrives at the bottom of the outside in a state of considerable attenuation, as compared with the condensed and compact form it assumes when passing from the ball in close contact with the side of the jar, on which the whole force impinges, and is exerted on a mere point of the glass, the fracture of which, from an intense charge, is almost certain.

Respecting the theory of the Leyden jar, although various opinions have been advanced, that proposed by Dr. Franklin seems the most admissible. That philosopher supposed that the Leyden jar has at all times of its existence the same, or nearly the same, quantity of the electric fluid on its two surfaces; that is, whether the glass be neutral or charged, the absolute quantity of fluid is not altered; and he accounts for it in this manner:—Franklin supposes that when a jar is in that condition called *charged*, the redundancy is only on one side of the glass; and that, in all cases, a deficiency of fluid, to precisely the same amount, takes place on the opposite side of it. Let us suppose for instance, that one hundred particles of the electric fluid be forced on to the inner surface of the jar by the power of the machine; then, according to Franklin's theory, one hundred particles will, or must of necessity, have left the outside surface; so that the *charging process* would appear to be nothing more than a mere transference of the fluid from one side of the glass to the other: and we are told by the same philosopher, that the *discharging* process, by the application of the discharging rod, is simply a restoration of the electric equilibrium on the two sides of the glass.

In the ordinary processes of charging and discharging jars, Franklin's theory affords a tolerably plausible explanation; but I shall have to show you in another place, that glass can be similarly electrized on its two opposite surfaces as decidedly as any other body: and therefore that part of the theory which insists on the two surfaces being necessarily in opposite electric states when charged, must fall to the ground.

Franklin, however, has contrived some very beautiful experiments in favour of his theory. He has shown that if the outside of a Leyden jar be completely insulated, its inside surface is incapable of receiving a charge. If, for instance, we unscrew the ball from the top of the wire of the jar, and put a ring in its place, then we can hang the jar on the wire at the end of the prime conductor as represented by Fig 49,

Fig. 49.

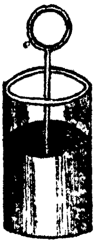


and leave its outside completely insulated by the surrounding air. In this state very little accumulation of fluid will take place, although every exertion be made with the machine; and you will see, that if we stop the working of it before the application of the discharging rod, scarcely a spark is discoverable between the ball of the latter and the ball of the conductor to which it is applied. But if we vary the experiment by presenting the knuckle close to the coating of the jar whilst the machine is in motion, you will see, a series of sparks traversing the plate of air between the jar and the hand, and the jar becomes charged, as may be ascertained by applying the discharging rod. If now, instead of the knuckle, we were to apply to the outside of the jar a brass ball B, mounted on a metallic stem, as shown by the figure, we shall have better defined sparks than before: and by bringing this ball gradually towards the outside of the jar, we can ascertain the precise distance between the two at which a spark will pass from one to the other during various stages of the charging process. Now this experiment which has been but little attended to, is exceedingly interesting; for you will see that the plates of air which the sparks are capable of transpiercing are of very different thicknesses at the different periods at which we obtain them; the maximum thickness being at the commencement, and the minimum thickness at the termination of the charging process, and eventually the sparks cease altogether. At this stage the jar is fully charged; and if we do not apply the discharging rod immediately, it will very likely discharge itself, either by the fluid rushing over the top of the jar, or by perforating the glass. Both of these accidents very frequently happen when the discharging rod is not employed in time. In the latter case, the jar is for ever afterwards useless as an electric apparatus; but, the discharging over the top does not injure it, unless indeed, a zigzag streak which the fluid frequently leaves on that part of the glass over which it travelled, can be called an injury. When a jar thus discharges itself the occurence is called a *spontaneous discharge*: and although a discharge through the pores of the glass is not designated by that name, it is, as decidedly as the other, a *spontaneous discharge.*

Another of Franklin's experiments shows, in a very decisive manner, that the fluid which is forced on the inner surface of the jar does not lodge in the metallic lining. For this experiment we generally employ a jar furnished with metallic coatings which can be removed from the surfaces of the jar, or replaced at pleasure. The jar for this purpose is often in the shape of a frustum of a cone, with the smaller end downwards, for the purpose of giving facility in placing and displacing the metallic parts.

This, however, is not neccessary, as common cylindrical jars answer very well, by not making the metallic coating and lining to fit the glass too closely. The lining of this jar is furnished with a brass wire stem, which reaches a few inches above the top of the jar and terminates in a ring, as represented by Fig. 50.

Fig. 50.



To make Franklin's experiment with this jar, I present the ring to the ball of the prime conductor, and when charged I take it away and place it on the electrical stool, Fig. 30, page 88 ; a quire of dry paper, or a piece of glass, or, indeed, any insulator, would answer very well for this purpose. Then by means of a small glass rod, which I introduce to the opening of the ring, I remove the metallic lining and place it on the table. I now take hold of the jar by its coating, invert it on the insulating body, and take away the metallic coating. I now bring the coating into contact with the lining, and you do not perceive any spark pass between them: and now, indeed, we might apply either metallic body or both of them to the most delicate electroscope, without indication of electric action ; hence we say they are neutral. I now replace the coating on the outside of the jar, and turn it the right side upwards ; and afterwards replace the lining by means of the insulating glass rod. Both the metallic appendages being thus in their proper situations, and consequently the apparatus again complete, I apply the discharging rod, first to the coating with the lower ball, and then to the ring with the other, and you see that a bright flash of light, with the usual report, is the consequence. From this result, Franklin has inferred, that the charge is not lodged in the metallic lining, but either in the pores of the glass or in a thin stratum of air on its surface. This inference forms another portion of the Franklinean theory of the Leyden jar.

As far as our illustrations have proceeded, the Franklinean theory of the Leyden jar would appear to be perfectly correct; but I must solicit your attention to a few other experiments which, although by no means militating against the general principles of Franklin's theory, develope results which tend to qualify, at least, the rigour of the experimental demonstration.

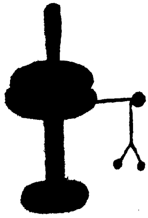
If, for instance, we were to pay strict attention to the exciting process of the plate electrical machine, we should infer from the circumstance of both sides of the glass being excited alike, that both sides became electro-positive, which is absolutely the case; and, therefore, we learn that both sides of the glass can be similarly electrical at one and the same time.

To illustrate this fact still farther, I employ a sheet of window glass, and present first one face and then the other of it to a pointed wire fixed in the prime conductor. By these means both surfaces of the glass have received a charge of the electric fluid from the metallic point: I transfer a portion of the accumulated fluid from one of the surfaces of the sheet of glass to Bennet's gold leaf electroscope, and by testing in the usual way, I find it electro-positive. I dismiss this electric action from the electroscope, and re-electrize it again, by applying the other side of the glass plate: and in this case, also, I find the electric action to be positive.

I vary this experiment by first diverging the gold leaves of the electroscope by the positive electric action of an excited glass tube, and afterwards presenting, in succession, the two electrized surfaces of the glass plate; and still find that both sides are electro-positive.

To determine whether or no there be any of the charge of coated glass attached to the metallic coatings themselves, I employ a disc of window glass, coated with two loose metallic discs which can be removed from the glass at pleasure, for the purpose of electroscopic examination. Fig. 51, represents the two metallic discs; the lower of which is furnished with a pith ball electroscope, and the r one with a glass handle: the plate is placed upon the lower , and the upper disc upon the glass, and the whole insulated by resting on a glass pillar.

Fig. 51.

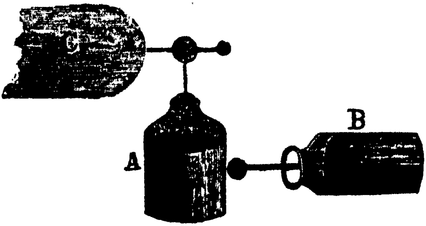


By means of a metallic wire I form a communication between the upper metallic disc and the prime conductor of the machine, and by means of another wire, the lower metallic disc is connected with the table. The glass plate having become charged, I insulate the whole apparatus, by taking away the lower wire of communication: by means of the glass handle I lift the upper disc from the glass plate and present it to Bennet's electroscope: and, by the usual tests, find that it is electro-positive. I replace the metal disc on the glass plate, and the pith balls belonging to the lower disc, which showed but little divergency before, now diverge to a considerable extent: and by the presentation of an electro-positive glass tube, and afterwards of an electro-negative rod of sealing-wax, the balls are found to be electro-negative; and after the removal of the glass plate, with its upper metallic disc, the lower glass plate is still found to be electro-negative.

In order to be certain that the replacing of the upper metallic disc was not absolutely essential to the lower one displaying negative electric action, we will discharge the glass plate by an application of the discharging rod to its two coated surfaces; and after removing the pith ball electroscope from the lower metal, we will arrange the apparatus as before, and again charge the glass. This being done, I remove the glass plate, with its upper metal, from the lower metal, leaving the latter insulated; having in readiness an electrized gold leaf electroscope, the character of whose electric action is known, I present the insulated metal disc to the instrument, and find it electro-negative. Thus we are enabled to prove that the metal coatings of charged panes of glass are as decidedly electrical as the glass itself; and by making similar experiments with the loose coatings of the cylindrical jar, Fig. 50, we also find them to retain a trifling electrical action: the character of which, in *high* charges, is always the same as that on the surface of the glass with which they were in contact; but, in *low* charges, the electric action of the loose coatings does not always correspond with that on the vicinal surfaces of the glass; because the latter becomes the cake of an *electrophorus*, and operates on the metals in precisely the same manner as the resinous cake, Fig. 14, page 55: and in this capacity its action may be continued for many hours, nay, even days, without any repetition of the charging process. There are some other exceedingly interesting phenomena, the display of which appears to be peculiar to charged glass and other non-conductors, but which we must defer offering to your notice until our closing lecture of the present course, in which it is intended to bring forward some of those theoretical particulars which are not essential to our present stage of illustration.

From the successful experimental results which Franklin obtained in favour of his theory of the Leyden jar, it was an easy step in the analogy to suppose that two jars might be as easily charged as one jar only, by collecting the fluid from the *outside* of that placed in connection with the prime conductor, in contact with the inside of the second jar, whose outer surface was connected with the ground: and the idea led to the establishment of new experiments of an exceedingly interesting nature. If, for instance, I insulate the jar A, Fig. 52, by hanging it on the prime conductor C, as in

Fig. 52.

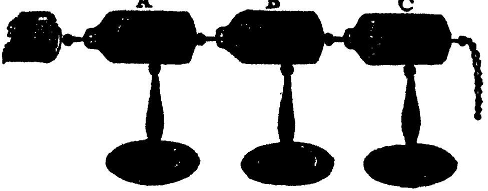


a former experiment, and present the ball of the jar B to its outer surface, the moment that the machine is put into motion a series of sparks are seen passing between the coating of the jar A, and the knob of the jar B, and when these sparks have nearly disappeared, both jars are found to be charged; as is shown by a proper application of the discharging rod, first to the jar A, and as soon as possible afterwards, to the jar B.

This experiment is a beautiful exemplification of the Franklinean doctrine of the Leyden jar, as far as regards the departure of the electric fluid from the outer surface of the first jar A; and it may be shown by a further extension of the number of jars in sequence, that the same explanation applies to the most remote jar in the series.

We will now arrange a series of jars, A, B, C, &c., insulated on glass pillars as in Fig. 53, and we shall find

Fig. 53.



that by such an arrangement the whole series will become charged at one and the same time, by the fluid which departs from the outside of the foremost jar A, being transmitted to the inner surface of the second jar B, and the fluid of the outside of B, being transmitted to the inside of C, and so on, throughout the whole series: the last jar of which has its outer surface connected with the table, and consequently, *indirectly* with the ground, by means of the metallic chain or wire.

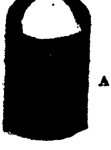
Now in order to be perfectly satisfied that every jar in the series is charged, I first separate them from one another, and the jar A from the prime conductor. I then apply the discharging rod to each jar separately, and find that the usual phenomena accompanying a discharge are exhibited by every individual jar; and since the jar A was the only one which could possibly derive its charge *directly* from the prime conductor, the other jars must of necessity have become charged by the fluid which departed from the outer surface of their immediate predecessors in the series.

There is still another method of illustrating this beautiful theoretical point by experiment. I will again arrange the jars in the same order as before, Fig 53, and again put the machine into motion; and, of course, the whole series of jars become charged as decidedly as in the preceding experiment. Now, instead of separating them when charged, I will apply one ball of the discharging rod to the chain hanging from the last jar C, and the other ball of it to the ball of the first jar A, or to the prime conductor in connexion with it, which answers the same purpose; and by this means I discharge the whole series of jars at one and the same moment. By this arrangement I cause the jars to neutralize one another: for the redundant fluid on the inner surface of the jar A, rushes through the discharging rod to the negative outer surface of the jar C; and the redundant fluid of the inner surface of C, supplies the deficiency on the outer surface of the jar B, and so on throughout the series: and although perhaps we may not find an exact equilibrium established on the two surfaces of every individual jar in the series, the process accomplishes their discharge as completely as by applying the discharging rod to each jar separately; which is an additional proof, though an indirect one, of the jars having become charged by each others electric fluid, and it is a *direct* proof, as far as experiment is capable of proving any thing, that the restoration of a general equilibrium in the series has been accomplished by a return of the previously expelled fluid to its original abode on the outer surfaces of the jars.

If, instead of the jars touching one another, as in our last experiment, we were to place them at a short distance from one another, we should see a series of sparks traversing the thin plate of air interposed between the coatings of one jar and the ball of the other, during the whole period occupied in the process of charging; and when the discharge takes place by connecting one ball of the discharging rod with the chain attached to the coating of the last jar, C, in the series, and with the other ball approaching the knob of the first jar A, the whole of the spaces between the several jars will become highly and simultaneously illuminated. This experiment has a very beautiful effect when performed in a darkened room. The noise produced will be in proportion to the intensity of the charge, and to the size and number of jars employed in the series.

In all these operations of the Leyden jar whilst in the act of charging, either *directly* from the prime conductor, or *indirectly* from the electrical influence of that apparatus, through the medium of other intervening jars, we find no difficulty in tracing a progressively increasing polarization of the opposite sides of each individual jar, which gradually become more and more positively and negatively electrical respectively, whatever may be the extent of the series; and when the polarization is at a maximum, the jar is as fully charged as the machine is capable of carrying on the charging process. Hence you will easily understand that the charging of a jar to a high degree requires a proportional facility of becoming polarized; which facility, when the machine's action is uniformly the same, appears to be effected by an attention to two principal circumstances:—the thinness of the glass, and the connection of the outer surface with the ground: which circumstances are analogous to those that are required for the electro-polarization of metallic bodies, as already illustrated in former lectures: for in those cases a thin plate of air between the bodies becomes electro-polar as decidedly as the metals themselves; and the facility of polarization is enhanced by the last metal in the series being in good conducting connection with the ground.

Fig. 54.



Some other very interesting experiments are performed by having two jars so united with one another and with the prime conductor as to enable us to charge the one independently of the other. If, for instance, we attach the wire belonging to the inside of the large jar A, Fig. 54, to the outside of the smaller jar B; we can very conveniently charge the large jar A, by connecting its inner surface with the prime conductor by means of a copper wire; and as the inner surface of the jar B is insulated, it will receive no charge, with the exception of a small portion of the fluid which rests on its outer coating by being in metallic connection with the prime conductor and inner surface of the jar A.

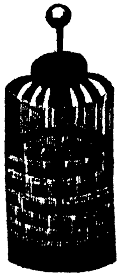
In this condition of things, the small jar, though not charged according to the general acceptation of the term, is nevertheless in a state of polarization; and its inner surface is negatively electric; for the fluid naturally belonging to that surface has been expelled as far as circumstances will allow, and a portion of it will be found in the ball o, which is in an electro-positive state. Hence, the metallic appendages belonging to the inner surfaces of the jar B are electro-polar, and as the two surfaces of the glass are also electro-polar in the same direction, being under the same powerful polarizing influence of the accumulated fluid on the inner surface of the lower jar A; the inner surface of B has a strong tendency to part with its own fluid, and is in an excellent condition to discharge it suddenly to any negatively electric body that may be brought within the sphere of its influence. To show you this fact, I place the lower ball of the discharging rod on the metallic plate on which the jar A is standing, and then make the upper ball approach the knob o of the jar B; we observe a bright flash of light and hear a report: the usual attendants of an electrical discharge; which in this case has been a discharge of a portion of fluid from the inner surface of the jar B, to the external surface of A. Therefore, both jars are now charged, the inner surface of A, and the outer surface of B, being electro-positive, and their opposite sides consequently electro-negative: and both jars may be discharged either separately, or at the same moment, accordingly as we apply the discharging apparatus. If I join the inside of the upper jar B, with the outside of the lower jar A, by means of a metallic chain or wire, and after placing one ball of the discharging rod on this chain, I bring the other ball towards the stout wire on which the small jar stands, or towards any of the metallic appendages joining the inside of the jar A and the outside of the jar B, you find that the usual phenomena of discharge takes place: and by examining the jars afterwards we shall find that both are as neutral as jars usually are after the first application of a discharging rod.

Let us now charge the large jar again, and by the same means as before, electrize the small one also, in order that I may give you a specimen of the curiosities displayed by discharging them separately. I will first apply the discharging rod to the outside of the jar A, and then I bring the other ball of it to the wire connected with its inside; the flash and report are produced, and the jar becomes discharged by a metallic connection between its inner and outer surfaces. But the moment I remove the discharging rod, the jar A again becomes electro-polar by the electric influence of the upper jar B. I now apply the discharging rod to this jar, in order to discharge it also: and by a few moments' metallic connection of its two sides, we find that both jars are rendered neutral.

I will now again charge both jars as in the last case, but in the *discharge* I will proceed in a very different manner to any I have hitherto shown you. I first apply the discharging rod to the two sides of the upper jar B, and discharge it in the usual way; by transporting the redundant fluid from its outside to its negative inside, and thus restoring the equilibrium of the two sides. But the moment I take away the discharging rod, the jar B again becomes electro-polar, in the same manner as when first under the influence of the lower jar A: but as this latter jar has lost a portion of its contents by supplying the small jar B with the previous charge, the polarizing influence is not now so great as at first: and, consequently, the tendency of B to dispose of its inner-surface fluid is also proportionally less. However, you will observe a bright flash and a smart report by again applying the discharging rod to the outer surface of A, and the ball o, of the small jar B; and the latter again becomes charged. I will now again discharge the jar B, and render it neutral as before, by conveying another portion of fluid from its outer surface. The charge of the large jar A having now lost another portion of its fluid, has consequently suffered a corresponding relaxation of its polarizing influence, and communicates to the inner surface of the jar B a still less tendency than before to dispose of any of its electric fluid to other bodies. Notwithstanding, however, this diminution of electric force in the large jar A, by every successive partial discharge through the medium of the jar B, the phenomena may be repeated many times over before a complete neutralization takes place; and especially when the lower jar is large and the upper one very small. It is an experiment of great interest, and highly favourable to the theoretical views which Franklin entertained of electric actions.

We will conclude this lecture by an exceedingly beautiful experiment: which, in consequence of being one in the series of experimental illustrations of the the theory of the Leyden jar, necessarily commands a corresponding interest.

Fig. 55.



The instrument we are about to employ is usually called the diamond jar, in consequence of its metallic coating and lining being made up of detached diamond-shaped spangles of tinfoil: as represented by Fig. 55. When the ball of the diamond jar is placed at a short distance from the ball of the prime conductor, a series of powerful sparks are transmitted to the jar: and as they cannot spread over the inner surface, from spangle to spangle invisibly, they are seen jumping from one to another during the whole time that the charge is going on: and as the departure of the electric fluid from the exterior surface is also attended by a similar display of sparkling light amongst the spangles constituting the coating, the spectacle becomes very beautiful, especially when viewed in a darkened room. As the charge proceeds, the sparks become less frequent and brilliant, because of the resistance presented by the fluid already accumulated on the glass to every succeeding spark from the prime conductor. When the jar has become charged to a considerable degree of intensity, I accomplish its discharge by the usual application of the discharging rod; and you will observe a brilliant, but momentary, illumination of every part of the jar within the boundaries of the metallic spangles, which is the consequence of a sudden rush of the fluid from one surface of the jar to the other.

LECTURE VIII.

NOTWITHSTANDING the satisfactory character of the experimental data, presented to your notice in our last lecture, in illustration of Franklin's theory of the Leyden jar, there are still some others, in connection with them of no less interest in support of that theory, nor less beautiful in the display of their phenomena; on which account, and also in consequence of their affording an opportunity of our making an important use of the *negative* side of the machine, it is in this stage of our illustrations that they can be most advantageously brought forward.

We have already seen that a series of wires (Fig. 26, page 81), whilst transmitting an electric current, exhibit the electrical *pencil* and *star* at every opening in the metallic part of the circuit; and that a pointed wire in the remote extremity of the prime conductor exhibits the pencil, and a similar wire attached to the rubber is tipped with the electric star. Now, as these phenomena are perfectly distinct from each other, and indicative of distinct functions of the metallic points which exhibit them, one might infer from these phenomena alone that, during the working of the machine, the prime conductor c, and the conductor o, in connection with the rubbers (see frontispiece), are in opposite electric states, which is absolutely the case, when both are insulated: hence that which is connected with the rubbers, is usually called the *negative* conductor, whatever may be the fashion of the machine to which it is attached.

To illustrate the different electric conditions of the two conductors still farther, I attach to each of them, by a long thread, a light paper globe; and by bringing these balls to within the sphere of each others action, you will observe that they attract one another, and when permitted, they join in close contact.

This experiment, however, like the former one, serves no other purpose than that of proving, according to the rules of the science, that the two systems to which the paper balls are attached, are in different electric states: but neither experiment is calculated to show that the conductor o, which is connected with the rubbers, is not in its *natural* electric state; or in the same electric condition as the floor on which the machine stands. We therefore still require another experiment to prove that the conductor o is, with regard to the surrounding group of bodies, decidedly in a *negative* state. This fact is easily ascertained by placing Henley's quadrant electrometer in a small hole in the upper side of the conductor o; the repulsion of its index from the stem shows it to be electrical.

If, whilst standing on the floor, any person presents the knuckles of the hand or any other part of the arm, close to that conductor, a series of smart sparks will pass between them, as decidedly as if those parts were presented to the prime conductor itself. If I stand on the electrical stool, and whilst in connexion with the conductor o, o, o, I hold the quadrant electrometer in my hand, its repulsed index shows that the whole system, conductor, electrometer, and myself, are in an intense electric condition.

I have already stated, in a former lecture (see page 69), that the insulated cushion or rubber of a machine yields but a small portion of fluid to the revolving glass, because of a want of supply from the ground. It is thus that the conductor to which it is attached becomes electro-negative as well as itself. Now the negative condition of all bodies being best enforced when the facilities for the departure of the fluid is greatest, it will be obvious that the degree of electro-negation of the system attached to the insulated rubbers, will be regulated by the facilities afforded for the escape or departure of the electric fluid from the prime conductor: and, consequently, the rubbers with their conductor, attain the highest degree of negation when the prime conductor is in the most perfect uninsulated condition. Hence, in a practical point of view, we usually, by means of a chain, connect the *prime* conductor with the table, whilst operating with the other, or *negative* conductor.

Having now shown the electric characters of the two systems of conductors of the machine, we are prepared to proceed with our proposed experiments with the Leyden jar. The prime conductor being first uninsulated, I present the ball of a jar to the negative conductor, and a series of sparks are seen to pass between them, but gradually become less and less frequent until they entirely cease. The jar is now in a high state of electrization, which is proved by a proper application of the discharging rod: a bright flash of light, with a loud noise, announces the discharge of the jar; which in this case was *from* the exterior *to* the interior surface: for the inside of the jar being in connexion with the negative conductor, became robbed of a great portion of its natural share of electric fluid by the action of the machine, whilst a similar portion accumulated on the uninsulated exterior surface from my hand and other articles directly and indirectly in connexion with it. Hence we learn, that insulation of the surface of glass is not absolutely essential to its becoming electro-positive even in a high degree. We learn also by this experiment, that the jar, and the same remark applies to flat pieces of glass, can as easily be made to assume an electro-polar state, usually called a charged state, at the negative, as at the positive side of the machine.

Our next step in the illustration is to show that two jars of equal size, whose balls are placed in close contact with the prime conductor during one and the same period of time, become charged to the same degree of intensity. To prove this fact I hold one jar in each hand, and whilst the prime conductor is neutral, I place both of their balls in contact with it. The machine is now put into motion, and when I think the charge sufficiently high, I take both the jars away at precisely the same moment, and place them on a sheet of tinfoil, previously laid on the electrical stool. I now apply the balls of the discharging rod to the balls of the jars, one to each; no flash of light is observed, nor the smallest spark seen by thus connecting the inner surface of the two jars, which indicates an equalization of electric intensity. I now apply the discharging rod in the usual way, to each jar separately, and find they both discharge with the usual phenomena of light and sound.

I next perform a similar experiment at the negative side of the machine, in order to show you that the same extent of electrization in the two jars, as regards one another, is the result in this case as decidedly as in the preceding one.

Having proved these points in our series of illustrations, I next proceed to show that the electric fluid can be transferred from one jar to another with nearly the same degree of facility as wine, or any other liquid, can be decanted or poured from one vessel into another. For this purpose I again employ the two jars: one of which I place uncharged on the tinfoil on the electric stool; the other jar I charge by holding its ball to the prime conductor, and as soon as charged I place it alongside the neutral jar. I now immediately apply one ball of the discharging rod to the ball of the neutral jar, and then bring the other ball towards the ball of the charged jar. A discharge from one jar to the other takes place, and by completing the metallic union of the jars by the discharging rod, about half of the fluid constituting the original charge has been transferred to the jar previously neutral. This fact is proved by the usual application of the discharging rod to each jar separately: by which means their discharges are accomplished; and by due attention to the two consequent flashes and reports, a tolerable good idea of the degree of their respective charges may be formed. Were the two jars of precisely the same thickness and character of glass, and of the same form and size, coated alike, &c., there can be no reason shown why, by this process, the electric fluid should not be equally divided between them.

The converse of this experiment is made by applying the discharging rod to the balls of the two jars, whilst one of them is neutral, and the inside of the other in an electro-negative state. A discharge of a portion of the fluid naturally due to the inner surface of the former, to the inner (negative) surface of the latter, immediately takes place, and both inner surfaces become electro-negative. This negative state is equalized in the two jars by a few moments' contact with the discharging rod, and is nearly of one-half the intensity as that displayed by the originally electrized jar. The electro-positive state of the exterior surfaces of the two jars becomes equalized by means of the sheet of tinfoil on which they are placed, which in this and the preceding experiment, operates as a *discharging piece* as decidedly as the discharging rod itself.

With the essential preliminary data now before us, we are well prepared for appreciating the beautiful and highly interesting character of the facts that our next experiment will develope; and which, for the present, will conclude the experimental series expressly selected for this occasion in illustration of the Franklinean doctrine of the Leyden jar.

In this experiment I shall electrize both jars at the same time, and, as nearly as I can, to the same degree; but, as regards the inner surfaces, one jar shall be electrized positively and the other negatively. To accomplish this I insulate both sides of the machine; that is, both the *prime* and the *negative* conductors. I then hold a jar in each hand and present the ball of one of them to the prime conductor, and the ball of the other to the negative conductor; after a few turns of the machine have been performed, I take away both jars at one and the same moment, and place them on the sheet of tinfoil, by which medium their exterior surfaces are connected. I now form an union between their inner surfaces by means of the discharging rod. The usual phenomena of discharge occur, and by a subsequent application of the discharging rod to each jar individually, I find both jars to be neutral. From a comparison of this fact with the facts previously observed, we are constrained to infer that the discharge which took place was from the two positive to the two negative surfaces; that between the exterior surfaces being through the medium of the joining tinfoil, and that between the interior surfaces through the medium of the discharging rod. Moreover, since both jars became neutralized by the discharging process, we infer, also, that both jars were electrized to precisely the same extent; and consequently, that precisely the same quantity of fluid left one jar as entered the other.

On a retrospection of the progressive steps hitherto taken in this illustration of the theory of the Leyden jar, we see nothing but order, regularity and harmony, in the series. The data concur, in the most strikingly exact manner, in bearing out the general principles advanced by Franklin; and I am not aware of any fact that militates against them. They afford considerable advantages in the study of electricity, and form a code of laws not hitherto surpassed for beauty and interest in all the theoretical superstructures within the range of experimental philosophy.

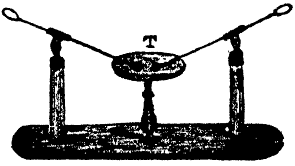
The grand actuating agent in all the multifarious operations of electricity, by expanding its influence into every explorable region of the universe, furnishes a splendid idea of the vastness of its sphere of action; whilst a knowledge of the abundance and diversity of its phenomena, and of the mightiness of its power, enforces a confession of our inability to calculate on the immensity of its operations in the physical world. Lightning, the aurora borealis, and other grand appearances in the atmosphere, being imitable by electric action, and even traceable to its influence, proclaim the prevalence of this agency in meteoric productions: whilst the uniformity of its laws in the display of magnetic and chemical phenomena, expand the claims of its influence in accomplishing the most recondite operations that nature has revealed to man.

In its present state of cultivation, electricity has become a more prolific source of surprising and dazzling phenomena than any other of the experimental sciences; and for the mere purpose of entertainment and the excitement of wonder, a display of brilliant electric experiments, even when performed in the most promiscuous and confused order, never fail to afford ample gratification to the curiosity. The studious observer, however, whose business is to inquire into the true beauties of the science, requires the most judicious arrangement of the phenomena that can possibly be devised, in order to facilitate his acquaintance with them, and with the laws by which they are displayed and associated with each other. Such a classification being almost indispensable at this stage of our illustrations, we will first distinguish all the varieties of electric phenomena by a general classification, and afterwards proceed to their illustration in the same order in which they are named.

The four grand divisions of electrical phenomena are the mechanical, the chemical, the magnetical, and the physiological: they are frequently simultaneous productions, and also attended by heat, light, and noise.

Electro-mechanical phenomena can be exemplified by such an extensive variety of experiments, that the choice is very great, although some difficulty may present itself in selecting the most suitable for illustration. We will, however, endeavour to fix upon some of the most simple cases, and avail ourselves of the best means of ensuring success; for which purpose we shall require the assistance of another piece of apparatus, called the *universal discharger*.

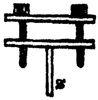
Fig. 56.



This instrument, which is represented by Fig. 56, consists of a mahogany base board, near to each end of which is fixed a glass pillar, surmounted by a brass piece, consisting of a socket for the introduction of the upper end of the pillar, an universal joint, and a small spring tube for the reception of a sliding brass rod. The brass rod moves freely in the tube, and is furnished with a loop at one extremity, and a brass ball at the other: the latter screws on to the wire, which terminates in a sharp point, which, by taking away the ball, can at any time be exposed when required for experiment. From the centre of the base board rises a short wooden pillar, which carries a small table, for the purpose of placing on it certain objects for experiment.

This table can at any time be removed from its supporting pillar, and replaced by another exceedingly useful appendage called the press. It consists of two flat pieces of well-polished mahogany, furnished with a screw-bolt at each end, by means of which the boards can be screwed firmly against any article placed between them. Fig. 57, is an edge view of the electrical press; which, when the shank s, is placed in the socket of the pillar of the universal discharger Fig. 56, is ready to receive those articles on which the experiments are to be made.

Fig. 57.



If now we raise both balls of the universal discharger from the table, and adjust them to about an inch from each other, and connect the loop of one of the sliding wires with the prime conductor, and the loop of the other wire with the floor, a series of brilliant sparks will be seen darting between the two balls, and the fluid constituting them will pass off invisibly, through the uninsulated series of conductors in connexion with the receiving ball, to the ground. If the balls be brought closer together, the sparks will be smaller and more frequent; and if removed farther asunder, the sparks become more powerful and brilliant, and make a louder noise, but will appear less frequently than before.

To give an idea of the mechanical effects of such sparks as these, I place against the receiving uninsulated ball a ply of thick writing paper. The sparks pass, as in the previous experiment, and by removing the paper to and fro, I cause them to impinge on various parts of its surface. On examining the paper it is found to be perforated in all those places where the sparks struck it, and appears like an exceedingly fine colander or sieve.

We will now increase the resistance against the passage of the sparks, by placing a double or a treble ply of paper in their way; still, however, we find they make their way through them: but by increasing the plies of paper the resistance becomes too great for the electric force to overcome.

These specimens of the mechanical effects of electric forces, though minute, are far from being contemptible illustrations of the tremendous havoc which formidable discharges are capable of producing.

The electro-mechanical forces producible by sparks from even the largest prime conductor that any machine can charge, are much inferior to those accompanying the discharge of a Leyden jar. If, for instance, I charge a jar to a high degree of intensity, and then discharge it in the usual way, the superior brilliancy of the flash over any that attends the discharge of a prime conductor alone, indicates the transmission through the air of a greater mass of electric fluid; whilst the difference of the noise proclaims a corresponding difference in the quantities of air displaced, which, with its subsequent collapsion, are the electro-mechanical effects of the respective discharges.

To illustrate the mechanical effects of discharges from coated glass still more conspicuously than by attention to the flash and report only, we will place between the balls of the discharger a whole quire of writing paper, pressing the balls closely against its two opposite sides, and connecting one of them with the tinfoil on which the jar is to be placed. When the jar is charged to a high intensity, as indicated by the quadrant electrometer, I apply the discharging rod to the other wire of the universal discharger and the ball of the jar. The discharge takes place through the quire, every leaf of which is perforated by the transit of the fluid.

We will vary this experiment by operating on another quire, which is purposely made somewhat damp. I charge the jar to the same degree of intensity as before; and then discharge it through the damp quire. The leaves in this case are not only transpierced, but many of them are torn to a great extent, and in a very curious manner: showing that the electro-mechanical effects are greater in this than in the previous experiment, which arises from the damp paper offering a less resistance to the electric force than that presented by the dry paper. There is also another cause for the paper being so much torn in the last experiment. The heat, which always attends electric discharges of high intensity, has in this case converted a portion of the moisture into steam, which by its sudden expansion necessarily assists in tearing the paper.

We will now endeavour to show the electro-mechanical action of discharges of *similar quantities* of fluid under different circumstances of intensity. For this purpose we shall be obliged to employ jars of different sizes: two jars, for instance, whose coated surfaces are nearly as one to two. For more exact measurement of the mechanical effects of electric forces, under different degrees of intensity, it might be necessary to be more exact in proportioning the size of the jars; but for a general illustration of facts only, it is merely necessary to have one of the jars considerably larger than the other. In very nice enquiries of this kind it would be useful to have the assistance of an exact measurer of quantity: but I have already stated that we have no instrument hitherto contrived that will measure exactly the relative *quantities* of the electric fluid in the charges of coated glass, nor indeed of any electric charges whatever. Attempts, however, have not been wanting to supply this great *desideratum*, but hitherto without success; and as none of the instruments intended for *quantitive* measurement can render any assistance in our present illustrations, we shall defer further notice of them till our concluding lecture, in which the particulars of their structure and the principles of their action will be clearly pointed out.

For our present illustration we will depend on the uniformity of the machine's action during the short period of time that will be occupied by the experiments, and in this we shall not be liable to much error. According to this supposition, therefore, each revolution of the glass plate of the machine will produce a certain quantity of the electric fluid, which certain quantity shall be our unit of measure; and two of these units shall constitute our *standard quantity* in the experiments.

Now, as we are about to show the mechanical action of this standard quantity of the electric fluid under two different degrees of intensity, which in this case will be nearly as one to two, or, in other words, the intensity of the small jar's charge will be about twice the intensity of that of the large jar: it will be convenient to have some *standard resistance* for these electric forces to act against.

This standard resistance shall be six dry paper cards, each about the thickness of a common playing card. I place these six cards edgewise on the table of the universal discharger (see Fig. 56, page 124) between the two balls of the sliding wires, which I press against them, taking care that they are exactly opposite to each other. One of the sliding wires I connect with the metallic plate on which the jars are to be placed, and the other, by means of the discharging rod, will be made to communicate with the interior of the jars when the discharges are required.

Having thus pointed out the conditions of the operations and the arrangements for carrying them into effect, we will now proceed to the experiments themselves.

I first charge the large jar with the fluid excited by two revolutions of the glass plate of the machine, and afterwards place it on the metallic plate in connection with one wire of the universal discharger. This done, I immediately apply the discharging rod, but no flash of light is seen, nor is any report heard, excepting a feeble hissing noise at the cards. This hissing noise, however, indicates a partial discharge having taken place; and by applying the discharging rod to the coating and ball of the jar, the remaining portion of the charge is discovered.

We next charge the smaller jar, by the standard quantity of fluid produced by two revolutions of the machine, and when charged, place it on the metallic plate in connexion with one of the wires of the universal discharger; and then apply the discharging rod as before. The usual phenomena of flash and report occur, indicating a sudden discharge to have taken place; and on examining the cards we find every one of them perforated, the fluid having transpierced the whole pack.

These facts are of a highly interesting character, whether practically or theoretically considered. A knowledge of them assists the experimenter in prosecuting certain of his operations with success: and the philosopher discovers in electricity the same laws of compressibility, tension, and elastic force, as those he is familiar with in other branches of physics.

Now, since forces of all kinds are proportional to the resistances they are capable of overcoming, and where practicable, may be accurately measured by those resistances: and since the resistance which the cards presented, in the two last experiments was too great to be overcome by the fluid of the large jar, but was completely vanquished by that of the smaller one, it follows, that the mechanical force in the former case was *less* than the mechanical force in the latter, though the same quantity of fluid was brought into play in each. Again: the standard quantity of fluid was distributed over two coated surfaces whose measurements were as one to two; and, accordingly with the general law of condensation of elastic fluids, the densities of the electric charges would be inversely proportional to those surfaces: or the density of the electric fluid in the small jar would be twice the density of that in the large one. In electrical language, *density* corresponds with the term *intensity*: therefore intensity implies density of the fluid; the degrees of the one corresponding to the degrees of the other. Now, as the mechanical force of elastic fluids generally, is in the ratio of their densities, and as the effects of the experiments have shown that electro-mechanical forces correspond to the same law, it follows that the mechanical effects of electrical discharges might be estimated with nearly the same degree of accuracy as those of the air-gun, or of any other application of pneumatic force: the *intensity* always implying the density of the fluid constituting the electric charge.

The experiments that may be brought forward in favour of the electro-mechanical forces being subjected to the same laws as govern pneumatic forces, are not only numerous, but also satisfactory, as far as our present means of experimental admeasurement admit of approaches to accuracy. But, unfortunately, no means have hitherto been devised by which researches in this branch of electricity can be expected to be attended with rigid uniformity of results, from which alone the data essential for calculation can be collected. The torsion balance electrometer (Fig. 22, page 64), is the only instrument by which even an approach to accuracy need be expected in the admeasurement of electric forces of different degrees of intensity. But the application of this beautiful instrument is limited within very narrow bounds, and to feeble forces only.

The quadrant electrometer (Fig. 31, page 89), although an almost indispensable instrument in operations with high charges on glass surfaces, is far from being an exact indicator of even the relative *intensities* of such charges; and has no pretensions whatever as an indicator of quantitive admeasurement. If the forces operated merely between the pith balls at the termination of the index and some fixed point on the stem, the ascent of the former causing the distance between it and the fixed point to vary, would necessarily require a calculation which would take into account the variation of the forces at different distances; but the complexity of calculating the intensity of the forces by the indications of the quadrant electrometer, is still greater than under this supposition; for the whole length of the stem, and also the whole length of the index, being under the influence of the electric forces, and those forces not uniform the whole length of each line, the mathematical formula necessary for such computations would be too complex to admit of general adoption in electrical enquiries, and quite out of place in these lectures. Notwithstanding, however, the quadrant is an exceedingly useful, and indeed a valuable instrument, to the experimenter; for to those accustomed to its indications, it shows the progress of the charging process, expresses certain points of intensity required for particular investigations, or for experimental illustration; and, by giving timely information when danger is at hand from too high a charge, which might force its way through the body of the glass, the quadrant electrometer stands high in the favour of the electrician, as a protector of the most expensive part of his apparatus, from frequent and utter destruction.

From the *desiderata* thus enunciated, it will appear obvious that all that can be accomplished whilst illustrating this particular topic, is to proceed with such popular experiments as tend most to favour those laws of electro-mechanical forces which, we have reason to suppose, correspond with the laws of pneumatics. To a certain extent, our two last experiments have answered this purpose; but we will proceed with a few more, in order to extend the analogy and render the illustration still more complete and satisfactory.

In the experiment we are about to perform, six new cards, similar to the former, shall be placed in the circuit, on the table of the universal discharger. I charge the large jar with the fluid produced by two turns of the machine, having first taken care that the machine had got into an uniformity of action. In endeavouring to discharge the contents of the jar through these cards, I again fail: the resistance presented by them being too great to allow of their being broken through by the force employed.

Now, in our previous experiments in these illustrations, no change was made in the resisting bodies: a difference in the intensity of the charges being all that was required at that time. In the present case, however, we must proceed in a different manner, and instead of varying the intensity of the charge, we will vary the resisting force. This may be accomplished in different ways: we may diminish the resistance by reducing the number of cards, or by moistening them with water, and by taking advantage of both these methods, the resistance may be reduced to a very low degree.

We will first reduce the resistance to one-half of that before employed, by taking away three of the cards, and pressing the remaining three with the balls, between which they are placed. The large jar being again charged by the standard quantity of electric fluid, and placed on the metal plate, we again apply the discharging rod: the discharge takes place, and the resistance is vanquished: the whole pack being transpierced by the electro-mechanical action.

We next employ six new cards, four of which have been slightly soaked in water. These wet cards we place in the centre of the pack, between the two dry ones. A discharge of the standard quantity of fluid from the large jar transpierces the whole of them: some of the wet cards being torn in various directions.

All these experimental facts tend to favour the idea that electro-mechanical forces, like the forces of all other elastic fluids, are proportional to the density or state of compression, the quantity being constant, and that the effects produced are proportional to those forces.

The greatest havoc amongst a pack of cards by electric discharges, is made when the cards are a little moist and not closely packed together. Under these circumstances they are frequently torn in a strange manner, when the electric force is considerable and a great quantity of fluid transmitted.

From the electro-mechanical effects we have hitherto had an opportunity of observing, our minds become naturally impressed with the idea of an *electro-momentum*; which, in accordance with the laws of dynamics, ought to be proportional to the quantity of electric matter discharged, and the velocity of its motion: that is, the one multiplied into the other would give the momentum. In mathematical language $m = q\ v$; in which formula m represents the momentum, q the quantity of matter in motion, and v the velocity with which that matter moves.

Now, although we cannot pretend to nice admeasurements, we have some experimental facts which are in strict accordance with the doctrine of momentum. It has already been seen that the quantity of fluid produced by two revolutions of the machine, when operating against the six dry cards, produced very different effects when discharged under different circumstances of intensity. Now, as the velocity of air, or any elastic fluid, when escaping through any given aperture or channel from confinement, would be proportional to the degree of its compression, or density; and as the whole of that air which had been forced into confinement, would be discharged in one body in a moment, were the aperture of proper dimensions and suddenly opened, it follows that the *initial* momentum of that body of air would be proportional to its density prior to its discharge. But we have already seen that the mechanical *force* of air is also proportional to its density; therefore the mechanical force is also proportional to the initial momentum: and consequently the initial momentum is proportional to the effects produced: or, which amounts to the same thing, to the quantity of resistance which the force is capable of overcoming: or more strictly, to the resistance which the force would exactly balance.

By applying similar reasoning to our electrical discharges, that is, estimating the momentum by the quantity of resistance overcome, we have reason to infer from those cases where the same standard quantity of fluid was capable of overcoming the greater resistance when discharged from the high degree of condensation, that the velocity, and, consequently, the momentum, was greater in the former than in the latter case: and a series of carefully prosecuted experiments would be productive of results which would approach closely to an accordance with the laws of pneumatic forces.

We will now proceed to experiments by which it will be proved that the electro-mechanical action can be modified by the fluid traversing conductors of different qualities, and of different dimensions.

I charge the large jar until the index of the quadrant electrometer reaches 80°, and I discharge it against six cards, placed as before between the balls of the universal discharger: the whole pack becomes transpierced. I now vary the conducting part of the circuit by the introduction of an insulated basin of water, at an opening in the metallic part of it. This done, the jar is again charged to 80°; but in this case the resistance of the six new cards checks the discharge and they remain uninjured.

If now we operate against one card only, we immediately accomplish its perforation, although the discharge be transmitted through the water as before. Thus we learn that the water, although a conductor, offers a considerable resistance to electric forces: and the result of our next experiment will show that the resistance is considerably exalted by diminishing the transverse dimensions of the aqueous conductor.

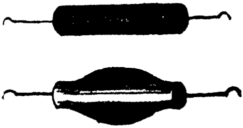
It is very well known that the discharge of this large jar from an intensity of 80°, if transmitted in the usual way through even an extensive chain of persons joining hands, would produce a violent shock to every one in the circuit; and if transmitted through one individual only, the effects might be of serious consequence. Now although the shock would be very much abated by transmitting a similar discharge through the basin of water, it would still be far from agreeable: but by employing a narrow thread of water in place of the basinful, the effect of the discharge may be reduced till no shock can be experienced.

To illustrate this fact, I place a wet hempen thread in the circuit, and myself in another part of it, taking care to stand on the insulating stool. With one hand I take hold of the loose end of the wet thread, and in the other hand I hold a stout brass wire, terminated by a ball of the same metal. When the large jar is charged to 80°, as in the preceding cases, I approach its ball with the ball that I hold in my hand; the discharge takes place, and the contents of the jar are transmitted through myself; but I experience no shock, nor any disagreeable sensation whatever. In this case, the momentum which such a charge of fluid would produce when transmitted in a compact body, and with the usual velocity through good metallic conductors, is entirely done away with, on two accounts: the velocity is abated by the inferior aqueous conductor, and the fluid, during the discharge, is drawn out into a stream, and does not pass through any section of the circuit in sufficient quantity at a time to produce much momentum. The discharge, under these circumstances, may be compared to a discharge of air through a narrow sieve, with exceedingly small apertures, which, by being retarded, and drawn out into a harmless breeze, loses all that powerful mechanical action which it would assume were it liberated in a body.

By making an extensive series of experiments on cards, paper, &c., with uninterrupted discharges, we find many curious effects produced. In some cases the fluid passes through some of the plies and not through the rest: in several instances the cards are curiously torn; and in all cases a peculiar odour, resembling that of phosphorus, is left on every piece of card or paper operated on. Some of these effects will be shown in another part of this lecture.

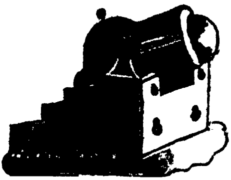
We may now try the electro-mechanical powers on some other kinds of matter. Let us take a piece of very stiff pipe-clay, roll it into the shape of a cylinder, and introduce two wires to its axis, one at each end, and push them into the clay till they are within about one-eighth of an inch of meeting each other in the centre of the cylinder. Now it is very obvious, that if the clay between the inner ends of the wires does not offer too great a resistance, the discharge from the jar will pass through the cylinder. We will charge the large jar to 80°, and now, by discharging it through the route I have pointed out, you find that the pipe-clay is no longer of a cylindrical form, but has bulged out at the centre round the opening between the wires. This effect is occasioned partly by the expansion of a small quantity of air in that part of the clay, partly by the direct expansion of the electric fluid, and possibly by the conversion of a small portion of the moisture into steam. Fig. 58 will represent the pipe-clay both before and after the discharge of the jar. When the pipe-clay is not too moist it is frequently shattered to pieces.

Fig. 58.



There is a very interesting electro-mechanical experiment made with an instrument called the electric mortar: it is the invention of Father Beccaria. This pretty little apparatus is an ivory model of a military mortar, such as is employed for throwing bomb-shells. The ball is also of ivory, and reaches only a little way down the piece. The bottom of the bore of the mortar is conical. Through opposite sides of the mortar, near the breach, are passed two small brass wires, which almost, but not quite, meet in the bottom of the bore. See Fig. 59. One of these

Fig. 59.



wires is connected, by means of a brass chain, with the outside of the jar, and the other with one branch of the discharging rod. Now, all being ready, that is, the ball in the mortar, and the jar charged to 80°, or upwards—fire. You see the flash of electric light, and hear the report as usual, but the ball has not left the mortar. This is often the case under these circumstances; but if we vary the experiment, by merely moistening the bottom of the mortar's bore with a drop of water, between the inner points of the wires, we shall succeed in propelling the ball to a considerable distance—even twenty or more yards.

Now I think it is pretty obvious, in this case, that a portion of the moisture was converted into steam, whose expansive power had much to do in projecting the ball. It is obvious, also, that since a moderate sized jar, such as we have hitherto used, will project a ball to so great a distance, a larger jar, or, still better, several jars properly arranged in a manner which I shall shortly explain, when discharged in a similar manner through a small portion of water, would be the means of suddenly generating a sufficiency of steam to project a large ball to a great distance indeed.

Another exemplification of the electro-mechanical effects produced by the discharge of a jar, is that of breaking through masses of hard matter; if, for, instance, we send the discharge through a piece of lump sugar, it will be broken into a great number of small fragments, and scattered in all directions; and when the experiment is made in the dark, you will observe that every fragment has become illuminated with something like a feeble phosphorescent light; and, as in other cases of electric discharges, the peculiar odour is developed on every fragment of the sugar.

By discharging the jar through a thin piece of resin, or hard sealing-wax, similar mechanical effects to those on the sugar are produced, but the phosphorescent light does not appear. We can break common window glass very easily by similar electro-mechanical powers. To prove this fact, let us place a narrow strip of gold leaf between two slips of glass, and having squeezed them close together in the electrical press, Fig. 57, page 125, and put the press in its proper place in the universal discharger, Fig. 56, page 124, we bring the balls of the sliding wires of the instrument into connection with the extremities of the gold leaf, one to each. This done, and the jar charged to a high intensity, we transmit the charge through the circuit. The glass is broken to pieces, and the gold leaf has disappeared, being consumed or converted into an oxide. Some of the gold, however, is absolutely forced into the glass in a pure metallic form. By a similar process, on a large scale, we are enabled to produce beautiful permanent specimens of the effects of electro-mechanical forces.

Another method of breaking the glass, is by placing two thin wires between two pieces of glass, in such a manner that they point towards each other, in the middle of the glass, without being in contact. When the discharge is sent through these wires, an explosion takes place at the opening, and if the glass be hard pressed down, by a weight or otherwise, it is generally broken into small fragments: even the weight itself is agitated by this process.

This last effect has given rise to the idea of forming an experiment the effects of which should be imitative of those of an earthquake. A few small light models of houses are placed on a flat slab of ivory, which covers the two wires through which the discharge is transmitted, and the explosion between the inner points of those wires shakes the ivory; and its little town, when properly built, is overthrown by the shock. When this experiment is made on a large scale it has certainly a very imposing effect.

If we insert two pointed wires in a thin piece of deal wood, with a small space between them, a discharge from a large jar will splinter the wood; but much precaution is required to succeed with this experiment. In all these cases the effects are produced by an expansive or *lateral* electric force.

In all the electro-mechanical operations, the direct effects are enhanced by confining the action within narrow limits, or by concentrating the electric fluid in that part of the circuit where those effects are intended to be produced; and I know of no instance of electric action which better illustrates this position than that produced by the experiment I am now about to offer to your notice.

In a small glass phial, containing sweet oil, I place a finely-pointed brass wire, which passes through the axis of the cork. The upper end of the wire is formed into a ring, or is terminated with a brass ball, and the lower end, just above the point, is bent at a right angle, so that the point can be brought into contact with the inner surface of the phial, below the surface of the oil. I now hold the phial in my hand, and place the thumb against that part of the glass nearest to the point of the wire. With this position of the wire and the thumb, I take a few sparks from the prime conductor to the ring of the wire, and these sparks absolutely pass through the glass, and produce a pungent pricking sensation on the thumb. By turning the wire, so that the point may touch another part of the glass, another perforation is immediately produced; and they may be made sufficiently large to permit the oil to pass through them. Now, the oil being a non-conductor, and the wire reduced to a point, the sparks become much condensed at that part of the circuit, and produce a mechanical effect on the glass, which cannot be accomplished when the point is surrounded with air, which gives way by the slightest explosion, and allows of an attenuation of the electric force.

We have alluded to some other curious effects produced by experimenting on cards and paper, which will be worthy of notice in this place. I will place a card vertically between the balls of the universal discharger, which do not press firmly against it, but merely prevent it from falling, whilst its lower edge rests on the small table. Thus arranged, I discharge the jar through the card, and the usual perforation is made; but by close observation you will find that the card, about the edges of the hole, is protruded on both sides, as if the electric fluid had passed in opposite directions. Few experiments in electricity have caused so much discussion as this one, and its trifling variations. It has been the means of leading philosophers to very different opinions respecting the cause of the two burs on the opposite sides of the card, and has, consequently, been the subject of much ardent discussion. Dr. Franklin was the first person who pierced a card by an electrical discharge, but the protrusions on the opposite sides were first observed by Mr. Symmer on one of the cards which had been pierced in Dr. Franklin's experiments. Mr. Symmer made many experiments of this kind, varying them in several ways, all of which produced similar effects, and led this electrician to infer that there are two opposite electric fluids dependent on each other, that they may be uncombined by the power of the machine, and occupy the opposite sides of a jar or any other charged glass; but by means of a conducting communication, they avail themselves of the opportunity of reuniting with a promptitude unparalleled by any other kind of matter, and thus, whilst travelling in opposite directions, produce all the effects of electric forces, the double protrusion of the card being supposed to be an instance of the effects of their opposite actions.

If we vary this experiment by perforating several plies of writing paper instead of the single card, we find that the protrusion of the paper from the centre of the pile is in opposite directions, and that no individual ply of the paper has the protrusion, or bur, as it is often called, on both sides. Many attempts have been made to explain this phenomenon, though it must be acknowledged, not very satisfactorily. Those who advocate the existence of two electric fluids, think their views triumphantly demonstrated by the double bur experiment; whilst others consider that expansion is the real cause even of both burs, which is by far the most probable view, though it generally happens that the bur or protrusion on the positive side is smaller than that on the negative side.

If, instead of a card or several plies of paper, we were to set up a piece of tinfoil between the balls of the universal discharger, a discharge from the jar will perforate the foil. But any inferior conducting substance can be much easier penetrated when the expansion of the electric fluid is more limited, than whilst passing through the unconfined air; that is, by surrounding the interruption with more dense fluids, such as oil, or even water.

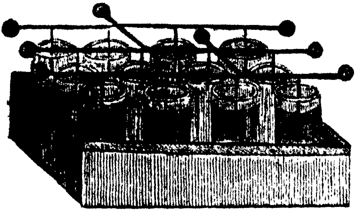
If we immerse a pointed wire, bent as in the experiment with the phial of oil, to some depth in a tumbler of water, and opposite to the point, place a thin piece of metal, such as thin sheet brass, then by passing a series of sparks from the prime conductor through the pointed wire to the thin metal, the latter will become perforated by the mechanical action of sparks which passed from the point. When the sparks are passed through oil instead of water, they are still more compact by a less lateral expansion, and accomplish the perforation sooner. The lateral forces, however, in all these cases, are still considerable, and mechanical effects are produced by them as decidedly as by the direct action.

It must be here noticed, however, that if a bullet be discharged from a gun through a sheet of copper, effects are produced analagous to those exhibited on the card or paper by an electrical discharge. I have lately received from my friend, Mr. Marsh, of Woolwich, two penny pieces which were shot at whilst flying in the air; and they are both pierced by the leaden shot; one of them by a bullet from a rifle, which has taken a piece out of the side of the coin, to the depth of little more than half a diameter of the ball, leaving a bur on each side of the metal, along the margin of the semi-lunar breach at the edge of the coin. The side which was hit by the bullet is easily known by the copper being bent by the blow, and the bur on that side is far smaller than that on the other or off side. The other penny has been struck by seven small leaden shot —perhaps the size of duck shot—four of which have pierced the coin, and the other three have made deep indentions, but not passed through. In this, as decidedly as in the former case, the bur occurs on both sides, but less on the near side, or that which the bullet first struck, than on the other.

LECTURE IX.

In many electrical enquiries experimenters have found it necessary to augment the force beyond that which can be accumulated by a single jar, however large, which has given rise to the formation of the electrical battery, consisting of several jars, so arranged as to have the whole of their inner surfaces united by metallic conductors, and all their outer surfaces also united by similar means. In Fig. 60, we have a battery of this kind very accurately represented. The battery consists of twelve jars placed in a mahogany box, whose inside

Fig. 60.



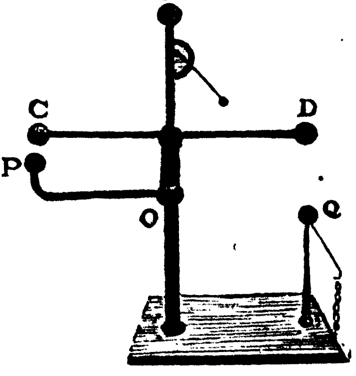
is lined with stout tinfoil, which, of course, comes into intimate contact with the metallic coatings of the whole series of jars. From the inside of each jar rises a stout brass wire, and the twelve jars are divided into three groups of four each, by three brass rods, each of which unites the interior of four jars; and, by means of two cross wires or rods, the groups of jars can be united with each other; so that, by this contrivance, we have an opportunity of employing either four, eight, or twelve jars, as we please. The horizontal rods are terminated with well polished brass balls, to prevent loss of fluid.

When we employ the battery of jars, we bring one of the horizontal rods into connection with the prime conductor, and it is obvious that, by these means, the whole of the jars will become charged at the same time; and by connecting one of the branches of the discharging rod with a chain in connection with the lining of the box, and approaching any of the rods with the other branch, the discharge of the whole will take place. There are, however, many precautions to be taken in the employment of a formidable battery, some of which it may be necessary to point out before we proceed to experiments with it.

In pointing out the particulars to be attended to in the employment of the electrical battery, I shall in the first place observe, that if the battery be charged to a high degree of intensity, and discharged in the usual way of discharging single jars, and especially if the circuit between the inner and outer surfaces be short, one or more of the jars is almost sure to be broken, and the battery, consequently, so far spoiled that it cannot be charged again until the broken jar, or jars, be removed. Thence the necessity of watching carefully the progress of the charge, so that we may make the discharge before the intensity gets too high. To prevent accident, by inattention or otherwise, from too high a charge, Mr. Cuthbertson invented a *discharging electrometer*, by means of which the battery will discharge itself at any required intensity, without depending on the attention of the operator.

Fig. 61 is a representation of Cuthbertson's *discharging electrometer*. It consists of a stout mahogany

Fig. 61.



board as a base, from which rise two glass pillars, o and Q, the former of which is rather stout, and the other only slender; the latter is surmounted with a brass ball, into which is screwed one end of a stout brass wire, to which the outside of the battery, either directly or indirectly, is to be connected. The other glass pillar, o, carries vertically a wide brass tube, terminated at each end by a hollow brass ball, into the lower part of which is inserted, and firmly cemented, the upper end of the supporting glass pillar; and into one side of that brass ball is screwed a horizontal tube or stout wire, bent upwards near the outer end, and terminated by a brass ball, P, as seen in the figure. Through the middle of the upper large brass ball passes a horizontal brass rod, C D, terminating in a ball at each extremity. This rod is nicely balanced on a knife-edged fulcrum in the interior of the large hollow brass ball; and the arm, C, which projects over the lower bent arm O P, is graduated, and furnished with a sliding weight, which, when placed at different distances from the fulcrum, loads the arm with a proportionate weight, from one grain to sixty grains. The ball C of the graduated arm of the balance rests upon the ball P of the lower bent arm. The ball D, at the other end of the balance, will then be four inches from the other ball Q, which surmounts the slender glass pillar. If, now, the metallic part of the instrument, supported by the stout brass pillar, be connected with the prime conductor, or the interior of the battery, then, while the latter is charging, there will be a repulsion between the ball P of the bent arm, and the ball C of the balance which rests on it; and, at the same time, an attraction will take place between the other two balls D and Q; and when these repulsive and attractive forces overcome the weight at the other end, C, of the balance, the attracted arm will descend, and discharge the battery on the lower ball Q. Now, as the attractive and repulsive forces are supposed to be proportional to the intensity of the charge, and as these forces have to overcome the load at the other end of the balance, that load, whatever it may be, is considered to be a proper measure of the intensity of the charge, and is, unquestionably, the nearest approach to that measure hitherto arrived at, though by no means perfectly correct. The instrument is usually surmounted by a quadrant electrometer, as represented in the figure, as an indicator of the progress of the charge, which is not shown by the discharging electrometer itself.

It is obvious, from a consideration of the beautiful arrangement of the various parts of this instrument, of the principles upon which it operates, and of its functions as a self-discharger at any required intensity, that it is well calculated to relieve the anxiety, and dispense with much of that attention of the experimenter, which he invariably labours under by the employment of the ordinary discharging rod alone; for the sliding weight being once adjusted on the horizontal arm, for any given intensity, and the body to be operated on properly placed in the circuit, the experimenter's care is at an end, as the machine has now only to be worked till the discharge takes place.

The mechanical action from a discharge of an extensive battery of jars is exceedingly great, and bodies of every kind, whether conductors or nonconductors, can be perforated, torn, or shattered to pieces by means of it. If, for instance, we now place a quire of paper vertically between the two balls of the universal discharger, and arrange this apparatus so as to bring the paper into the circuit of the battery when charged to about 80° or more, per quadrant electrometer,* the electric fluid rushes with violence through the quire, and tears the outer leaves to a considerable extent, whilst the inner ones are sometimes partly torn, but more frequently perforated in several places. Several thick cards may also be torn in a strange manner by a discharge from the battery; and if the paper or cards be made slightly

* As there are scarcely two of these electrometers which give the same indications for any given intensity, 80° will not express the requisite intensity with different electrometers; I should, therefore, wish it to be understood, that as the mechanical effects depend more on the *intensity* than on the *quantity* of fluid employed, the intensity for purposes of this kind should always be considerable.

damp, the ruptures made by a discharge are frequently much greater than when operated on in a dry state; and as the moisture communicated to them enhances their electric conduction, a greater number of plies can be perforated when so treated.

The electro-mechanical and electro-chemical phenomena, especially in the display of calorific effects, are sometimes so intimately connected with each other, that it would be impossible to separate them by any mode of experimenting hitherto known. For, although there are some singular exceptions to the general rule, it often happens that the greater the mechanical action the more certain is the discharge in accomplishing the ignition of bodies through which it is transmitted.

Let us, for instance, employ the force of a single jar when charged to a high intensity, upon a narrow strip of gold leaf placed between two dry cards. The whole of the circuit, I should wish you to observe, is of good conducting materials: metals. Now, the discharge being made, we examine the result on the strip of gold leaf, and find that the metal has entirely disappeared; but both cards are stained with a beautiful purple or violet-coloured tint, very curiously distributed, and extending over nearly the whole of the inner surfaces of the two cards; being most dense, and of the deepest colour along the middle, where the gold leaf was placed, and becoming more and more attenuated from thence to the outermost skirts of the stain.

Now, by paying attention to the complicated results of this experiment, we first discover that the metal is destroyed, or, in fact, deflagrated, and thus, by oxydation, has assumed a different colour: we next observe that the mechanical action has distributed this oxide over a much larger space than the gold originally occupied: and what is particularly remarkable, these mechanical effects are chiefly produced *laterally*, and but very little, if any, are to be observed longitudinally, or in the direction of the discharge. I shall, however, as we proceed, endeavour to vary this experiment, and shew the effects by different arrangements of the apparatus. At present, I offer to your notice but one or two variations, which will be sufficient to convince you that when the electro-mechanical action is sufficiently abated, the gold leaf suffers no change, even from the most formidable electrical charge that we are capable of producing.

The experiment by which I am about to prove this fact, will differ in no other respect from the last one, than by the introduction of an inferior conductor to the circuit whilst discharging the jar. The inferior conductor which I employ for this purpose is simply a piece of wet thread, about eight or ten inches long; it forms a part of the circuit, as in a previous experiment, and will be the means of lessening the mechanical action; and you will observe that, by this arrangement, the gold leaf remains uninjured by the discharge, although the intensity of the charge was as great as in the former experiment.

As it is still possible that you may require further evidence respecting an abatement of the mechanical action by such an arrangement as that last employed, I will again vary the experiment to convince you of this fact, and to show you that the calorific effects on the gold have a dependence on the electro-mechanical action in the manner I have already stated.

In this variation of the experiment I will make a slight opening in the metallic part of the circuit, and in that opening I will place some light seeds, which, by the lateral force would be blown away, were I to discharge the jar through them when the rest of the circuit is metallic: but now, as the discharge has to pass through the inferior conducting wet thread, you will find that the seeds remain almost unmolested; they are not scattered abroad, as before, and the only disturbance which they experience is a mere consequence of some trifling attraction which takes place between them and the ends of the wires where the metal circuit is interrupted. The gold leaf, you will observe, is not in the least changed.

I will now vary the experiment in another manner, by dispensing with the wet string, and making the whole circuit metallic, with the exception of a small opening where small seeds may be placed, as in the last experiment. Now, in this case, you have a fair opportunity of comparing the mechanical action on the seeds with that of the last trial; you will find that the seeds are blown away, and the gold leaf is destroyed.

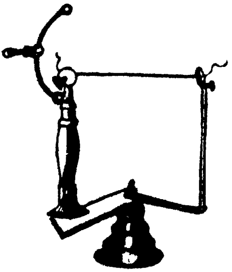
I know of no experiment by means of which I could show you to greater advantage that the calorific effects on the gold depend on the electro-mechanical action of the discharge.

• However, I have still one other variation of the experiment, which I shall now proceed with. You are aware that when a jar is discharged in the usual way, through any person, a violent shock is produced; and also, that if I place the wet thread in the circuit, no shock whatever is experienced. Now, by placing myself, the wet thread, and the gold leaf in the circuit, I discharge the jar from a high intensity, without producing any effect either on the gold leaf or on myself.

The experiments shown on strips of gold or silver, may be varied by employing wires instead of metallic leaf. For this purpose the thinnest watch pendulum wire that can be procured is exceedingly useful, as it can be fused from the discharge of a moderate sized jar.

Several methods have been proposed for arranging metallic wires intended for explosion by electric action. Dr. Hare, the inventor of the single leaf electroscope, described at page 60, has invented and employs the apparatus represented by Fig. 62, for this purpose. The base of this instrument is either of metal or heavy wood. On the top of the pedestal two horizontal arms are placed; which, by means of a pin passing through one end of each, and a screw nut, they can be adjusted to any angle, and fixed in the required position.

Fig. 62.



From the outer extremity of each arm rises a vertical pillar, the larger of which is of glass and the smaller of metal: and each surmounted with a small pincer, for holding the thin wire intended to be operated on, which is stretched horizontally from pincer to pincer, as seen in the figure. The vertical brass pillar is to be united with the outside coating of the jar, or battery, and the discharge is transmitted through the wire by applying one arm of the discharging rod to the brass cap on the top of the glass pillar, as seen in the figure, and the ball of the other arm to the inside of the charged glass battery, or jar.

In all contrivances for this purpose, where pincers are used, much time is lost in adjusting the wires; and, as there are frequently many wires of different metals to operate on in one lecture, I have found it necessary to resort to simpler means for their adjustment. I have prepared about a dozen wires, by first cutting them to the required lengths, and to each extremity attaching a piece of tin-foil, by rolling it into a compact lump with the end of the wire within it. Thus prepared, they are laid over the sliding arms of the universal discharger, either vertically, horizontally, or obliquely, in a moment, and operated on in succession as fast as the battery can be charged.

I will first discharge a large jar through a piece of this steel wire about ten inches in length, and you will find that the wire is barely made visibly red hot, although the intensity of the charge was tolerably high. Now the reason of my not succeeding in fusing the wire by this discharge, was not because of its being too thick, but simply because it was too long; and in order to convince you of this fact I will shorten it by one half, leaving a length of five inches only to be traversed by the next discharge of the same jar; the intensity of the charge being the same as in the former case. The result is as was predicted, the wire is fused, and you will observe also, that the mechanical action was so great as to scatter the globules of the fused steel to a great distance on every side. I shall presently make a similar experiment on a larger scale, but must first vary it with the same jar.

Now in varying the experiment I will simply introduce a piece of wet thread into the circuit, in order to abate the mechanical action of the discharge, as on former occasions. In this experiment I will operate on the five inches of wire which was cut off from that employed in the last experiment. Now, observe attentively, that the intensity of the charge is quite as high as before, indeed, somewhat higher, but the visible effects on the wire by the discharge of the jar are simply a few tremulous motions, and not the slightest indication of redness from an elevation of temperature is perceivable. Here again is another proof of the influence of electro-mechanical action in accomplishing the fusion of metallic bodies by ordinary electric discharges.

When experiments of this kind are carried on for the purpose of ascertaining the effects of certain electric charges on wires of different dimensions, the balance electrometer of Cuthbertson (see Fig. 61, page 142) will be found very convenient. There is also another circumstance to be noticed in experiments of this kind. If the air within the jar be perfectly dry, the quantity of electric fluid that it will contain will be somewhat less than if the air were a little moistened, either by breathing into it, or by any other means.

I now place the bent arm of the balance electrometer in connection with the prime conductor of the machine, the inside of the jar also being in connection with it. I will place about two inches of watch pendulum wire between the insulated ball of the electrometer, and the outside of the jar; I also adjust the sliding weight on the graduated arm of the instrument to fifteen grains. Now, it will be obvious that when the charge has arrived sufficiently high for the repulsive action between the balls P and C to overcome the load of fifteen grains, that they will separate by the upward motion of the ball C; and when the ball D, at the other extremity of the balance arm has, by its descent, arrived sufficiently near to the insulated ball Q, as to be within the *striking distance*, the discharge will take place, and the contents of the jar will traverse the steel wire. These arrangements being complete, and the route of the electric fluid being understood, we will now proceed to the experiment. A few turns of the machine causes the ball C to move, and a few more, you will observe, accomplishes the discharge.

The steel wire is not only made red hot, but is fused, and partly scattered in small globules.

If I were now to add another inch to the length of the steel wire, and transmit through it a similar discharge to that employed in the preceding experiment, we should find that the wire would become just red hot, but not fuse; and to satisfy ourselves on this point, it is necessary to repeat the experiment two or three times. This being done, still the wire remains perfect; so that it is pretty certain a discharge measured by fifteen grains is not sufficient to accomplish its fusion. I will now slide the weight to twenty grains, and having charged the jar to that point, the discharge through the steel wire immediately accomplishes its destruction.

In order to show that a jar will hold more of the electric fluid when moistened within, I will first try what length of wire can be fused by the highest intensity of the jar when dry; and afterwards moisten the air within the jar by breathing into it. The experiment will prove that the discharge from the moistened jar will fuse a much longer piece of wire than one from the dry jar.

When the coated surface of glass is very extensive, as in a battery of jars, for instance, this class of experiments can be exhibited on an extended scale, and with the most brilliant results. If, for instance, I were to connect the inside of the battery (Fig. 60, page 141) with the prime conductor, and place the sliding weight at about forty grains, I should be enabled to fuse thin steel wire above forty inches in length. To convince you of the beauty of this class of experiments, I will place a piece of iron wire about two feet long, in the circuit. Now observe attentively what takes place. Did you ever behold such a splendid sight? The wire, you will have observed, is first heated to the brightest redness, progresses perceptibly to an intense white, swelling in thickness to six or eight times its original dimensions, and eventually it burst into thousands of minute balls, which were projected in every direction, and fell in a shower of fire.

The beauty of this experiment is considerably enhanced by coiling the iron wire into the shape an open helix, like a cork-screw. You will observe that when the discharge has passed through the helix, the latter retains its shape for a perceptible time, more than a second for instance, before it bursts; which done, it is dispersed into a multitude of fiery globules.

By transmitting similar discharges through wires of platinum, gold, silver, copper, brass, &c., their fusion is very readily accomplished, and when very thin they are converted into a cloud of smoke, which becomes dispersed on every side in the surrounding air. Now, by making a series of experiments on these different metals, whilst suspended in the air, and in a darkened room, we shall see that each metal, during fusion, yields a peculiar coloured light. The platinum wire, you will observe, yields a whitish light, not very intense; the gold yields an orange-coloured light; and the silver a beautiful yellowish-green light, of considerable intensity. The light proceeding from the copper is of a much deeper orange than that from gold, but the brass yields scarcely any light whatever.

If such a series of wires were to be exploded between cards, those cards would be stained by different colours; and you will observe, by a few experiments, that whatever be the character of the wire, the deepest stain on the cards between which it was placed is precisely in its own direction; and that the intensity of the stain becomes more and more attenuated from the axis of the discharge to the margin of the cards. Moreover, by a close examination of those cards, especially those between which brass, silver, or gold were exploded, you will perceive that a complete gutter is made in each card, directly opposite to the axis of the discharge, or the direction of the wire.

The stain made by brass is nearly black, and the figure much resembles a caterpillar. That from silver is of a greyish colour, and much scattered; gold yields a purple or violet-coloured stain, much scattered, and the tints beautifully blended. Iron and platinum give no very striking colours, nor do they stain the cards to any great extent. They seem to be fused into a train of minute globules, which are left on the cards in the directions of the original wires. When iron wire is exploded between two pieces of glass, a series of minute globules of iron are firmly fixed on the surfaces of each piece, and stand very prominently above the surface of the glass.

In pursuing our illustrations on the electro-mechanical agency in the production of certain effects, it may not be amiss to employ different kinds of bodies in the circuit, in order to show how they are differently affected by modifying the mechanical action in the discharges of similar quantities of the electric fluid upon them.

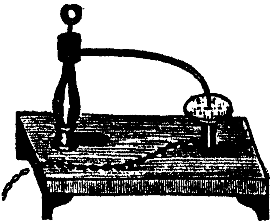
I will, for instance, place a small loose ball of tow between the balls of the universal discharger, and discharge upon it a large Leyden jar, from a high degree of intensity. You observe that the tow, although an inflammable body, is not ignited, but several of its fibres are broken, and it is somewhat flattened by the mechanical action of the discharge.

Now, although the tow has escaped conflagration in this case, it does not always remain unignited by operating upon it in this manner. Its ignition, however, is very much facilitated by scattering some finely powdered resin amongst its fibres, as you will presently see, by sending a discharge of a similar quantity of electric fluid through it.

If, instead of resin, I sprinkle the tow with oil of turpentine so as to make it somewhat moist, you will see, by a few experiments, that the ignition is as easily and as regularly accomplished as by the employment of resin. We occasionally employ other inflammable matter amongst the fibres of tow, for purposes of this kind; and when tow is not at hand, other fibrous matter, such as cotton-wool, is resorted to, but sheeps' wool is seldom, if ever, employed.

In all these experiments you will have observed, that a considerable *report* attended each discharge of the jar, which, as I have before shown you, can take place under no other circumstance than when the velocity of the electric fluid is very great; for if we abate the velocity by passing the fluid through an inferior conductor, the wet string, for instance, a scarcely audible noise attends the discharge. I will vary the experiment in different ways, and the result in every case will serve as so many facts in the direct process of demonstration. But, as I am about to employ gunpowder, another piece of apparatus will be required. It is represented by Fig. 63, and consists of a base board, a small metallic table, a glass pillar, and a bent wire, one end of which is soldered into the brass cap on the top of the glass pillar, and the other end is pointed, and depends over the metal table. The gunpowder is placed on the table, which is connected with the outside of a jar or battery, by means of the chain.

Fig. 63.



In the first variations of the experiment we will again place a ball of tow, sprinkled with oil of turpentine, between the balls of the universal discharger; and in another part of the circuit we will place another ball of tow, sprinkled with powdered resin, between two other insulated balls. Between the inside of the jar and the first portion of tow, I place in the circuit a piece of tinfoil, between a few leaves of writing paper, and on the other side of the latter ball of tow I place some loose gunpowder on a card, and the card on the small metal table of the apparatus represented by Fig. 63. Now, by this arrangement, the electric fluid will have to traverse the whole of these bodies; it will first pass through the paper and tinfoil, next through the tow and turpentine, then through the tow and resin, and after leaving that combination of inflammables, it will traverse the loose gunpowder, and proceed to the outside of the jar. The results of the discharge of the large jar from a high intensity, are easily predicted by those conversant with experiments of this kind; but to others there may appear to be something mysterious in them. Now I will discharge the jar. The result on the two balls of tow are probably such as you might be led to expect—both are set on fire; but what has become of the gunpowder? It also is an inflammable body, but it is not ignited, nor, indeed, is it left in its place. It is blown away, and scattered in every direction from the axis of the electric path; not even a single grain is left where the fluid passed through the heap.

You will probably ask how I know the path of the discharge through the gunpowder, now that it is gone from the place? This is very easily ascertained: for if you will examine the card on which the powder was placed, you will find it perforated by the electric fluid, and by calling to your recollection the position of the gunpowder on the card previous to the discharge, you will identify the perforation with the centre of the base of the heap. Consequently the electric fluid, which has so obviously pierced the card, must have traversed the gunpowder *from* the pointed wire above it, *to* the perforation of the card.

You will observe also that this perforation is in the *centre* of the blank space on the card left by the gunpowder. Hence we have, by this fact, a complete demonstration not only of the existence of the lateral force of the discharge, but also a demonstration of that force being exerted on every side alike.

Now call to your recollection what you have already seen, that no card can be pierced by a discharge of this jar when a wet string forms a part of the circuit, and that through such a circuit the velocity is much lessened. From a knowledge of these facts you are led to understand that the velocity, and consequently the mechanical action of this discharge, must have been great, otherwise the card could not have been perforated. Moreover, the scattering of the gunpowder is another manifestation of a great velocity and consequent momentum of the discharged electric fluid.

Now let us examine the paper and tinfoil in the other part of the circuit. Both are perforated: another indication of the great electro-momentum attending the discharge of the jar through this compound circuit.

Let us now make a slight change in this experiment, by introducing a piece of wet thread as a portion of the circuit. The jar shall be charged to the same intensity as before, but the result of the discharge will be very different. Neither the paper nor the tinfoil will be perforated; neither of the balls of tow will be burnt, but you will see the gunpowder exploded. If, however, I were to enlarge the lateral dimensions of the aqueous part of the circuit, so as to increase the velocity of the fluid, and thus permit it to move in a more compact body, the paper and tinfoil would suffer perforation, and the whole of the inflammables, with the exception of the gunpowder, would take fire.

It is a remarkable fact that the gunpowder should not ignite under the same circumstances that accomplish the ignition of the other bodies; but *time* seems to be an essential element to insure success, and it is a matter of no consequence what are the means employed to give *sufficient time* for the electric fluid to be in contact with the gunpowder, for it will invariably ignite provided a sufficient period of time be procured, and the quantity of electric fluid transmitted be sufficient also.

Gunpowder has been ignited by a series of heavy sparks from a large prime conductor transmitted through a compact cartridge; but, in such cases, the quantity of electric fluid was great, and the velocity lessened by the retarding power of the gunpowder itself, which being confined could not be blown away. Heavy discharges, with great velocities, from a battery of jars, have also been the means of igniting gunpowder; but in those cases the ignition of the powder was a secondary effect, arising from the wire which led the fluid into the cartridge being intensely heated by the discharge of the electric battery. Formerly it was a common practice to mix the gunpowder intended to be exploded by electricity with iron filings, which becoming red hot by the discharge, set fire to the gunpowder as a matter of course. We are not without experimenters at the present day, who conceal a thin platinum wire in the powder, for the purpose of accomplishing the explosion.

Another method of illustrating the fact that the ignition of loose gunpowder requires *time* for the electric fluid to act upon its particles, and a consequent abatement of the velocity with which it moves through a circuit of good conductors, is that of first placing a portion in a circuit of that kind; transmit through it a discharge of a certain degree of intensity of the jar, and you will find the powder blown away as in the compound circuit of paper, tinfoil, tow, and gunpowder, when all the rest of the circuit was metal. Having satisfied yourself on that point, next vary the arrangement, by placing a wet thread in the circuit. The discharge of the jar from the same degree of intensity, explodes the powder.

I have already shown that, by an introduction of the moistened thread as a part of the circuit, the electro-momentum is sufficiently abated to be deprived of the power of communicating a shock to a person through which the fluid passes. Now from that fact, and from the fact also of accomplishing the ignition of gunpowder when the electro-momentum is thus abated, there can be no reason why the gunpowder should not be ignited by the *same* discharge of the jar, in the circuit of which a person is placed without experiencing the shock.

In order to give a striking illustration of this fact, I will place a battery of six miniature pieces of ordnance in one part of the circuit, and myself in another part of it. When the jar is charged to the usual high intensity, I will operate in the capacity of discharging rod, by presenting the brass ball which I hold in my hand towards the ball of the jar. The result is the simultaneous discharge of the six pieces of ordnance, but not the slightest shock is experienced by myself, although the electric fluid that discharged the guns traversed my arms and chest, prior to its arriving at them.

Glass tubes, filled with water, have been employed in place of the wet string, in the process of firing gunpowder by electric discharges; but if the tube be too wide, the electro-momentum would be too great for any person to stand in the circuit without experiencing a severe blow; and even by long use of a narrow tube the electric momentum becomes too great for any person to stand in its way. I have employed a glass tube of narrow bore for several successive years, but I found that it gradually augmented the velocity of the transmitted electric fluid, till eventually I could not ignite gunpowder by its use, unless, indeed, I considerably augmented the quantity of fluid transmitted. This circumstance, I afterwards found, was owing to the nitric acid which had been formed by previous discharges from the atmospheric air which the water held in solution, thus increasing its conduction, and giving greater freedom to the electric transmission.

This fact, which I have not seen mentioned in any other place, would not happen if a new portion of water were employed in every experiment, and the inside of the tube well cleaned. Another fact that I sometimes meet with when operating on gunpowder, is that of setting the string on fire at one or both of its ends, when they happen to get too dry by previous discharges.

LECTURE X.

The chemical class of phenomena exhibited by electric action, I have considered as embracing all those calorific effects which produce change in the constitution of the matter operated on: such, for instance, as the explosion of wires, deflagration of gold, silver, and other metallic leaf, &c., also the ignition of gunpowder, resin, turpentine, &c.; all these effects come under the class of chemical phenomena. I have still a few more experiments to offer to your notice on other chemical compounds, in which heat and flame are developed.

If, for instance, I place a portion of ether in a metallic spoon, which I hold in my hand, and hold the liquid beneath the ball which projects from the prime conductor, at a proper distance to receive sparks from it, the sparks which pass through the ether immediately inflames that liquid, or rather the vapour which hovers over its surface; for never do we see a liquid on fire, although we often express ourselves as if such were the case.

The ignition of inflammable fluids is carried on by degrees, whatever may be their character: with *liquids* which are so situated as to expose but a small surface to the air, the ignition is very slow, for no part of them can ignite but that which has previously assumed the state of vapour; hence, strictly speaking, no liquid is inflammable. The vapour of ether first ignites by the electric spark; the heat thus produced assists the evaporation of the top stratum of the *liquid* ether, which in its turn becomes vapour and burns. The heat is now augmented, and the evaporation of the liquid stratum next below is more rapid than in the previous stratum; and thus it is, that stratum after stratum becomes converted into vapour, and burns in succession, until the whole is consumed. By an attention to this mode of reasoning, the circumstances attending the next two experiments will be easily understood.

I will now place in another spoon a portion of alcohol, and submit it to a series of powerful sparks, as in the case with the ether; but no ignition takes place, which seems to be the consequence of a want of vapour over the surface of the alcoholic liquor. I now warm the spoon with its contents, and again pass sparks through them to the spoon: ignition is accomplished, and the alcohol becomes gradually consumed. In this case the density of the vapour was increased by the more rapid evaporation occasioned by the elevation of temperature communicated to the liquid.

If I now place oil of turpentine in another spoon, and without elevating its temperature transmit a series of sparks through it, no ignition takes place; but if I warm the oil, and thus increase the cloud of vapour over its surface, that vapour ignites by the first spark that traverses it.

The same reasoning will apply to solid resinous substances, in all those cases where ignition takes place. A small portion of vapour is raised by the heat produced by the advance portion of fluid in sufficient time to be ignited by the action of the rear of the discharge; for although the time occupied by a discharge is too small to admit of measurement, there must be *time* occupied in even the most rapid discharge. Moreover, the fluid constituting a charge occupies space, and one side of the mass of fluid must precede the opposite side, whenever it is in motion, as decidedly as one side of a cannon ball precedes the other whilst in motion. Therefore, it is easy to understand that the *advance* portion of a mass of the electric fluid, whilst in motion from one side of a jar to the other, would produce one effect, *evaporation*, on the resin, and thus make preparation for the accomplishment of another effect, *ignition*, by the *rear* part of the same mass of fluid. This explanation, however, I believe to be perfectly novel; but it appears to me to correspond with all our notions respecting the ignition of various bodies, whether solid or liquid.

I will now make a few experiments on some of those inflammables which are of a permanently gaseous character: the hydrogen and oxygen gases for instance. For experiments on these gases we usually employ an instrument called the electrical pistol, and sometimes another called the electrical cannon. Fig. 64 is a representation of the pistol. Its barrel is a tube of brass, fitted on the wooden stock by screws and cement, so as to be perfectly air-tight.

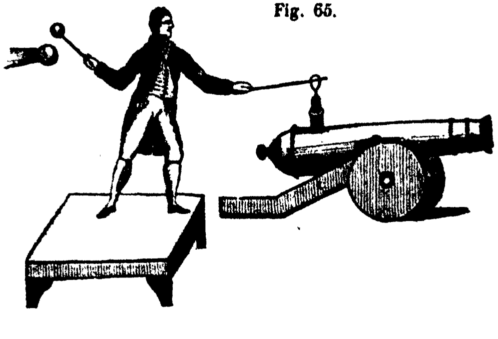
Fig. 64.

Through the lower side of the barrel, near the breach, a hole is drilled and tapped, to admit a small ivory cylinder which screws firmly into the hole. The axis of the ivory cylinder is perforated throughout, to admit of a small brass wire which reaches nearly, but not quite, across the bore of the barrel, leaving a small space between its inner extremity and the upper side of the barrel. The exterior end of the wire is furnished with a ball, as seen in the figure. Now, it will appear obvious that if sparks were received by the ball of the wire from the prime conductor of the machine, whilst the pistol is held in the hand, with a finger on the barrel, they would have to pass through the small opening inside, and traverse the air, or any gaseous matter with which the pistol was charged.

The hydrogen gas, for loading the electrical pistol, is usually obtained from water, by decomposing that liquid with zinc and sulphuric acid, thus:—Place in a clean olive oil flask a few chips of zinc, and cover them with water, then add a little sulphuric acid, by degrees, until a considerable effervescence is observed. When this occurs the decomposition is going on well, and in a short time all the atmospheric air previously contained in the vessel will be expelled. Now hold the pistol vertically with its mouth over the neck of the flask; and, as the hydrogen is lighter than the atmospheric air, it ascends to the upper part of the barrel, and by displacing the latter, soon fills it. I now put a cork pretty tight into the muzzle of the piece, and apply the little ball to the prime conductor: sparks pass freely, but no explosion occurs. I now take out the cork, and hold the muzzle of the pistol upwards for a few seconds: this permits a portion of the hydrogen to escape, and a corresponding portion of atmospheric air to enter the barrel. Reintroduce the cork, and again receive sparks on the ball: a loud explosion takes place, and the cork is projected to the further side of the room. This method of proceeding with the experiment is interesting in a chemical point of view, since the former part of it shows that hydrogen alone will not ignite by the electric spark; and the latter part shews that when mixed with atmospheric air, or rather with the oxygen part of it, ignition, with explosive rapidity, occurs.

We may vary this experiment by permitting the electric fluid to pass first through the human body, and afterwards explode the gaseous mixture. For this purpose we may use the electrical cannon, represented by Fig. 65, which

Fig. 65.



is furnished with a wire insulated by an ivory cylinder in the same manner as that in the pistol. The cannon being loaded with the gaseous mixture, is placed on the table; and whilst insulated, by standing on the electric stool, I connect one of my hands with the top of the little transverse wire, and by a ball which I hold in the other hand, I take sparks from the prime conductor. The corresponding sparks which pass between the lower end of the wire, and the barrel of the cannon, explode the gases with a loud report. The whole arrangement for this experiment is well represented by the figure.

Now, although the experiments best calculated for illustrating the distinction between the electric fluid and the calorific matter, or that which produces the phenomenon of ordinary fire, belong to voltaic electricity, and cannot, with propriety, be introduced till we arrive at that part of our undertaking, it may not be amiss, in this place, to attempt an explanation of the calorific effects hitherto produced by means of that hypothesis.

The grand physical truth necessary to be kept in view whilst reasoning on this topic, is simply this: *no two bodies can occupy the same place at one and the same time;* therefore, if the electric matter and the calorific matter be two distinct fluids, it would be impossible that they could be in the same place at the same time. Both of them are acknowledged to be resident in the pores of all other matter, both solid and fluid; and their particles may, and probably are, closely mixed with one another, and also with the magnetic matter. This being admitted, it would appear obvious that a redundancy of any one of them, forced upon a previously statical group, within a metal, for example, would be the means of disturbing all the rest; and, by the same rule, an abstraction of a portion of any one of these elements ought to cause a disturbance amongst those that were left behind, under the supposition that, in both cases, the elemental forces, *prior* to such addition or abstraction, balanced one another; and, consequently, that an equilibrium existed amongst them.

We have many well known facts in accordance with both these positions. All our thermo-electric phenomena depend upon additions and abstractions of the calorific matter to and from the bodies operated on; or, in general terms, the display of the electric phenomena is due to a pre-disturbance of the calorific matter. Hence, conversely, we have reason to infer that a disturbance of the electric matter would be attended by a display of calorific phenomena. An admission of this principle would afford an easy solution of electro-calorific phenomena: for the sudden electro-mechanical pressure against the calorific particles, during the transmission of a heavy discharge through a thin wire, would be as likely to displace and condense those particles as a few smart blows of a hammer on the metal would condense them, and the former process produce a *red heat* as decidedly as the latter, which is well known to produce that phenomenon. Another circumstance favourable to this hypothesis, is that shown by metallic conductors at different temperatures. When a thin metallic wire is surcharged with the calorific matter, by raising it to a high temperature, it impedes the progress of the electric fluid to a far greater extent than when cold, or, in electric language, it becomes a worse conductor; but the grand experiment in support of this hypothesis is that in which the electric current drives the calorific matter entirely out of the circuit, rendering a portion of a stout copper wire red hot. The experiment producing this interesting theoretical fact, will be minutely explained in our lectures on voltaic electricity.

In the experiment I am now about to offer to your notice there is some reason for supposing that the first calorific effect produced arises from a compression of atmospheric air, which was probably the case in some of our previous experiments. I strew some powdered resin on a tumbler full of water, and bring the latter into the circuit of a discharge from one side to the other of a jar. This is done by connecting the two opposite sides of the water with the two points of the sliding wires of the universal discharger, Fig. 56, page 124, the balls being previously removed; and by means of a chain connecting one of these wires with the outside of the jar, and discharging the jar by the usual application of the discharging rod to its ball and the other sliding wire of the instrument, the electric fluid traverses the surface of the water, and ignites a train of the powdered resin.

In many of the electro-chemical phenomena no ignition takes place, nor is any unusual light produced. Such is the case in those decompositions which are accomplished by electric action of low intensity, and where the liberated constituents of the compound are always developed at particular points in the circuit. These phenomena are displayed to the greatest advantage by voltaic-electrical currents, and will be extensively illustrated when we arrive at voltaic electricity; but it will be necessary in this place to show you a few specimens of them by the operation of the machine.

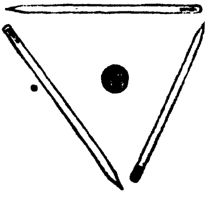
I soak a few pieces of white blotting paper in a strong solution of hydriodate of potash, in which a little starch is mixed, and after placing two or three plies of the wet paper on a sheet of platinum, I hold it beneath the inferior extremity of a platinum wire, which hangs pendent from the prime conductor. A few turns of the machine accomplishes decomposition of the hydriodate, as is manifested by the dense brown speck of liberated iodine immediately beneath the point of the pendent wire; but on examining the lower side of the pile of paper no mark of decomposition is seen. This is the uniform result by this mode of proceeding: the iodine being always liberated at the positive wire, but never at the negative one; or in other words, it is liberated at the *delivering* metal, and not at the *receiving* one. The uniformity of this law may be shown by making the experiment at the negative conductor. If, for instance, I were to hang the platinum wire to the negative conductor, and hold the soaked paper beneath it as before, no brown speck would appear on the upper side of the pile; but if I place the platinum sheet with its pile of paper upon the negative conductor, and hold the point of the platinum wire over the paper, the electric fluid which leaves my hand and traverses the paper to the negative conductor decomposes a portion of the solution, and the brown speck of iodine appears below the point of the wire.

We will next operate on a solution of the sulphate of copper, also held suspended in blotting paper. By means of a copper wire I join the prime conductor and the paper, and with the point of a platinum wire I touch another part of the paper. The machine being put into motion, an electric current traverses the solution, the electric fluid being *delivered* into it from the copper wire, and *received* again from it by the platinum wire, which I hold in my hand. The decomposition takes place, and the liberated copper attaches itself to the platinum wire and soon cases it with metallic copper.

In this case, as in those cases with the hydriodate of potash, there is an immutable law which governs the display of the phenomena, and by which the copper and all other metals liberated from their solutions by electric currents, appear on the *negative* or *receiving* wire. The results of this experiment will afford an idea of the nature of the electrotyping process, and also of electro-gilding and silvering, all of which depend upon the same principles of decomposition.

These few illustrations of the laws of electro-chemical action being sufficient for our present purpose, our next business is to introduce a specimen of the *electro-magnetic* class of phenomena; but here, as in electro-chemistry, our principal apparatus belongs to voltaic electricity, and little more can be done now than that of magnetizing a few morsels of steel. The first experiments of this kind were made by Sir Humphry Davy, a short time after the discovery of electro-magnetism by Professor Œrsted, of Copenhagen. I will on this occasion employ the large battery of twelve jars (Fig. 61, p. 141). I arrange three sewing needles so as to enclose a triangular space on the face of a card, to which I fasten them by means of sealing-wax. Through the centre of the triangular space I pass a strong copper wire, at right angles to the face of the card, and as the wire is vertical, the ends of the needles will be horizontal. Moreover, the

Fig. 66.



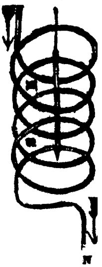
arrangement of the needles is such that, to a person supposed to be standing in the centre of the triangular space, and looking at the needles in succession, their points would all lie on his *left* hand, and their eyes on his right. The whole arrangement is represented by Fig. 66. If now we discharge the battery from a high intensity, through the central wire, *from its superior to its inferior extremity*, the needles will all be rendered magnetic, having a *north pole* at the *eye end* of each needle, and a *south pole* at the point; but if we transmit the discharge upwards instead of downwards, the polarity of the needles would be in the reverse order. Such is the uniformity in the display of this disposition of magnetic polarity, with reference to the direction of the electric current through the wire, that it has become an established law in electro-magnetics: and it is a matter of no consequence whether we operate upon a system of needles disposed as in the figure, or upon one needle only; the results are uniformly the same with reference to the direction of the electric current and the disposition of the north and south magnetic poles, which it brings into existence at the extremities of the steel.

Now, since the needles were situated on different sides of the conducting wire, and, consequently, on different sides of the electric current, which it transmitted; and as the whole of the three needles were rendered magnetic, in the same order of their poles, it is obvious that the magnetic forces of the electric current are uniformly exerted on every side of it. This fact being kept in view, it appears that it is a matter of no consequence on which side of the conducting wire we place the needle, provided the one be at right angles to the other, magnetization will be the result, and, as might have been expected, the magnetizing forces of any given electric discharge are most powerful close to the conductor: and diminish as the square of the distance between the wire and needle increases: which law, in mathematical language would thus be expressed, M is as $\frac{1}{D^2}$: in which M and D represent the magnetic force, and the distance of the needle from the axis of the electric current, respectively.

When, as in the preceeding experiments, we employ a straight conducting wire, it will be observed that the magnetic forces of the current operate principally on one side of the needle only, and only against one of its transverse sections: but the magnetic powers excited in the needle, by any given electric discharge, may be much exalted by causing the magnetizing forces to operate on all sides of the needle at the same time, and to be repeated over every part of its surface. This is accomplished by taking advantage of a spiral conductor, and placing the steel needle in the centre of the spiral. This plan was first thought of by M. Arago, of Paris, at the same time that Sir H. Davy was pursuing similar enquiries in London, and independently of any knowledge of each others experiments.

In illustration of the advantage of the spiral conductor, we will suspend a stout steel needle in the axis of a helix of copper wire, and opposite and at right angles to another, but straight part of the same wire, and at the same distance from it, we will place another needle: the whole arrangement being represented by Fig. 67.* We will now charge the battery of jars; and when charged, discharge their contents through the copper wire, from its superior extremity N to its inferior extremity S. The direction of the current will be indicated by the small arrows. The discharge having taken place, we examine the two needles, and find that the spiral enclosed needle is much more powerfully magnetic than the other; but the position of their poles, with reference to the direction of the electric current, is the same in both needles.

P Fig. 67.



N

I now enclose two other steel needles in pieces of narrow glass tubes, and afterwards suspend one of them in the axis of the spiral, and the other opposite to a straight part of the conductor, as in the last experiment. The discharge of the battery through the copper wire again polarizes the needles, and to the same extent as when no

* The artist has omitted the lower needle by mistake.

glass enclosed them: showing that glass does not interfere with the magnetic action.

Whilst pursuing enquiries of this kind some years ago, I was led to institute the following experiments,* and the results afford a good idea of the influence of *electro-momentum* in the magnetizing process. Having previously discovered that soft iron could be magnetized by electric currents, to a much higher degree than steel, it seemed likely that *soft* steel would be rendered magnetic by a less electric force than would be required for magnetizing *hard* steel. This being found to be the case, needles of soft steel were employed in the experiments now about to be offered to your notice.

In the axis of a spiral conducting wire I place a soft steel needle, which is insulated from the wire by a covering of silken thread. I now charge a Leyden jar, and afterwards transmit its contents through the wire constituting the spiral. On examining the enclosed needle it is found to be polarized, in accordance with the before-mentioned law of electro-magnetism.

I next place another needle within the helix, and in another part of the circuit I place a strip of gold leaf between two pieces of window glass. I charge the jar to its previous degree of intensity, and again discharge it through this new circuit; the gold leaf is deflagrated, has entirely disappeared, and the needle is magnetized.

I vary the arrangement by introducing a wet string to the circuit; and after placing a new soft needle in the helix, and another strip of gold leaf to the circuit, I again discharge the jar, charged as before, through this new series of conductors. The gold leaf seems agitated, but does not otherwise suffer, and the needle remains neutral. These results would seem to imply that the electro-mechanical action, or electro-momentum, to a certain extent at least, is essential to produce magnetic polarity in steel bodies. But I will give another variation to the experiments, by means of which this view will be much supported.

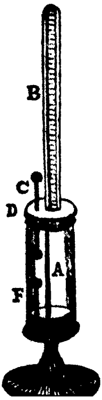
* A full description of these enquiries appears in the "Annals of Electricity, &c." vol. viii.

In these experiments I will introduce the gunpowder exploding apparatus, Fig. 63, page 153. On the table of this apparatus I place a small heap of loose gunpowder, and in another part of the circuit I place a strip of gold leaf, and in another part I introduce the wire helix, with its contained steel needle. In this case the whole of the circuit is metal, with the exception of the gunpowder and the plate of air between the ball of the jars and the approaching ball of the discharging rod. I discharge the jar and examine the results, and find that both the gold leaf and gunpowder have disappeared; the former being deflagrated, and the latter blown off the table without being ignited. The needle is highly magnetic. Now, in this case the discharge was attended by a considerable momentum.

I now vary the experiment by the mere introduction of a wet string to the circuit, a new needle and a new strip of gold leaf, and another portion of gunpowder replacing those previously operated on. On discharging the jars through this new circuit the gunpowder explodes, but the gold leaf is not injured nor is the needle magnetized. I think it will now appear pretty obvious that the whole of the results attending this series of experiments favour the idea that an electro-momentum has an essential influence in the production of electro-magnetic phenomena, at least of this peculiar class of them. In our lectures on electro-magnetism, we shall have other classes of phenomena to introduce, and shall endeavour to illustrate the whole subject, both theoretically and practically, by a more extensive series of experiments than has hitherto been embodied in any course of lectures on this branch of physics. Electro-chemistry also will receive the most ample experimental illustration, when in our lectures we treat of it as a distinct branch of electricity.

I will now introduce an experiment in which heat is produced without being accompanied by any chemical change in the heated body. The apparatus we employ in this experiment was invented by Mr. Kinnersley, in the year 1760, and by that philosopher called an

Fig. 68.



electrical air thermometer. It is represented by Fig. 68. D F is a cylinder of glass, an inch and half diameter, furnished with a brass cap at each end. Into the centre of the lower cap is screwed the pedestal of brass which supports the rest of the instrument, and a short brass stem, surmounted by a brass ball, rises from that cap inside the glass cylinder.—Directly over this ball is another, attached to the inferior extremity of a brass wire, which, by passing through a collar of leather in the upper cap, can slide air tight to and fro for the adjustment of its lower ball to any required distance from that beneath it. In another part of the upper cap is screwed a brass ferrule, into which is cemented a narrow glass tube open at both ends, and reaching downwards to nearly the bottom of the cylinder, and upwards to about six inches above the upper cap. To this narrow tube is attached an ivory scale of inches, tenths, &c. When this thermometer is used, coloured water is to be placed in the cylinder till its surface reaches nearly to the lowest ball; the glass tube is then screwed air tight into its place. Now blow gently through this tube, in order to raise the water in it till it reaches as high as the upper cap. This done, and the metallic pedestal connected with the outside of a charged jar, the discharging rod directs the charge to the upper ball of the sliding wire, and a flash is seen between the balls inside the cylinder. The contained air becomes disturbed and heat developed; a subsequent expansion of the air takes place, which by pressing on the surface of the water causes a rise in the tube, sometimes to its top, and even throws some out.

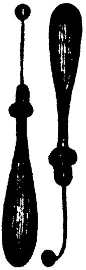
As a specimen of the electro-physiological class of phenomena, no fact is better known than the electric shock. But, as has already been shown, the shock depends on an electro-momentum, and therefore the sensation alone may probably be the effect of a sudden mechanical blow given to the system by the transit of the electric fluid through the person who experiences it; and were the shock the only effect produced by an electric discharge through the animal system, it would scarcely be permitted an introduction to the list of physiological phenomena. But when we find that such discharges quicken the pulse, promote insensible perspiration and glandular secretions, slacken constipa-ions and relieve the viscera, allay inflammations, remove pains, cure disease, exhiliarate the spirits, and excite activity in the vital functions generally, we no longer regard an electric discharge on the animal system in the mere light of a mechanical power. Moreover, since by an undue administration of electric discharges on the animal body the most serious changes in the system might occur, such as intense burning, decomposition of the fluids, relaxation of the absorbent power, dessication of muscular fibre, deafness, blindness, deprivation of the senses, torpitude, and even death itself, with prompt and immediate putrefaction, we at once recognize an agency productive of the best defined physiological phenomena. In fact, we have at once in electricity, an agent of sanation or destruction, accordingly as it is judiciously or injudiciously administered.

Fortunately, however, the predjudicial bear so small a proportion to the sanatary effects, that the advantage has been taken of electrical agency for the removal or abatement of disease of almost every variety to which the human body is incident: and in some cases with a degree of success which has not attended any other medical agent.

Electricity has been particularly successful in the removal of rheumatic affections: relieving visceral constipations; promoting glandular secretions and tumurous suppuration; allaying local inflammations, especially of the eyes; removing deafness, headache, and other local affections; and, by exalting the action of the vital organs, electricity has been beneficially applied in cases of asthma, liver complaints and indigestion.

In the exhibition of electricity as a medical agent, it is fortunate that the requisite apparatus are neither numerous, complicated, nor expensive. A cylindrical machine of about ten inches in diameter (see Fig. 23, page 66), is that generally used for medical purposes; though the plate machine (see Fig. 24, page 72) is occasionally, and with equal advantage, employed.

Fig. 69.

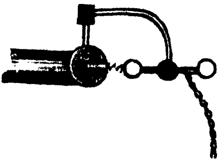


The other necessary apparatus are the electrical stool, Fig. 30, page 88, a Leyden jar, a pair of medical directors; Lane's discharging electrometer, and two other pieces for applying to the eye and and to the ear.

The medical directors are represented by Fig. 69, and consist simply of glass handles with a socket and wire joined to each. Each wire terminates with a ball which can be removed at pleasure when the included point of the wire is wanted. One of the wires is bent, the other straight.

Lane's medical discharging electrometer is applicable for regulating the power of either sparks from the prime conductor, or shocks from the Leyden jar. As applied to the prime conductor for regulating the uniformity of sparks, it is represented by Fig. 70. It consists of a bent stick of glass, a sliding wire with a ball at each end, and a brass pin, which, by being placed in a hole on the upper side of the prime conductor, keeps it firmly attached to it. The sliding wire passes through a brass piece containing a spring tube, which keeps it steady wherever placed, and by removing it to and fro in this tube its inner ball can be placed at any required distance from the prime conductor, and whilst stationary, at any given distance, the sparks from the conductor to that ball will be of uniform intensity. When the distance between them is small, the sparks will be feeble, but will increase in power as the distance is increased. A chain or wire is attached to the outer part of the sliding wire, for the purpose of conveying the fluid constituting the sparks, to any required place.

Fig. 70.



For the purpose of conveying the electric fluid to any particular part of a patient, the chain or wire is to be attached to one of the medical directors, and the other director, also furnished with a wire, receives the fluid from the patient's body, and conveys it either to the ground, or to the negative side of the machine. Figures 71 and 72, will afford ample illustration of the usual applications of the medical director: the former to a limb, the leg, only, the latter to the whole system of the patient. In both cases we are to suppose the patient insulated, by standing on the electrical stool. Fig. 72 represents the patient operating on himself, and assisted by another person who applies one of the directors to the foot. By this application of the directors, the electric fluid traverses the whole system from the shoulder where the patient applies one of the directors, to the foot where the other director is applied. The head, both arms, and one leg, being out of the circuit, are not affected.

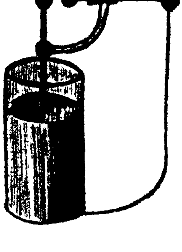
Fig. 71.

Fig. 72.

It must not be supposed, however, that the electric fluid traverses the body in a narrow channel between the two balls. Every spark produces an electric *wave* in the system, which extends *laterally*, more or less according to the power of the sparks.

Fig. 73 is a representation of Lane's discharging electrometer, as applied to a Leyden jar. In this application, the electrometer is inverted. When the ball of the jar is connected with the prime conductor, by means of a copper wire, the jar receives a

Fig. 73.

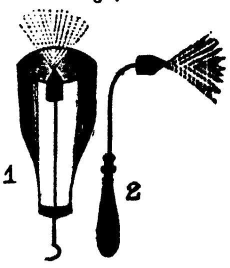


charge, which, at a certain degree of intensity, sufficient to overcome the resistance of the air between the two balls, discharges itself spontaneously through the interval, and through the wire connecting the electrometer with the outside of the jar.

If now, instead of having a short continuous conducting wire, as in the figure, to convey the charge to the outside of the jar, that wire were to be cut open, and its ends connected with the directors, one to each, and the balls of the dischargers applied to a limb or to any part of the body, as in Figs. 71 and 72, the force of each discharge would be experienced between the balls, as in the case of sparks from the prime conductor, only the sensation would be more severe. By this means, however, the shocks may be reduced to any required degree of intensity, by lessening the distance between the ball of the jar and that of the electroscope, which affords a more convenient method of administering electric sparks or shocks than any other instrument known.

The delicacy of the eye requiring every precaution against injury, almost prohibits the administration of either shocks or sparks to that organ. Its usual treatment by electricity is by the *aura* proceeding from a *wooden* point, which renders the electric stream softer than when flowing from a *metallic* point.

Fig. 74.



The instrument for throwing the electric aura on to the eye is represented by No. 1, Fig. 74. The wooden point is screwed on to one end of a brass wire, which is enclosed in the axis of funnel-shaped glass tube, with an oval opening at the wide end for adapting it to the affected eye. The wire slides to and fro in a collar, at the smaller end of the glass tube, and has a hook at its exterior extremity for connection by a wire or a chain with the prime conductor. The operator holds the instrument by the glass, and is thus insulated from the wire and wooden point. He places the wide end over the eye, and the wooden point being adjusted to the proper distance, the machine is put into motion, and the aura issues from the point as represented by the figure.

In applying electricity to the ear, sometimes sparks and at others the *aura* answer best, but in no case should shocks from a jar be administered to any part of the head, for fear of injuring the brain. The bent medical director, Fig. 69, with its ball, is well adapted for transmitting sparks to the interior of the external ear: and by removing the ball and replacing it by a wooden point, as represented by No. 2, Fig. 74, the aura can be exhibited to that organ.

In applying electricity to the body, no violent shocks should on any account be administered; they never do good, and may be productive of serious evil. The perforation of paper, shown in previous experiments, would indicate to the physician the probability of injury to delicate tissues, and we are not without instances of blood-vessels being ruptured; therefore, in all cases of the head and body the greatest caution is required.

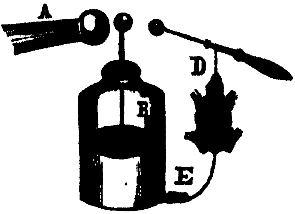
Pains in the limbs frequently require more formidable electric shocks for their removal, though in many cases powerful sparks have a better effect. The process is sometimes tedious, requiring a daily application for several weeks, but more frequently the cure is performed in a much less time. In some cases the pain disappears the first day.

To small animals a powerful discharge is almost sure to be fatal, especially if directed through the head. A pigeon for instance, is killed by a discharge from a large jar, and small fishes may be killed by transmitting a discharge through the water in which they are swimming. If, for instance, small smelts, or whiting, were placed in a basin of water, and a discharge transmitted from a large jar through the water, by an arrangement such as is represented by Fig. 75, the fish would experience a shock that would immediately deprive them of life.

Fig. 75.

If, instead of small fishes, we were to place a frog in the basin of water, a discharge through the water would kill the animal. It is difficult, however, to kill a wet frog when placed on a table, but he is easily killed by suspending him in the circuit in the manner represented by Fig. 76.

Fig. 76.



It is not only during life that the animal system is affected by electricity, but long after the functions of life have ceased to be in operation some of the most remarkable phenomena have been displayed, even life restored, by the stimulating agency of electricity. The electro-physiological phenomena exhibited by dead animals will be extensively illustrated in our lectures on galvanism.

LECTURE XI.

In pursuing electrical enquiries from the productions of the machine to those of nature, we find every principle that is exhibited from the one source, corresponds with those displayed from the other: from the simple attractions and repulsions, to the most magnificent phenomena producible by electric action. The air surrounding this globe of earth being intermixed with the electric fluid as decidedly as the materials of the earth itself are charged with that subtle agent, it is reasonable to suppose that electro-fluctuations take place in the atmosphere as well as in the earth, by every change of temperature, hydrometric condition, &c., to which it is exposed; and as these changes are frequent, rapid, and occasionally great, they are attended by corresponding sudden and great changes in the electric condition of the aeriel shell.

It is a remarkable fact that, in a still, cloudless atmosphere, the electric condition of it, as high as has been explored, is that of a gradually increasing charge, from the earth's surface upwards; and as this is uniformly the case, under these circumstances it becomes an established fact in atmospheric electricity, which may be conveniently employed as a standard or normal condition in studies of this subject.

The ratio of electric increase with increasing atmospheric altitudes having never yet been determined, we are not in possession of any definite law; and as different results have been obtained by different observers, under circumstances apparently similar, the data hitherto collected are too uncertain, and too scanty, to form any basis whereon mathematical assistance could be available in the establishment of a correct law on this interesting topic. Notwithstanding, however, the want of precise theoretical laws on the electro-distribution in the atmosphere, being an acknowledged fact, the desideratum is pleasingly, though partially supplied to the observer, by the unfading picture which is formed in his mind, of the certain increase of electric agency at increasing altitudes from the earth's surface: every succeeding stratum being electro-positive to every stratum beneath it, and the whole atmosphere electro-positive to the globe which it surrounds.

The easiest and surest mode of ascertaining the different electric conditions of the atmosphere at different altitudes, is by means of a series of kites, with a wire strand in each string.

The kites, which ought to be four or five in number, are to be floated at the same, and with different lengths of string, from a hundred to a thousand or more yards. Let, for instance, the lowest of a series of five kites have only one hundred yards of string, and the highest one thousand yards. Under favourable circumstances the former will attain about seventy yards, and the latter between eight and nine hundred yards of altitude; and the intervening three kites will float at different altitudes between these two extreme ones of the series. If now we place the ball of a Leyden jar to the insulated string of the lowest kite, it will become charged to a low intensity in a certain period of time, and by applying the ball of the jar to an electroscope, and testing the character of the electric action, either by sealing wax or by glass, in the usual way, we find that it is positive.

The same operations are to be proceeded with at the other kite strings, and it will be found that the whole of them display positive electric action, with an increase of intensity in the charge of the jar, from the first to the highermost kite in the series. We next proceed to ascertain the *relative differences* of the electric actions of the kite strings, by bringing two of them at a time in their insulated state, close to each other, and we observe a spark pass between them. After satisfying ourselves by these means that, although the whole series are positive to the ground, they are positive and negative with respect to each other, we next insulate a jar, and by connecting one kite string with its exterior surface, and another with its interior one, the jar becomes charged, and in such a manner, that the highest or longest string of a pair invariably communicates the positive charge to the glass, whether it be the inside or outside of it with which it is in contact.

There are, however, frequent cases, whilst experimenting with kites, in which that with the longest string will not be the highest; under such circumstances the *intensity* of the charge of such string is not so great as that of a shorter one, whose upper end is much higher; although the *quantity* obtained by a discharge from the former is occasionally somewhat greater than that discharged by the latter. Now, since there is a general law in electricity by which we are enabled to understand that the fluid cannot be transmitted from one body to another, unless the former be positive to the latter, it becomes obvious that the exploring wires in the kite string must have been negatively electrical to the atmosphere, prior to their receiving their respective charges from it, and as those electric charges were not communicated to the wires prior to their ascent, it is obvious, also, that they were received from those portions of air through which they ascended, and eventually from those regions which were invaded by their highest points. Since also the electric charges are found to be the highest from the highest altitudes, the electric pressure is also greater in those places: hence the exploring wires become electro-polar, having their lower and upper parts *positive* and *negative* respectively; and since the circumambient pressure at the lower ends of the wires is uniform, the electric state which each wire displays will depend on the electric state of the air surrounding its highest point; and consequently, the relative electric actions exhibited by the lower ends of the kite strings are true representatives of the relative electric conditions of those strata of air in which the kites are floating.

The same fact may be proved by the opposite process. If, for instance, from a balloon at a great altitude, several insulated wires of different lengths were to be let down by weighting their lower extremities, each wire would be found negatively electrical with respect to the balloon itself, and consequently with respect to its contents and the surrounding air. The shortest wire, in this case, would be the *least electrical*, and the longest one the *most electrical* in the series; and every one in the series would be negatively electrical as some function of its length, no two of them being alike; hence, if the longest wire touched the ground, it would be negative to the whole of the remaining part of the series. By this process, as decidedly as by that with the kites, the wires would become electro-polar; and because the lower extremities of all the wires would be subjected to a *less* degree of electric pressure than that investing their upper extremities; the lower pole of each wire would be electro-positive. The polar action, however, would be of different degrees of intensity, and consequently, the lower ends of the wires would relatively display different electric states, being positive and negative throughout the series. The lowermost wire, if insulated from the ground, being *positive*, and the uppermost one *negative* to all the rest. Hence we understand, that it is a matter of no consequence whether the wires proceed from one common station *downwards*, or from one common station *upwards*, they will in either case be *relatively* positive and negative, accordingly with their respective lengths, when in a vertical position.

Again, since the different *degrees* of polarity, or different electric states of the extremities of the wires, depend upon different degrees of electric pressure at the upper and lower stations, it is obvious that if the pressure was equal from one end of the wire to the other, no electro-polarity could possibly take place. Moreover, since no electric discharge can possibly happen independently of polarity, we learn the reason why balloons have passed, with impunity through dense clouds highly charged with the electric matter not experiencing even the slightest indication of electric action, excepting, perhaps, the unpleasant sensation which the aeronaut might experience from the great circumambient electric pressure.

I have already informed you, that the quantity of electric matter in bodies generally is almost continually varying, from the ever-varying surrounding electric pressure ; and that different bodies have different degrees of susceptibility for the reception of the electric fluid. Therefore it will be easy to conceive that any insulated body of *great* dimensions, would receive a greater quantity of the electric fluid than a small one of the same kind when both were under the same degree of pressure. Hence it is that a long insulated copper wire stretched *horizontally* at the height of a few yards from the ground, will, occasionally, even when no cloud is present, receive a considerable charge from the surrounding air ; sufficient, indeed, to communicate powerful shocks, although a very *short* piece of the same wire would never receive an appreciable charge under any circumstance of surrounding pressure in a cloudless sky. But it must be observed, that such a wire being surrounded by an equable electric pressure, cannot possibly become electro-polar, and consequently, could not dispose of any of its charge to a vicinal insulated wire of the same kind, whether the lengths were equal or unequal; unless, indeed, the latter had not been exposed to the same pressure for a sufficient period of time to receive all the fluid due to its susceptibility of being charged with, from that pressure.

Now, although no wire could dispose of any part of such a natural charge of the electric fluid to another of the same kind and similarly situated, the *distribution* of its fluid would suffer a change by certain approaches of the other wire. If, for instance, the two wires approached one another longitudinally until they came close together, and laid side by side from one end to the other, under these circumstances, the fluid previously occupying those parts of the two surfaces, which forms the *plane* of contact of the wires, would become displaced by mutual repulsion; and after a moment's disturbance of the whole of the fluid in both wires, a new distribution and electro-equilibrium would be established.

With respect to the approach of insulated matter of other kinds, to that constituting the insulated wire, it is obvious that electrical phenomena would be displayed in consequence of a difference of electric pressures which the bodies would exercise on each other as the surfaces approach. If the approaching body were uninsulated, a polarization would take place, whatever were the character of that body, because the electric pressure on the wire would be lessened at, and about the point approached. It would there exhibit a *positive* pole, and if the body approached were near enough, a discharge from the wire would take place; the force of which would be proportional to the extent of the wire and the electric pressure of the surrounding aerial medium at that time; and as that pressure is continually varying, the charge in the wire will vary also. Therefore the same wire cannot be charged to the same extent at all times, which is a fact well ascertained by several electricians of the highest repute. From the whole of these circumstances, a long insulated wire appears to be well adapted for an important part of an *electrŏ-phorascope*, which would indicate the changes of electric pressure in the lower strata of the atmosphere, under a cloudless sky; and as such a wire would always represent the electrical state of that stratum of air in which it was suspended, it would also form an important part of an *electro-metaboliascope*, which would indicate those changes from *plus* to *minus*, and *vice versa*, of the air with respect to the earth, which occasionally take place by the approach, transit, and departure of clouds.

Mr. Stephen Grey, a Charter-house pensioner, who discovered the difference between conductors and non-conductors, and other capital facts, appears also to have been the first electrician who entertained the notion of an identity between electricity and lightning. In the concluding paragraph of one of Mr. Grey's papers, printed in the Transactions of the Royal Society, the author says, whilst contemplating the results of the experiments he had been describing in the same paper, "By these experiments we see, that an actual flame of fire, with an explosion, and an ebullition of cold water, may be produced by communicative electricity (communicated to a metallic rod, an iron ball, and other bodies, on which he had been experimenting): and though these effects are at present but in *minimus*, it is probable that in time there may be found out a method to collect a greater quantity of it, and consequently to increase the force of this electric fire, which, by several of these experiments seems to be of the same nature with that of thunder and lightning."

These predictions, which were printed in the Transactions for the year 1735, ten years prior to the discovery of the Leyden jar, and about seventeen years before the first successful experiments on atmospheric electricity, were wonderfully verified in these two memorable events.

After the wonderful powers of the Leyden jar had become generally known, there can be no wonder of the identity of electricity and lightning being suspected by those electricians who paid close attention to the character of the phenomena; indeed it soon became a prevalent opinion: but it is certainly to Dr. Franklin that the honour is due, of earnestly calling the attention of philosophers to this topic by his admirable observations on the analogies which the effects of lightning and electricity present, and also of placing before them a plan by which a satisfactory experiment might be made. Dr. Franklin's plan of experimenting bears date 1749, and the following description of it is in his own words:—

"To determine the question whether the clouds that contain lightning are electrified or not, I would propose an experiment to be tried where it may be done conve-

Fig. 77.

niently. On the top of some high tower or steeple place a kind of sentry-box, as in Fig. 77, big enough to contain a man and an electrical stand. From the middle of the stand let an iron rod rise, and pass bending out of the door, and then upright twenty or thirty feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when such clouds are passing low, might be electrified and afford sparks, the rod drawing fire to him from the cloud. If any danger to the man should be apprehended (though I think there would be none) let him stand on the floor of his box, and now and then bring near to the rod the loop of a wire that has one end fastened to the leads, he holding it by a wax handle: so the sparks, if the rod is electrified, will strike from the rod to the wire, and not affect him."

The plan for this grand experiment being made generally known throughout Europe and America, many philosophers of both countries made preparations for carrying it into execution. The French were the first in the field on this memorable occasion, and M. Dalibard's apparatus, erected at Marley-la-Ville, had the honour of being the first that was visited by the "ethereal fire," though that philosopher himself, in consequence of an absence from home at the time, was deprived of the glory of being the first beholder of it, the enviable good fortune falling to the lot of his servant, Coiffier, who was left in charge of the apparatus.

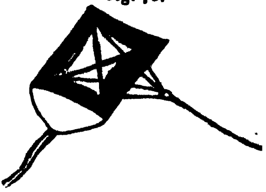
Dalibard's apparatus was similar to that proposed by Franklin, which, however, was not placed on a steeple, but on some high ground. It consisted of an iron rod forty feet long, the lower end of which was brought into a sentry-box, where the rain could not come. On the outside the rod was fastened, by silken cords, to three stout wooden posts firmly fixed in the ground. On Wednesday, the 10th of May, 1752, between two and and three o'clock in the afternoon, Coiffier saw the first electric spark drawn from the atmosphere ever witnessed by man. He heard a clap of thunder at some distance, and on applying a small Leyden bottle to the iron rod, electric sparks were obtained, and the great question set at rest about one month earlier than Franklin himself had an opportunity of making a satisfactory experiment, which he did by means of an elevated kite in June of the same year, and without having any information of what had been done in France.

Franklin's kite was simply a silk handkerchief stretched diagonally by two sticks, with the usual loop, tail, and hempen string, which was insulated by means of a silken cord at the lower end.

The first indication of electric action observed were the repulsions among the fibres of the string, which stood erect and avoided one another as if attached to the prime conductor of a machine. Shortly after these appear-
s from a key which he had
A dense
l in conse-
s string, and
the electric fluid was
copiously exhibited in various ways. From the time that Franklin's kite experiments became known to the present, an electric kite has been consider as an indispensable apparatus for explorations of the atmosphere.

The electric kites that I employ differ little from that first used by Franklin, excepting in the manner of applying the string, the tail, and in making them portable and convenient for carriage.

Fig. 78.



I provide a square of sarsenet, and a pair of stretchers made of light wood, and well varnished for protection against the wet. These stretchers are coupled together by means of a pin which passes through the centre of both, and on which, as a pivot, they can turn and be set to the proper angle for stretching the silk, or they can be brought close and parallel together. One extremity of each nearly balance each other,

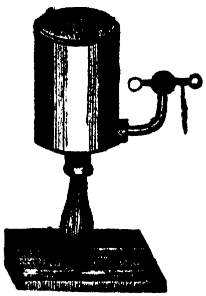
accomplished b

direct

nicely, a

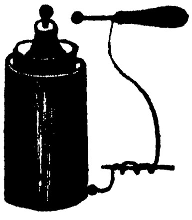
The reservoir consists of a hollow tin cylinder, mounted on a stout glass pillar, as represented by Fig. 79. The upper end of the tin cylinder is open for the purpose of lodging in it that part of the string not taken up by the kite, and in order to keep the strain of the string from pulling down the reservoir, the latter is anchored by silken cables, which keep it steady; the string, also, has a silken cord termination, which reaches over the mouth of the prime conductor, and has its other end anchored in the ground. To the lower part of the reservoir is screwed a Lane's discharger, with a wire for occasional connexions.

Fig. 79.



The coated bottle is enclosed in a cylindrical brass case, to protect it from breaking. When the cover is taken off the body of the case, the neck of the bottle, with its brass ball, is exposed. A small discharging rod, with one metal branch and a short ivory handle, is attached to one end of a copper wire, the other end being connected with the brass case, and consequently with the outer coating of the jar. Within the lid of the cylindrical case is the compass card and its magnetic needle, which being covered with glass, in the usual way of fitting up small compass boxes, is protected from injury, and when removed from the case is placed horizontally on the ground, and the needle takes its proper position. The jar, with its neck and ball exposed, and the discharger applied as in the act of discharging the bottle through the spiral wire, is represented by Fig. 80. The lid of the case in the capacity of a compass-box is seen below the jar.

Fig. 80.



When the kite is about to be used on a fine cloudless day, for the mere purpose of ascertaining the character of the electricity of the air at a considerable altitude, it may be let fly from the hand in the usual way, by paying out the string as fast as it can be taken up. When sufficiently high, a *single hitch* is taken round the reel, or stick, if wound on one, to prevent more string leaving it. The silken cord is now fastened to the kite-string, and the other end anchored in the ground. In cases of this kind there is no need of the reservoir. When the kite has been anchored a few minutes, the knuckle may be presented to the string, and probably a spark will be experienced. The bottle is now to be charged by applying its ball to the string, and afterwards discharged by the proper apparatus. If the charge appears high, the spiral with its enclosed needle is to be placed in the circuit as shown in Fig. 80, and a few discharges sent through it. These will magnetize the needle: which, when presented to either pole of the compass needle in the box, will display the character of the pole presented, and this polarity of the magnetized needle will indicate the direction of the electric current through the spiral wire, according to the law of electro-magnetism already explained. If the current traversed the spiral wire *from* the inside *to* the outside of the bottle, its inside was electro-positive; and consequently the string was electro-positive, and also the air was in the same state with reference to the ground. This is the usual electric state of the atmosphere, when perfectly clear and no appearance of cloud. Such an atmosphere, however, though constantly positive with reference to the ground, is much more powerfully so on some occasions than on others. I have usually found it most powerful during the sharp cold north east winds in March and the beginning of April.

With about half a mile of string out, during a smart breeze from the north-east, I have had a series of sparks too rapid to be counted through a plate of air between the reservoir and the ball of the discharger, Fig. 78, of an inch and a half in thickness. This circumstance occurred at the Military College at Addiscombe, in March, 1824.

During the afternoon of the same day I attached the lower end of the kite-string to the back-band of another kite, and by this means got up about another quarter of a mile of string. The upper kite now floated very high, and being of a light blue colour, nearly corresponding with the colour of the sky, required a good search of the eye to find it. When the lower string was anchored the shocks which it delivered to those who approached it were exceedingly severe. About fifty of the gentlemen cadets received shocks from the string, but not more than two or three of them could be prevailed upon to approach the string a second time. I experienced one of these shocks myself, and the blow was tremendous and general throughout the whole system, but most severe in the arm that received the discharge, the chest, thighs, and shin-bones. I next brought out a large Leyden jar of the capacity of three gallons, and applied its ball to the discharger of the reservoir. The charge of the jar was rapidly accomplished, with such an intensity as to occasion spontaneous discharges over the top. Under these favourable circumstances I made a great number of experiments. A piece of ordnance was several times fired by discharges from the jar, and twice by sparks from the string; all the sewing needles that could be mustered were magnetized; copper and silver were revived from their solutions, and water was operated on, but only very slightly decomposed.*

I will just mention in this place, once for all, that I have occasionally found it necessary to elevate the upper end of the string by the assistance of three kites in series, in order to get even a trifling charge of my small experimenting jar, Fig. 80.

If the kite experiments be intended to ascertain the electric state of the atmosphere at different altitudes, then it will be necessary to have four or more kites elevated with different lengths of string, in order that they may float at different altitudes. Experiments for this

* This series of experiments have been regularly alluded to in my lectures, but never before recorded; nor do I know of any similar series of experiments recorded by any other person.

purpose can never give satisfactory results only under a cloudless sky, and then in all cases, as I have before stated, it will be found that the atmosphere is more and more electrical as the strata explored are more elevated.

In hot sultry weather, and especially when hazy, the atmosphere is highly charged with the electric fluid at a very low altitude. I have on some occasions found the shocks from the kite-string quite insupportable when the kite was not higher than a church steeple, and this too when the string was not insulated. Undei these circumstances it is impossible to let out much string in the usual way, by paying it through the hand.

When the electric shocks are thus powerful from low altitudes, and it is desirable to get the kite higher, the best method is to bring down the kite, and when down stretch out on the ground the whole length of string intended to go up, with the kite attached at one end and the insulation perfect at the other; also the spare string in the reservoir and the ball of the discharging piece adjusted to a moderate distance, about an inch and a half from it, with its wire stuck in the ground. Thus prepared the kite will ascend from the hand, and when elevated a while, the apparatus at anchor may be observed. If sparks be seen between the reservoir and the discharging ball the power is great, too great indeed for the operator to approach the string. If no sparks be seen the ball may be pushed a little closer until they appear, which, under the circumstances mentioned, are likely to be copiously produced. In some instances during these hot hazy days, I have seen the sparks strike through more than two inches in rapid succession for more than an hour continuously. It is easy to charge a jar on such occasions, and by magnetizing a needle to ascertain the electric state of the haze, which I have always found to be positive.

During the summer season it is always difficult, if not dangerous, to elevate the kite when clouds are about, without the precaution of first stretching the string on the ground and making the other preparations already named: for want of such precaution I have frequently experienced severe blows whilst paying out the string.

When there is any appearance of lightning, even though not near, the string must never be let pass through the the hand whilst elevating the kite. Flashes of lightning invariably produce electric *waves* in the air to a great distance on every side, and these waves produce tremendous discharges through the medium of the kite-string when it happens to be in their way, and might injure or even kill the operator were he close to the apparatus at the time.

Floating clouds also, when no lightning is present, are invariably productive of electric waves, when they are highly charged. I have had a good deal of experience amongst electric waves thus produced, and occasionally have permitted others to experience their effects.* I have frequently been much annoyed by powerful shocks from waves whilst taking in the kite-string. On one occasion I was struck a violent blow by [illegible] which passed over about two yards of silk [illegible]n, though the kite-string was uninsulated at the time, [illegible] tied to a tree. The cloud producing the wave was thin and of small dimensions, and not within a quarter of a mile of the kite.

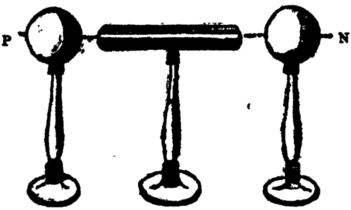
To give an idea of the manner in which electrical waves are formed, and of their influence on bodies amongst which they flow, it will be necessary to call to your recollection the illustrations already given on the subject of electro-polarization. You are already aware that an already charged body has the power of disturbing the natural electric equilibrium of those bodies which are placed within its sphere of influence; and that an electro-positive body repels the fluid *from the vicinal part* of the body on which it acts, and thus ren-

* Sergeant Rudd of the Royal Artillery, if still alive, remembers well the effect of an electric wave. Having presented his hand to the kite-string several times without experiencing even a spark, in the Artillery Barrack grounds at Woolwich, he began to laugh at the idea of electric shocks from the air. Shortly, however, I spied a cloud making its appearance behind the Repository, and on its approach asked the sergeant to try again. He did so, but before he got his hand near to the string a discharge struck it, and sent the sceptic reeling, to the great amusement of his brother non-commissioned officers who were present.

ders it negative; and the body itself, taken as a whole, becomes electro-polar whether insulated or not.

You may now suppose the polarizing body to be an insulated sphere as represented by P, Fig. 81, and that the nearest body is a brass cylinder, and beyond the cylinder another metallic sphere N, is placed all insulated. Now, accordingly with the doctrine of electro-polarization, the electro-positive sphere P polarizes the cylinder, rendering the vicinal end *negative* and the remote en

Fig. 81.



The cylinder now becomes a polarizing bo(cidedly as the original electrical sphere P, and turn polarizes the sphere N, by repelling its fluid to remote side.

In all cases of electro-polarization there is a polar axis, which is a line joining those two opposite points of the polar body on which the electric action is exerted to the highest degree. These points are in fact, the real poles of the body. The polar axis of a sphere passes through its centre, and consequently is coincident with a diameter. When the three bodies represented by Fig. 81, have their centres in the same right line, the polarizing axis of the system passes through the centres of all the bodies, as represented by the dotted line.

Now, in order to produce electric waves in the cylinder and the sphere N, we have only to move the polarizing sphere P to and fro, in, or nearly in the axis of polarization represented in the dotted line. Let us suppose, for instance, that the sphere P is first placed too remote from the cylinder to disturb its natural equilibrium: under these circumstances, both the cylinder and the sphere N will be neutral. Now advance the sphere P gradually towards one end of the cylinder: a corresponding departure of the fluid takes place from the vicinal to the remote parts of the latter, and the gradual accumulation at the remote end produces a corresponding and simultaneous movement of the fluid belonging to the sphere N. In each body, therefore, there is an *electric wave* during the advance of the disturbing body P. Now withdraw the sphere P: the fluid in both the cylinder and the sphere N now flows back again, and the electric waves in those bodies are in the reverse order to the former. It will now be quite obvious, that were the sphere P moved to and fro amongst a promiscuous group of bodies, that electric waves would be produced in the group, corresponding with the motions of the disturbing electrized sphere.

Hitherto we have considered the bodies to be insulated, and their centres all in the same right line; but we have seen in a former lecture, that if the sphere N were uninsulated, the polarization would take place with greater facility and to a greater extent; and if instead of moving the polarizing sphere P in a line with the centres of the other two bodies, the axis of polarization, and consequently the poles of those bodies, would be very differently situated. If the polarizing body P were to move past or over those other two bodies, the axis of polarization would be continually changing its position. Such also, would be the case were the sphere P to move over an uninsulated mass of any conducting matter whatever, as is the case in nature; for when a highly electrized cloud is floating over a tract of country, it polarizes the land as it passes over it, and produces electric waves within the surface when of good conducting quality, both in the direction of its path and laterally, on both hands, as decidedly as a vessel under sail produces waves on the surface of water otherwise perfectly at rest.

But it has already been shown that in the electro-polarization of conducting bodies, the intervening plates of air are also polarized, and consequently highly charged clouds polarize the atmospheric air all around them, repelling the electric fluid to a great distance, and leaving a vicinal negative space on every side. Now imagine the cloud to move on, the air around its path successively yielding to its polarizing influence, suffers its natural share of electric fluid to flow to remoter parts, and the advancing cloud, thus endowed with power, enforces an atmospherical electric tide, in correspondence with its progress through the air. It is this primary *tide-wave* in the air, that polarizes the ground, and produces a corresponding electric wave over the tract of country above which the cloud floats.

When an electric cloud is driven by the wind towards a high piece of ground whose substance is a bad conductor, that substance resists the electric wave, and will not suffer the fluid from the air to transpierce it: an accumulation then takes place on the face of the hill, which becomes charged, in the manner of charged non-conducting solids generally. The consequence is a reaction against the cloud, upon the principle of electric repulsion. The cloud being now under the influence of two forces, the wind and the electric repulsion, will have its speed retarded, if not arrested altogether. Its future path will depend on the relative power of the two forces, and on the direction lines in which they are exerted. Chatham Lines, which is a portion of the great chalk formation, is remarkable for giving new directions of motion to approaching electric clouds. Shooter's Hill, also, I have known to give electric clouds very different directions to those previously pursued from the force of the wind alone. It is far from being an uncommon circumstance to see electric clouds floating in opposition to a light wind; and very frequently indeed, their motions are oblique to it.

Now, since electric clouds travel with the greatest facility over a country which offers the least resistance to the grand electric tide wave, there can be no wonder at their greater tendency to pass over wet land, rivers, &c., than over dry land, which is a worse conductor, especially when such land is high. When clouds are deflected from the wind's direction, they are certain to be guided by the conducting character of the country below. With respect to Chatham Lines and Shooter's Hill, I have had frequent opportunities of observing clouds deflected by them to the respective neighbouring rivers, the Medway and the Thames. From these facts there seems to be a possibility, at least, of forming an idea of the character of the geological strata by observing the motions of thunder clouds and others highly charged with electricity.

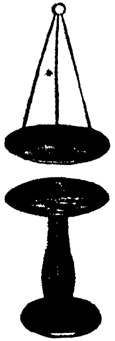
That flashes of lightning produce electric waves on every side, may easily be understood by considering what would happen to the cylinder, Fig. 81, were the sphere P to be suddenly charged and only for a moment. A sudden and momentary polarization would be the consequence, by an electric wave *from* the vicinal to the remote end of the cylinder, which would immediately retire again on the exit of the disturbing force from the sphere P. Electric waves produced by flashes of lightning, are necessarily rapid, and only of momentary existence, whilst those produced by clouds are slow and of long continuance. Both classes of electric waves may be illustrated by the following experiments.

Place three or four gold leaf electroscopes in a row, at some distance from one another on the table, then take hold of the coating of a highly charged Leyden jar, and pass its ball slowly over the electroscopes: the wave thus produced in the air causes their leaves to diverge as this artificial cloud passes over them in succession. If, instead of the usual ball of the Leyden jar, a large well-polished ball were attached to it by a long metal stem, the effect on the electroscopes would indicate the power of this class of waves in a very beautiful manner.

To illustrate electric waves produced by lightning, I place a gold leaf electroscope at a considerable distance from the prime conductor of the machine, and, before the latter becomes electrized, I hold a large brass ball against it. Now turn the machine: nothing happens to the electroscope, but the moment I remove the ball it receives a spark; in fact, a miniature flash of lightning; and the gold leaves of the electroscope are thrown open, indicating the influence of the momentary wave. In neither case is there left any trace of electric action in the electroscopes. But if each electroscope were to be furnished with a pointed wire, projecting upwards, the whole would remain electrical: the series of electroscopes over which the electric ball passed would show that tall rods pointing into the air receive electric fluid whilst an electric cloud passes over them; and the electroscope charged by the wave from a spark is a good illustration of the electrization of tall pointed rods by a wave from a flash of lightning.

Although I have employed the ball of a Leyden jar in these experiments, I am far from supposing that a charged jar is a just resemblance of an electric cloud; nor do I entertain the idea that the air becomes charged in the manner that coated glass is charged. In my opinion, there is not at the present day a more palpable, certainly not a more popular error, amongst writers on electricity, than that of supposing the air to be charged like glass. About the year 1755, an experiment was established by Æpinus and Wilche, at Berlin, which was supposed to show the identity of charged glass and charged plates of air; and although the apparatus was neither more nor less than a condenser on a large scale, the identity was supposed to be proved by means of it; and from that time to the present the same opinion has prevailed, even amongst the most famous of electricians. This Berlinean experiment is, however, exceedingly interesting, from its affording a better exemplification of lightning than any other. The apparatus for this experiment consists merely of two circular boards, of four or more feet diameter, both of which are covered with tinfoil. When used one of the boards is suspended by three silken cords to the ceiling, and connected by a wire with the prime conductor. The other is placed, uninsulated, directly beneath the former, their planes being parallel to each other. Fig. 82 will represent their relative situations. When the machine is put into motion the upper board necessarily becomes electro-positive; and upon the principles of polarization, the lower board becomes electro-negative: and the apparatus is now in the capacity of a condenser. If

Fig. 82.



the action of the machine be now arrested for a moment no charge is to be found in the intervening plate of air, nor any spark discoverable from the charged board, beyond such as is usually found at the prime conductor after the machine has ceased working: but coated glass would have retained the charge discoverable by these means ! ! !

If now, we place a well polished metallic hemisphere on the middle of the lower board, a series of sparks will strike it from the upper one; and when the distance is such that the sparks are not frequent, each spark is highly imitative of a flash of lightning, and the noise, though feeble, is the thunder accompanying the miniature flash; for lightning is an electric discharge in the atmosphere, sometimes between a cloud and the earth, but more frequently amongst the clouds themselves. The electric fluid thus discharged flies swiftly through the air, in which it leaves a vacuous track behind, but of momentary duration only: for the displaced air suddenly collapses, and the noise of thunder, as one sudden report, is produced; which, by reverberation amongst the clouds and neighbouring hills, is echoed and re-echoed many times over in a succession of peculiar sounds, of a gradually decreasing intensity, until the last murmur terminates the electro-acoustic event.

The cause of lightning clouds has long been a topic of speculation amongst philosophers. The celebrated Volta, of Como, showed that the vapour of water from the surface of the earth takes up an immense quantity of the electric fluid, and consequently charges the air with it. To illustrate the fact of vapour or steam taking up electric fluid, I have only to place a small tin dish containing water on the cap of the gold-leaf electroscope, and then put a red-hot cinder into the water. This produces a copious evaporation, and the gold leaves diverge. Whilst thus divergent I test the electric state of the electroscope, and find it negative. Hence it is obvious that a portion of its natural share of fluid has flown off by means of the steam. This is the simple fact, and nothing more, and gives no reason whatever why the steam should take away more fluid than naturally belonged to that portion of the water from which it was formed. By the help of Franklin's can and chain, however (see Fig. 19, page 61), we shall be enabled to arrive at a satisfactory explanation.

When the dish of water was at the common temperature it occupied a certain space, and contained its natural quantity of the electric fluid, or precisely that quantity which, in the character of water its susceptibility of charge would allow; but as soon as it became converted into steam, its dimensions expanded, and a corresponding expansion and consequent attenuation of the electric fluid took place, in precisely the same manner as in Franklin's chain when lifted out of the can. This attenuation of electric action in the steam rendered it negative, and being in contact with the unevaporated portion of the water absorbed electric fluid from it, and thus rendered it negative also.

The next step in the illustration is to shew that the vapour thus produced does absolutely carry up with it more of the electric fluid than naturally belongs to it when in the state of water. For this purpose I suspend, by means of a silken thread, a hemispherical tin vessel over the steam which rises from the water in the dish, in the manner represented by Fig. 83. The rim of this inverted vessel is turned inwards, and formed into a channel for the purpose of collecting the water from the condensed steam. By this means I not only collect the steam but its contained electric fluid also, which condenses as the steam condenses in the inverted vessel. When the evaporation and condensation has proceeded till the gold leaves of the electroscope below have diverged sufficiently for my purpose, I remove the insulated vessel to another electroscope, which immediately displays electric action; and by the application of an excited stick of sealing-wax this action is found to be positive.

Fig. 83.

The results of these experiments are very interesting in more ways than one; as they not only prove that steam is capable of absorbing more of the electric fluid than the water from which it is formed, but also furnish us with a satisfactory explanation of the origin of the electrization of clouds, which are well known to be masses of condensed aqueous vapour, which had ascended from the earth in a state of high attenuation. Recently, the electricity occasioned by condensing steam has been exhibited on a very extensive scale, by the experiments of Messrs. Patterson and Armstrong, at Newcastle-upon-Tyne.*

From these considerations it would appear that all clouds at the time of their formation are electro-positive; although, in consequence of a slowness of the cloud-forming process they may occasionally give off to the neighbouring air the redundant electric fluid almost as rapidly as it is condensed. In such cases, the resultant cloud would be neutral; but when by a sudden depression of temperature a dense cloud becomes rapidly formed, its condensed electric fluid has no time to escape in any other manner than by a sudden discharge, which is a certain result if a proper object be sufficiently near to receive it.

The objects nearest to a cloud thus rapidly formed, are other clouds, either previously formed, or just coming into existence: and as it is next to impossible that any two of these clouds should be in precisely the same electric state, the positive cloud of the group darts its lightnings to those around it which are less intensely charged than itself. These again, in their turn, discharge their lightnings to others *negative* to themselves: and thus it is that the greatest *quantity* of lightning is always amongst the clouds, the discharges to the ground being comparatively few. It is also a remarkable fact, that when lightning does happen to strike the ground, it is generally succeeded by a profound pause, of com-

* A full description of these brilliant experiments appears in the "Annals of Electricity, Magnetism, and Chemistry, &c.," vols. v and vi.

paratively long duration, during which not a glimmer of lightning is seen, nor is a murmur of thunder to be heard. Moreover, it is no unfrequent circumstance that the flash which strikes the ground terminates the electric storm.

The immensely large hailstones which frequently fall during an electric storm, even in the hottest part of the summer season, indicate a sudden depression of temperature to have taken place in the region of the clouds: and the subsequent cold that we almost invariably experience for several successive days, would lead us to infer that, whatever may be the cause of the depression of temperature, it originated at some considerable altitude in the atmosphere, and progressed downwards to the surface of the earth.

There is not, perhaps, a more prevalent idea respecting lightning, than that the danger is over immediately the rain commences falling. This is a sad mistake: and for want of knowing better many have become victims of this terrible element. Is there a summer passes over our heads without some fatal accident from lightning? Scarcely one. Men who are ignorant of the danger they are about to expose themselves to, and animals of all kinds, take shelter under trees, and other tall objects during an electric storm; not, however, from the lightning, but from the heavy rain which is falling. The tree is struck, and the ill fated shelterers killed on the spot, though prior to the fatal event no discharge had struck any object on the ground: every flash was between cloud and cloud, and the whole display in the aerial regions far above the loftiest object in the surrounding country.

That lightning strikes the ground more frequently during rain than previously, is a fact that cannot be denied: and that this fact is strictly in accordance with the principles of electricity may easily be demonstrated both by analogy and experiment. An electric storm is generally preceeded by a period of dry weather, the atmosphere below the clouds being very dry, and consequently a bad conductor, indeed it is ranked amongst the non-conductors, and the thickness of the stratum between the clouds and the ground is very considerable. But this is not the case in the region of the clouds: an immense quantity of aqueous vapour is there condensing, which renders the air a better conductor, and the distance between the clouds is but trifling. Hence, there is considerably less resistance between cloud and cloud than between the clouds and the ground; and though the difference of electric intensity might not be so great in the former, as in the latter case, the superior electric conduction, and the vicinity of the objects, tend to determine the discharges amongst themselves: and it is not till the falling rain has improved the conducting quality of the air below, and thus lessened the resistance to the electric force in the clouds, that lightning is capable of transpiercing it. It is, therefore, during the rain that the danger is greatest

The experimental illustration of this topic is remarkably beautiful and satisfactory. For this purpose I employ a large Leyden jar, the universal discharger, and a plate of glass about a foot long. I bring the balls of the sliding wires of the universal discharger into contact with the glass plate whilst placed on the table T, Fig. 56, page 124, at about two inches distant from each other. One of the balls I connect with the metallic plate, and when the jar, is charged to a high intensity I apply the discharging rod to connect the other with the ball of the jar: but no discharge takes place; which is in consequence of the distance between the balls on the glass being too great. I now bring the balls to about one inch from each other, get the jar up to the previous intensity, again apply the discharging rod, and the discharge takes place. Now the resistance of a plate of dry air of about an inch in thickness, is nearly as much as the most intense charge of the jar is capable of overcoming. I will now moisten the air between the balls, by breathing on the glass and I will remove the balls till they are three inches assunder. You will now see that the same extent of charge of the jar as before is capable of striking over the three inches of moist surface. I will now increase the distance between the ball to eight inches, and by means of a wet camel-hair pencil, draw an aqueous line between them. You will now have an opportunity of viewing a most beautiful phenomenon. The discharge of the jar traverses the eight inches between the balls on the glass, and the fluid is seen in a compact body, with all the brilliancy of lightning, passing the whole length of the aqueous line.

The *striking distance*, in electric language, is any distance between two bodies through which the electric fluid is capable of passing, or striking, in a compact discharge; and as the striking distance is increased by an increase of intensity of the charge, and also by reducing the resisting character of the medium, it will depend upon both of these circumstances: that is, it will be directly as the intensity, and inversely as the resisting character of the aerial medium; which in symbols will stand thus: D is as $\frac{I}{R}$, in which D represents the striking distance, I the intensity of the charge, and R the resisting character of the aerial medium. Hence, when the intensity is constant, the striking distance will be reciprocally as the resisting medium; or, in still more general and familiar language, the striking distance is greater as the non-conducting quality of the air is diminished; and as the air has its non-conducting quality lessened by an admixture with water, the striking distance of lightning from a cloud in the direction of the earth must be greater during rain than when the air is not so charged with water.

Again: when the resisting medium is constantly the same, the striking distance will be as the intensity of the charge, or D is as I. Hence it is that in discharges of similar quantities of electric fluid from different sized jars, the striking distance between the ball of the discharging rod and the ball of the jar is very different, because of the difference of intensity in the two cases; the striking distance being always greatest with the smallest jar.

The subject of lightning conductors is a branch of practical electricity of exceedingly high interest, and demands the contemplations of the most profound electricians. Hitherto, however, little more has been attended to than the erection of a pointed rod of iron, without regard to situation, altitude, diameter, inferior termination, or any of those theoretical points essential to the efficacy and protection of the conductors, so as to render it a safeguard to persons and property against the most formidable element of nature.

Franklin, the inventor of lightning conductors, first proposed "for protecting houses, churches, ships, &c., from the stroke of lightning, to fix on the highest parts of these edifices upright rods of iron, made sharp as a needle, and gilt to prevent rusting; and from the foot of these rods, *a wire down the outside of the building into the ground, or down round one of the shrouds of a ship, and down her side till it reaches the water.* Would not these pointed rods probably draw the electrical fire *silently* out of a cloud before it came near enough to strike, and thereby secure us from that most sudden and terrible mischief?"

This philosopher, however, subsequently recommended continuous iron rods, of about half or three quarters of an inch diameter; which he said "may be fastened to the wall, chimney, &c., with staples of iron. The lightning will not leave the rod, a good conductor, to pass into the wall, a bad conductor, through the staples. It would rather, if any were in the wall, pass out of it into the rod, to get more readily by that conductor into the earth.

"If the building be very large and extensive, two or more rods may be placed at different parts, for greater security.

"Small ragged parts of clouds suspended in the air between the great body of clouds and the earth, often serve as partial conductors for the lightning, which proceeds from one of them to another, and by their help comes within the striking distance off the earth or a building. It therefore strikes through those conductors a building that would otherwise be out of the striking distance.

"Long sharp points communicating with the earth, and presented to such parts of clouds, drawing silently from them the fluid they are charged with, they are then attracted to the cloud, and may leave the distance so great as to be beyond the reach of striking.

"It is therefore that we elevate the upper end of the rod six or eight feet above the highest part of the building, tapering it gradually to a fine sharp point, which is gilt to prevent its rusting. Thus the pointed rod either prevents a stroke from the cloud, or if a stroke be made, conducts it to the earth with safety to the building.

"The lower end of the rod should enter the earth so deep as to come at the moist part, perhaps two or three feet; and if bent under the surface so as to go in a horizontal line six or eight feet from the wall, and then bent again downwards three or four feet, it will prevent damage to any of the stones of the foundation."

Such were the instructions of the celebrated Franklin; and had he recommended copper rods instead of iron, and directed them to be kept clear of the building instead of being fastened to the walls "with staples of iron," perhaps no better instructions could have been given; as far, at least, as an individual rod is concerned. But besides the injury that buildings may receive from a flash of lightning striking a conductor fixed close to the slates and masonry, from lateral explosions, a conductor consisting of a single branch only might be the means of drawing down destruction to some parts of the building before the lightning reached that conductor. For, were the lightning cloud on one side of the building, and the conductor on the other, the lightning would neither go round nor over the house to arrive at the conductor, unless it met with greater resistance in a direct path, and as the destination of lightning is frequently a great distance from the cloud, and its path considerably oblique, it is possible that some part of its path might be through a part of the building before it arrived at a lightning rod which formed another part of its path.

Cases of this kind have occurred, and, consequently, may possibly occur again under similar circumstances: therefore it seems to me that unless lightning conductors be properly placed, and of proper materials and dimensions, they may be the means of causing the most destructive consequences to those buildings they were intended to protect. It is very seldom indeed that a flash of lightning proceeds in a vertical path: perhaps never.

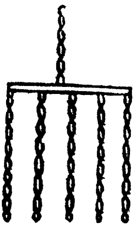
I never yet saw, or heard of, a vertical discharge of lightning; they are frequently very oblique indeed. The lightning which damaged Saint Michael's Church, at Liverpool, last year, was an oblique discharge, and struck the bronze cross at the top of the spire, several feet from its top.

There is such a display of ignorance in the erection of tall spires, that it is almost a miracle that the whole of them are not destroyed by lightning. The copper clamps and strings of lead, the former uniformly placed at intervals from each other, and the latter wantonly poured into the crevices of the masonry, render the spire a complete chain of alternate links of metal and masonry from top to bottom: the former inviting the lightning to the edifice, and the latter offering facilities for the most destructive explosions. From this very arrangement of the materials in the steeples of Saint Michael's and Saint Martin's at Liverpool, and in the steeple of Brixton Church, have these three steeples been shattered by lightning. If such modes of building tall spires be indispensable to protect them from the power of the wind, conductors are quite as indispensable to protect them from lightning. Three copper rods at equal distances from one another, from the top of the spire to the ground, and united at the top, and by one or two bands below, would secure each spire from lightning on which ever side it approached.

Lightning rods, however numerous about a building, should have a general metallic union; they then form a system of conductors in which the force of the lightning would be divided, whichever branch was struck. I have a beautiful experiment to offer to your notice, illustrative of this fact.

The apparatus represented by Fig. 84, consists of a series of iron-wire chains, so connected as to form a system of conductors of many branches. The chains hang vertically from a horizontal brass wire, and their lower ends rest on a sheet of tinfoil. The brass wire first receives the fluid from a discharge of the battery of jars, and the tinfoil carries it from the chains to the outside of the jar. The electric fluid, whilst traversing this circuit, illuminates every chain in the system to the same extent, showing that it is equally divided amongst them; and had there been ten thousand such channels it would have divided itself amongst the whole of them. This experiment shows two or more interesting facts. It proves that the iron scintillates at every link by an electric discharge through a chain of that metal; and these scintillations discover to us that the fluid occupies, and passes through, every channel in the circuit; and, as I shall prove more clearly by and bye, every metallic point in the chains throws off electric fluid into the air.

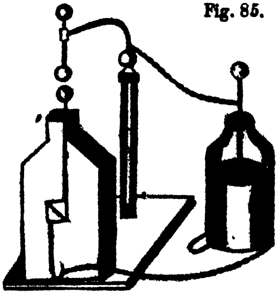
Fig. 84.



It is now time that we proceeded with some of those popular experiments which have been established for the purpose of illustrating the beneficial effects of conductors, when struck by lightning, and an experiment with the thunder house (an odd enough name), shall be the first on the list.

This long celebrated piece of apparatus is represented by Fig. 85, and consists of a model of the gable-end of a house, to which is attached a lightning rod, which can be made continuous or interrupted at plea-

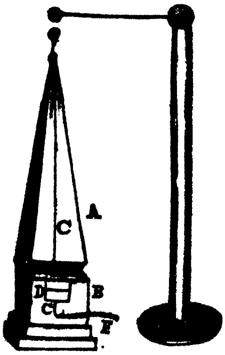
Fig. 85.



sure, by means of a square piece of wood which carries a portion of the rod being placed in certain positions in a hole which it fits in the gable-end. When in one position its wire unites the other two portions of the lightning rod, but when in another position it disunites them. The lower extremity of the discharging rod is in connection with the outside of a Leyden jar, and over the upper extremity hangs a brass ball in connection with the inside of the jar. When the lightning rod is complete, and the machine turned till the jar charges sufficiently high to overcome the resistance between the two balls, a spontaneous discharge takes place, and the conductor protects the building; but if the square piece be placed in its hole so as to make a breach in the conductor, the next discharge of the jar throws it out of its place to some distance on the table, which is considered as a representation of a displacement of masonry in a building struck by lightning.

The electrical pyramid is another piece of apparatus for illustrating the efficacy of lightning rods, and of the danger to which such structures are exposed when not so protected. The plinth on which the pyramid stands is fixed, and contains the important piece on which the fate of the edifice depends. Fig. 86 is a representation of the apparatus in which the wire of the key-stone D is placed at right angles with the general direction of the lightning rod C C, and consequently there is an interruption at that place. The base of the pyramid is furnished with three balls, as feet, by which it rests on the plinth, B F, one of the balls leaning on the moveable piece. Over the apex of the pyramid is suspended a brass ball supported by a glass pillar. When the dis-

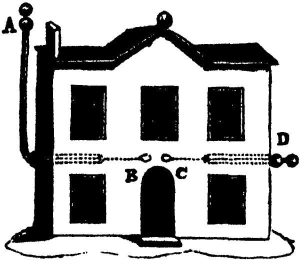
Fig. 86.



charge of a jar is transmitted to the pendent ball, the lightning strikes that on the top of the pyramid, the brass rod of which conducts it safely to the ball at the bottom, but finding an interruption there in the metal, it explodes to arrive at the lower portion, C F, of the conductor, and blows out the key-stone, which supported one side of the pyramid, and down it comes, and being made of several loose pieces which scatter about the table its destruction seems complete. Had the wire of the key-stone been placed in a vertical position, it would have joined the other parts, C C, of the lightning rod, and the damage would have been prevented.

We have several other striking experiments for the purpose of illustrating the effects of lightning, but in all our models we are obliged to take advantage of good conductors, and give them such positions as may produce the intended effect. Fig. 87 represents the model of a house containing combustible materials, such as has already been shown will ignite by an electric discharge, and the result of the experiment with this model will afford a good idea of the probable consequence of a flash of lightning striking a building that contains inflammable articles.

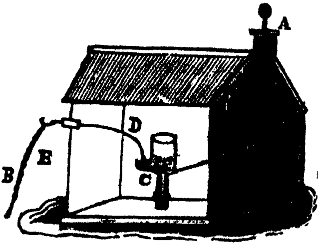
Fig. 87.



This model is made of tin plate to prevent its entire destruction by the experiment. A glass tube passes through each of the two opposite sides of the model, which insulate two brass wires within them. These wires have each a brass ball at their inner extremities, on one of which is placed some tow moistened with oil of turpentine. The shorter wire, C D, has a ring at its outer extremity, by which and a chain it is connected with the outside of a Leyden jar. The other wire, A B, is bent upwards, and the ball A at its upper extremity will receive the discharge from the inside of the jar. An explosion takes place within the building and ignites the tow and turpentine, producing all the appearance of a destructive fire.

The explosion of a powder magazine would be still more dreadful than the firing of a house containing other kinds of inflammable materials; and as the Royal • Powder Magazines at Purfleet have been struck by lightning even when several lightning rods were attached to them, but fortunately without explosion of their contents, no means that can be thought of for their protection ought to be neglected. The model represented by Fig. 88, will now receive a discharge from a Leyden jar, and the result will afford pretty good idea of the effects of lightning should it enter a magazine of gunpowder. The electric fluid shall be discharged on the ball A, and conducted to the powder barrel at C, and the wire and chain D E B, will conduct it to the outside of the jar. A wet string is also in the circuit. The powder barrel explodes, blows the roof off the magazine, and levels the walls with the floor. The various parts of the model are jointed together by hinges, and suffer but little by the explosion, so that the same model may be used several times.

Fig. 88.



Marine lightning conductors, or those employed on board of ships, are simply chains of copper, formed of links similar to those of the surveying chain, and are hoisted to the mast-head when there is an appearance of lightning striking the ship. But the lightning has frequently struck ships before the chain could be got up: showing the propriety of having a permanently attached conductor, which would always be ready to receive and carry off the flash. Such fixed conductors have been proposed, and some are now on trial in the navy: but singular enough, these conducters instead of carrying the lightning overboard, would lead it into the body of the ship, and should they ever happen to be struck with a powerful stroke of lightning, the consequences might be terrible indeed.

The idea of carrying a conductor through the body of the ship originated with Mr. Benjamin Cook, of Birmingham, about the year 1811, but it has been carried out by Mr. Harris, of Plymouth. Mr. H. has formed the conductors into strips of copper, which are inserted in grooves in the after side of the masts, from top to bottom, and through the keelson to the sea. In one of the smaller men of war, Mr. H. carried his mizzen conductor through the powder magazine ! ! ! The evils attending these conductors, arise, principally, from *lateral explosions*, and electro-magnetic influence. I have already illustrated the magnetic effects of electric discharges on a miniature scale, and from these we can form a good idea of the magnetizing influence of a flash of lightning passing through a conductor.

Imagine a chronometer to be placed near to a conductor carrying a heavy flash of lightning: the main and pendulum springs, the chain, arbours, and in fact every morsel of steel, would be rendered permanently magnetic, and consequently the machine rendered entirely useless : and the same fate would attend every chronometer and watch within the sphere of the electro-magnetic influence, which, in such cases, would be very extensive, and on every side of the conductor.

The lateral discharges are of three kinds, which I have distinguished 1st, 2nd, and 3rd, one of which I have already shown you, by the spreading abroad the grains of gunpowder, seeds, &c., and by the breaking of glass and other hard substances. These are the first kind, and take place at every interruption in the circuit.

The second kind of lateral discharge, specimens of which I shall now offer to your notice, occurs in the most perfect conducting circuit, unless the conductor be perfectly free from asperities, sharp edges, angles, &c.

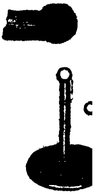
I shall endeavour to illustrate this kind of lateral discharge by a few decisive experiments.

A thick copper wire, bent at various places into angles, is suspended in the room, and I transmit a discharge of the battery, from a high intensity, through this wire. The room being darkened, the discharge takes place; and you will have observed that at every angle in the wire a brush of electric light sprang into the air.

I will now make a new circuit for the next discharge of the battery to traverse. In this circuit I place a strip of sheet copper about a foot long, in imitation of the copper conductors in masts. On making the discharge, both edges of the copper, from top to bottom, throw out fringes of electric fluid; which is a clear proof that in every discharge of lightning on to such conductors, an immense portion would issue from their edges, from the highest point of the mast to the step in the hold of the vessel. Of the consequences of such lateral discharges in the hold of a ship I must leave others to judge.

The third kind of lateral discharge takes place even from the best polished conductors under certain circumstances, and arises from the polarizing influence of the electric fluid whilst in motion. I cannot illustrate this kind of lateral discharge better than by two metallic rods, one of which shall receive miniature flashes of lightning from the prime conductor, and the other shall be placed near to the former. To insure the best conducting channel for the rod which receives the fluid from the prime conductor, I connect it by copper wire with the rubber of the machine, and also with the gas pipes which lead to the gas works. The other brass rod is in connection with the table, but has not the opportunity of carrying away the fluid which the other rod possesses.

Fig. 89.



The arrangement is represented by Fig. 89, In which the vertical rod receives the sparks from the prime conductor, and simultaneous lateral sparks are seen between the vertical rod and the vicinal end of the other. If, instead of sparks from the prime conductor, I discharge a jar down the vertical rod, the lateral discharge is seen as before. If I insulate the horizontal rod, and place another near to its remote extremity, lateral discharges takes place between these two simultaneously with the other. These effects are truly in miniature, but beautifully illustrative of those which happen from the discharge of lightning on a conductor situated near to other conducting bodies. But it is not requisite to watch a lightning conductor till it is struck by the primitive discharge from a cloud to convince us of the danger attending this class of lateral explosions; since an atmospheric electric wave, producd either by a distant flash of lightning, or by the transit of a highly charged cloud, not only satisfies the curiosity on this point, but demonstrates the fact in the most ample manner. Many are the instances of this that I have witnessed whilst experimenting with an elevated kite.

For the purpose of contemplating lateral discharges on such occasions, I insert a stout brass rod deep in the ground, and bend its upper part so as to lean towards the reservoir Fig. 79, which receives dense sparks, and corresponding lateral discharges take place between that lightning rod and other vicinal conducting bodies, as in the experiment already passed through.

But the most splendid series of experiments in illustration of electric waves, and of the lateral explosion at the same time, were made by Mr. Weekes, of Sandwich, on the 19th of May, 1841. This indefatigable philosopher has a stout copper wire suspended between the steeples of two churches, over a part of the town of Sandwich, and from this wire another descends to his laboratory, and ready to be attached to any piece of apparatus with which he is about to make experiments. In compliance with the rules which I have shown you for illustrating this kind of lateral explosion, Mr. Weekes arrayed his apparatus in the most suitable manner for obtaining brilliant results: which were most amply displayed on the 19th of May last.

A black cloud passed over the town, and flashes of lightning were seen, but no direct discharge ever touched the apparatus; nevertheless, "a mighty torrent of dense sparks, so vivid as to dazzle the eye of the observer, attended by contemporaneous stunning reports, and fraught with an unusual intensity, rush from the terminus to the ball in communication with the earth," though "separated to a distance of three and three quarter inches." At the same identical moment "a furious current of *lateral sparks* takes place between the wire and the leaden spout of the pump." Such is Mr. Weekes's own description of the first part of the electrical drama.

"But now comes to be described the most resplendent feature of the scene before us; the iron nail, serving to connect the pump machinery, suddenly exhibits the appearance of a magnificent fire-work, the splendour of which is repeatedly enhanced as *waves* of electric fluid rush through the arrangement, in obedience to each successive lightning flash from the storm cloud, and this sublime scene, with short intervals of lesser energy in the electric current, continues through the space of one hour and sixteen minutes. The combustion of the iron nail forcibly reminds me of the appearance which that metal exhibits when burnt in oxygen gas, or rather when brought under the influence of the oxy-hydrogen blowpipe, though the phenomenon was accompanied by a deep red kind of light, which does not belong to either of these comparisons."*

The iron nail which deflagrated so splendidly was absolutely in the circuit, and that circuit completely metallic down to the bottom of the pump pipe in the well of water; the phenomenon was, therefore, a lateral discharge of the same kind as that exhibited by the bent wire and strip of sheet copper. The other lateral discharges which Mr. Weekes observed were of the third kind. These he took from every part of the wire, pump, and other parts of the conducting circuit, many of which were productive of powerful shocks. A young lady, who accidentally stepped on the wire, received a lateral discharge which sent her "reeling across the laboratory."

* Annals of Electricity, vol. vi, p. 450.

Such facts as were developed in this series of experiments, and many others on record, and especially those of M. De Romas, made with an electric kite on the 7th of June, 1753, in which immense torrents of the electric fluid streamed down the string though never struck by lightning,* are not only necessary to be borne in mind by every kite experimenter, but should ever be kept in view by projectors of lightning conductors.

The electro-magnetic action of lightning is also an essential consideration, especially on board of ship; and if it were on no other account, this alone is of sufficient importance to discourage the idea of carrying a lightning conductor through the body of the vessel.

Marine lightning conductors should always be so placed as to carry the lightning over-board, and not so as to entice it into the vessel. Hence it is that even the usual chain conductors, if got to the mast-head in time, are a greater protection to the vessel than any conductor that would lead the lightning into the hold.

When Franklin had discovered that tall pointed rods would draw the electric fluid from the air during the transit of an electric cloud, he contrived an ingenious apparatus to give him warning when such clouds were passing over his dwelling. The indication given by this apparatus was a ringing of bells, upon the principles shown in a former lecture.

Fig. 90.

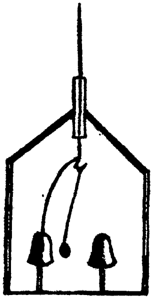


Fig. 90 is a representation of Franklin's atmospherical electric bell apparatus. The outside frame represents a section of the roof and walls of the house, from the top of which rises a pointed rod, which is insulated by passing through a glass tube in the roof. On the floor are placed two small bells, one of which is supported by a glass pillar and the other by a metal one. A wire connects the lightning rod with the insulated bell, and a small metallic ball,

* Annals of Electricity, &c., vol. v, p. 63.

suspended by a silken thread, rings the bells when the insulated rod and bell become electrized by a *wave* which a passing cloud produces.

If we place this model at the distance of a foot from the prime conductor, and put the machine into motion, you will find that the bells begin ringing by the fluid drawn from the air by the pointed rod; which gives a good idea of the indications afforded by Franklin's apparatus when an electric cloud passed over his house.

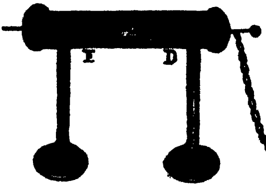
When lightning happens at a great distance from the observer, its effects are seen in the horizon amongst the clouds and vapour that are hovering in the atmosphere; it is then called *sheet lightning*, and by many persons considered to be of a different kind to that in which the electric fluid is absolutely seen darting through its zigzag path, and attended with loud thunder. This prevalent error may easily be illustrated by a very beautiful experiment which I will offer to your notice.

I place on the electrical stool three pieces of tinfoil in the same right line, leaving an opening between the ends of the middle strip and those of the other two. Over each opening I place a large decanter about half filled with water, to represent the clouds illuminated by the discharge of lightning. Having charged a large jar, and connected its outside with one of the outer strips of tinfoil, I apply the discharging rod to the other extreme strip and the ball of the jar. The discharge takes place through the intervals beneath the decanters, and these vessels, with their contents, are highly illuminated. In this experiment I take the precaution to screen the electric fluid from the spectators, so that nothing but its effects are seen in the decanters and water. This is an experiment beautifully illustrative of sheet lightning, which is merely the effect of a distant storm.

LECTURE XII.

In a former lecture, I have stated that the resistance of atmospheric air is much abated, when highly attenuated, and now I will solicit your attention to a few illustrations of that fact, and to some interesting phenomena which will attend them.

Fig. 91.



The instrument represented by Fig. 91 is called the *luminous conductor*, because of its beautifully illuminated interior during its electrization. This apparatus consists of a glass cylinder, about three feet in length and five or six inches in diameter, terminated at both extremities with hollow brass hemispheres: a point at one end for collecting the electric fluid, and a ball at the other end, from which sparks are taken.

The hemispheres screw on to brass caps, which receive, and are cemented air tight upon, the ends of the glass cylinder. A metallic point projects inside from the centre of one cap, and a ball projects inside from the centre of the other; so that when the hemispheres are properly placed, as in the figure, two points are connected to one of them, and two balls to the other. When the hemisphere carrying the ball is removed, the cap beneath exposes a stout brass pipe, tapped and furnished with a valve, for the purpose of being screwed to an air pump, and the air within the glass cylinder attenuated to the highest possible degree: which done, the hemisphere is replaced, and the apparatus, thus prepared for experiment, is laid on the two crutches which surmount the glass pillars, as seen in the figure.

If we now present the point of the luminous conductor to the prime conductor, it draws off the fluid and conveys it to the attenuated air inside the glass; and the air being now a tolerable good conductor, conveys it onward to the remote brass cap, from the ball of which it may be received in sparks or otherwise as decidedly as from the prime conductor itself. But the beauty of experiments with this apparatus consists in the variegated light which fills the glass cylinder, and shows at first view, that the electric fluid expands when permitted, and occupies every part of the conducting medium. When the remote extremity of the luminous conductor is connected with the floor we behold a steady purple-tinged cylinder of the electric fluid; but if the fluid be taken away in sparks, a momentary darkness succeeds each, causing the light within the conductor to quiver in correspondence with the sparks. A similar agitation of the light is occasioned by removing the exterior metal point, and permitting sparks to pass between the two conductors. Experiments with the luminous conductor are amongst the most interesting in electricity, especially when exhibited in a well darkened room, and with a powerful machine in action.

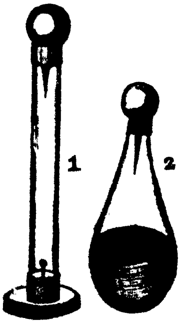
When the air within a vessel is not too much attenuated, the electric fluid is divided into a crowd of quivering streamlets, intersecting one another in a capricious and most astonishing manner, producing an evervarying fantastic reticulation of electric light throughout the whole vessel.

The beautiful variegations exhibited within the luminous conductor are usually resorted to as illustrative of the electric origin of the *aurora borealis*, or northern lights. This natural phenomenon does certainly, on some occasions, put on precisely the appearance as that seen within the luminous conductor, and its being displayed in the higher regions of the atmosphere, where the air is much attenuated, is strictly analogous to the conditions of the experiment; and although there are frequent displays of auroral phenomena which have not yet been imitated by electrical experiments, there can be little doubt of the whole of them emanating from an electric source.

In the space intervening the region of the aurora borealis and that of lightning, is another beautiful electrical meteor called the falling star. This phenomenon we also imitate by a beautiful electric experiment. For this purpose I employ a tall glass tube, represented by No. 1, Fig. 92. It is furnished with balls, points, and a valve in precisely the same manner as the luminous conductor, but the air within the glass tube is not so highly rarified. I now charge the battery to the highest intensity that I think it will stand; and having the lower brass cap of the apparatus in good metallic connection with the outside coating, I make a sudden connection between the ball on the top and the inside of the battery, and the discharge takes place through the four feet of attenuated air, the fluid traversing it in a compact mass highly imitative of the meteoric star. When the room is darkened this is an exceedingly beautiful experiment, and gives an opportunity for the eye to follow the electric ball from the top to the bottom of the tube.

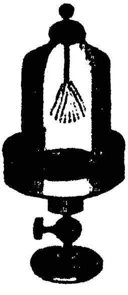
Since attenuated air is a good conductor, it may be employed as a coating to glass, in the place of tinfoil. This fact was first shown by the Abbé Nollet, who charged a bottle without any metallic lining, and on discharging it with his hand received a more violent shock than he had been led to expect. The instrument now employed to show this fact, is a Florence flask, having its neck enclosed in a perforated brass cap, furnished with a valve, and tapped for the application of the air pump. A pointed wire projects inwards from the metal cap, and a hollow spherical ball terminates the cap exteriorly. A small portion of the bulb of the flask is covered with tinfoil, but none within. A representation of this apparatus is seen at No. 2, Fig. 92.

Fig. 92.



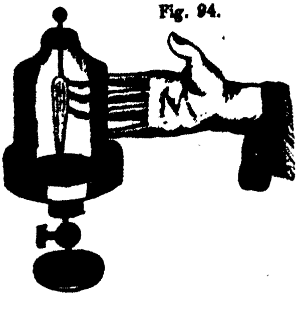
On presenting the ball of the exhausted flask to the prime conductor, whilst holding the coated part of the glass in the hand, a beautiful purple brush of light is seen to issue from the metal point, and spread itself over that part of the interior of the glass whose outer surface is coated with metal. If the charge gets two high for the flask to retain, the fluid will either flow over the top, from the edge of the cap to the metal coating, or it will spring through the solid glass, which it perforates, and thus renders the apparatus useless. If when the charge is high the hand be brought to the ball, a shock, even more violent than from an ordinary jar of the same magnitude, will be experienced. A residuary charge however is still left behind, which requires many contacts to dismiss entirely; and as each partial discharge is attended with a display of feeble purple light, the flask exhibits a series of beautiful flashes in a darkened room for a long time after the first discharge.

Fig. 93.



If, instead of the partially coated flask used in the last experiments, we were to employ a glass receiver, on the transfer plate of an air-pump as represented by Fig. 93, you will see the electric fluid shooting downwards through the attenuated air in a beautiful divergent brush of light, from the wire that passes through the cover to the metallic pump-plate: and in this case the fluid is conveyed away without charging the glass. But if I touch the side of the glass with my fingers, they become so many patches of coating, and the electric fluid bends towards them in in the most fanciful manner, and charges the opposite surface of the glass. By changing the position of my fingers I can lead the electric fluid to any part of the glass that I please. This is a beautiful experiment when the room is darkened, and is strictly conformable to the doctrine of the

Fig. 94.



Leyden jar, already illustrated. Fig. 94, will give some idea of the bending of the fluid towards the fingers.

By varying the density of the air in long glass tubes, we find that its resistance to electric transmission increases with its density, and consequently becomes a better conductor in proportion to its rarity: the probability therefore is, that vacuous space offers no resistance whatever, and thus becomes the best of all conductors.

Since we have shown, in a former lecture, that the conducting metals constituting the coatings of a Leyden jar, retain but a small fraction of the charge, it is but natural to ask what are their uses? They are indispensable both in the charging and discharging process. In the former process, one of the coatings recives the fluid at a mere point only, but by its conducting character it is enabled to distribute every spark over the glass surface which it covers; whilst the opposite coating allows of the departure of the fluid from the other surface. In the discharging process they perform the reverse functions, and allow of a sudden discharge from the electro-positive to the electro-negative surfaces. Independently of these appendages the charge could never be equally distributed, nor could a discharge be sudden and complete.

The doctrine of electric atmospheres is a subject of great interest, and is interwoven with the display of every electrical phenomena. It is a subject that requires much force of reasoning for its clear and satisfactory demonstration, and extensive series of experiments for its complete illustration. We must, however, on this occasion, content ourselves with a brief illustration of this beautiful doctrine.

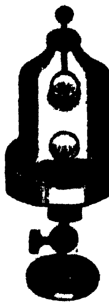
It appears that Otto Guericke, Burgomaster of Magdeburg, about the year 1670, was the first philosopher who noticed electric atmospheres, and their effects on bodies immersed in them: but the late Lord Stanhope, about 1778, seems to have studied the doctrine to a much greater extent. It is supposed by this nobleman that all bodies in an electric condition electrize the air around them to a considerable extent, and this electrized air is the atmosphere in question. Stanhope's two grand propositions in this doctrine are as follows.

"If a body be *positive*, and if it be surrounded by *air*, that electrified body will deposit upon all the particles of that air which shall come successively into contact with it a proportional part of its *superabundant* electricity, by which means the *air* surrounding that body will become *positively* electrified: that is to say, it will form around that *positive* body an electrical *atmosphere* which will likewise be positive.

"If, on the contrary, the body be *negative*, each particle of air that shall come into contact with it will deposit thereon a certain part of its *natural* share of electricity, by which means the circumambient *air* will become *negative*: that is to say, it will form a *negative atmosphere* around the body which is *negatively* electrified."

Beccaria, the famous Italian electrician, who studied the doctrine of electric atmospheres with perhaps greater care than any other philosopher, instituted a most beautiful experiment, by means of which an electric atmosphere is rendered perfectly visible. I will endeavour to repeat this grand doctrinal experiment by means of the apparatus represented by Fig. 95. The apparatus consists of a glass receiver with a brass cap and an air-tight sliding wire: and a transfer plate of an air-pump. The sliding wire is furnished with a ball at each end, and another short wire which rises from the pump plate is also surmounted by a brass ball. Having attenuated the air within the receiver, I remove it from the pump, screw on to the lower end of the pipe its wooden foot, and place the whole on an insulating stand. I now connect the upper wire with the prime conductor and uninsulate the transfer plate with its ascending stem and ball. The machine being in good order is now brought into play. No sparks are allowed to play between the two balls in the receiver,

Fig. 95.



but their polarization is perfect and complete, and the accumulated fluid on the lower side of the upper ball is distinctly seen as a luminous electric atmosphere, covering about half of the ball. This phenomenon is represented in the figure by the dotted atmosphere round the lower half of the ball.

I will now invert the order of arrangement by insulating the lower ball and connecting it with the prime conductor, and the upper ball of the apparatus I touch with my finger. Under these circumstances the luminous atmosphere appears on the upper side of the lower ball, and none on the upper ball; and by reversing the arrangements a few times we discover that that ball alone which is connected with the prime conductor, displays the luminous electric atmosphere.

If now, whilst the lower ball is in connection with the prime conductor, and the machine in action, I press down the sliding wire gradually, the luminous atmosphere on the lower ball expands upwards, gradually forms into a round-topped cone, and at last discharges itself in a dense spark to the upper ball.*

What a fund of intelligence is opened to our view by the display of these beautiful phenomena! An electric atmosphere is here exposed to our view, and no longer exists in the imagination alone; and as this phenomenon appears at the positive ball alone, it is one of the principal supports of the doctrine of a single electric fluid. It proves, also, that the electric fluid is *self luminous*; and the last phenomena exhibited by the experiment show that polarization precedes discharge.

We have no experiment, that I am aware of, that would favour the theoretical views of Lord Stanhope on this subject, unless under circumstances in which the charge of a body could be thrown off into the atmosphere: or, according to his second proposition, where the electric fluid could enter the negative body. When the bodies are rounded and well polished, they neither *receive* nor

* This last variation of the experiment, I believe, is quite novel. I have also shown that the luminous electro-sphere can be produced independently of attenuated air. See Annals of Electricity, vol. ii, p. 413.

deliver the fluid easily from, and to, the atmospheric air: and the polarization of such bodies must be very high before a discharge could be accomplished from one to the other through a thick plate of dense air, and especially when the vicinal surfaces are but little convex, Hence it is, that in the electro-polarizations already shown in an early lecture, no discharge took place from the positive disturbing body to the vicinal negative surface of the polarized body, excepting in those cases where pointed wires were employed and an uniform current transmitted.

The luminous *electro-sphere* of Beccaria, affords no idea of the electric matter being thrown into the surrounding air; but, on the contrary, would lead to the belief that the accumulated electric fluid *repels* the air with its contained electric particles, towards the opposite ball, and not being able to enter its smooth surface, renders its vicinal side negative by a *secondary* polarization: the polarization of the intermediate air being the *primary*. This view is supported by the fact that when the polarized body has points or sharp edges at its remotest side from the polarizing body, that its own electric fluid can be *driven out* of it by the repulsive action on the opposite side: but no fluid enters from the neighbouring air to make up the deficiency; consequently we find the body negative when the disturbing positive body is withdrawn.

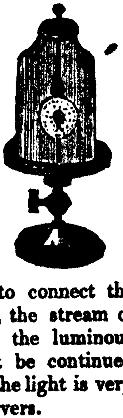
Beccaria, the illustrious Italian philosopher who discovered the luminous electrosphere shown in the last experiment, also devised another experiment, by means of which I shall be enabled to convince you of the resistance which the electric fluid meets with on its approach to smooth convex or flat metallic surfaces.

The apparatus for illustrating this interesting fact is that used in the last experiment, with the addition of a Leyden jar. The air in the receiver being attenuated higher than before, and the jar charged to a low degree of intensity, I discharge it through the receiver, and you will observe a narrow cylinder of light between the two balls, which spreads over the upper surface of the lower ball for a perceptible time before it disappears. The jar is next charged to a little higher intensity than before, and when discharged, the cylinder of light is of greater dimensions than by the first discharge, and a much greater portion of the lower ball is covered with the electric light than before.

In the preceding experiments the air within the receiver was not highly attenuated, nor the machine in full action; but if the attenuation be carried on till the air-pump ceases to act on the remaining air, and the machine brought into full play, a stream of purple electric light falls upon the surface of the lower ball, which it does not enter but breaks upon and runs over it and the stem to the pump plate in a beautiful cascade.

To enhance the beauty of the experiment, I will next use three of the battery jars. When these are charged pretty high I transmit their contents through the receiver, and now, instead of a partial covering of the lower ball, the whole of its surface and that of its stem of support are completely enveloped in a luminous electrical cloud of some duration, which seems to find more difficulty in entering the polished surface of the ball, than flowing over it through the attenuated circumambient medium to the asperous surface of the pump plate which it enters, and then disappears. The apparatus, with the enveloping cloud on the lower ball, is represented by Fig. 96.

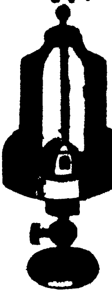
Fig. 96.



If instead of a Leyden jar we were to connect the sliding wire with the prime conductor, the stream of electric fluid between the two balls and the luminous cloud on the top of the lower ball might be continued for any length of time we pleased; but the light is very faint, and can only be seen by close observers.

Another experiment established by Beccaria, shows the direction of the fluid through the attenuated air, and forms a beautiful cascade. On the lower plate is placed a hollow hemisphere of glass, as represented by Fig. 97, and the ball is removed from the lower end of the slid-

Fig. 97.



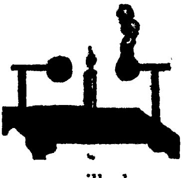
ing rod, which is again connected with the prime conductor. On bringing the machine into action, a stream of light flows from the lower extremity of the sliding wire and falls on the top of the hemisphere, which it partially illuminates, and in a short time the stream trickles over one side of the hemisphere to the pump plate, as shown in the figure. The *direction* of the electric stream is decisively shown and well defined, which gives a a peculiar interest to the phenomenon. The cascade, however, does not continue constantly on the same side of the hemisphere, but removes from place to place, which gives it a more lively and pleasing appearance.

The *direction* of the electric discharge is demonstrated by several other experiments, one or two of which I will now proceed with. I place two sticks of sealing-wax close together, laterally, on the table of the universal discharger, Fig. 56, page 194, so as to form a channel at the juncture of their rounded edges: on this channel I place a cork ball of about an inch in diameter. When the balls of the sliding wires are removed, I direct the points toward the ball, each being about three inches from it, and pointing towards its centre. One of the sliding wires is connected with the table, and the other with the prime conductor. On turning the machine gently the ball rolls along the groove *from* the positive to the negative wire.

I now remove the sealing-wax and the cork ball, and place on the table of the universal discharger a lighted candle, the flame of which is about the height of the sliding wires when placed horizontally. The points of these wires are directed towards each other, having the flame of the candle directly between them. The machine is put into motion, and the flame yields to the positive aura and bends towards the negative wire, now in connection with the rubbers of the machine. If the flame of the candle be blown out, the smoke from the wick bends in the same direction.

Both the prime and the negative conductors being insulated, I place the apparatus represented by Fig. 98 in connection with them by means of wires, one to each of the insulated horizontal wires. Each of these wires carries a metallic hemispherical cup, in which is placed a small piece of phosphorus, and between is a burning taper. I now put the machine into motion, and in a short time you will observe the phosphorus in the negative cup inflame, but the other piece does not.

Fig. 98.



These are some of the experimental data which have been brought forward in favour of the doctrine of *one* electric fluid only. There are several other phenomena which tend to give support to that doctrine, but having selected those which appear most satisfactory, it would be needless to dwell longer on this part of the subject. It may be necessary, however, to observe that, although an electric current proceeded from the point of the positive wire when operating on the cork ball, flame, smoke, &c., there can be no doubt of the existence of a current of air also, which added to the mechanical action.

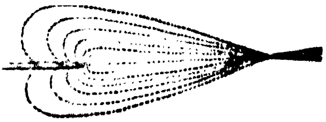
When the back part of the hand is presented to the point which throws out the aura, a cool and gentle blast is experienced; and uninsulated bodies, although attracted by presenting them to the *side* of the wire, are absolutely driven away from the point of it. If, for instance, I suspend a light pith ball by a moistened hempen thread, held between my finger and thumb, and present it to any part of the prime conductor, or to the side of the pointed wire fixed into its remote end, the ball is forcibly drawn into close contact with the metal, where it will remain as long as the machine keeps in action; but if I present the ball to the projecting point of the wire it is driven off, and will not come near to it.

The pith ball, in this case, may represent a particle of air, which being first attracted to the side of the wire would travel towards the point, in consequence of the electric force being gradually stronger in that direction;

but when it arrived at the point itself it would be thrown off by a repulsive force, and multitudes of particles of air following its example, would produce a current of air from the point.

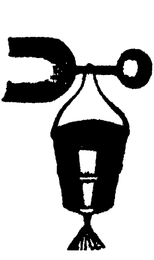
It appears singular, at first sight, to observe negative points which are *receiving* electric fluid from the air, repel the uninsulated ball as decidedly as those positive points which throw the fluid off; but the immediate cause is the same in both cases, for it can be shown that a current of air proceeds from the negative point also. The air contiguous to the side of the wire is attracted more and more towards the negative point, where it deposits its electric fluid, and is afterwards driven off by succeeding portions, which in their turns are driven off also: hence a continual wind is kept blowing from the negative point. Fig. 99 will give some idea of the manner in which the electric fluid would rush out of a positive point through the air to the negative wire.

Fig. 99.



If instead of a metallic point we were to employ water within a capillary tube, that water would be thrown out in a divergent stream similar to the aura in the air. For this purpose we employ a small metal bucket with a capillary tube inserted in its bottom. When this bucket is partly filled with water small drops occasionally fall from the lower orifice of the tube; but if it be hung on the prime conductor, as represented by Fig. 100, and the machine be put in action, the water flows copiously in a divergent stream, as represented in the figure. When the room is darkened the divergent current is slightly luminous.

Fig. 100.

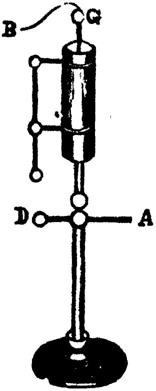


In a previous lecture, p. 127, I have promised to bring
… of those contrivances which have been in-

vented for the purpose of measuring the *quantity* of electric fluid constituting the charge of Leyden jars.

The only instrument for this purpose that has gained any celebrity amongst *writers* on electricity, is called the *unit jar*: and as we have one of these unit jars belonging to the Institution, I will describe its structure and point out its principles of action with some degree of minuteness. It is represented by Fig. 101.

Fig. 101.



This celebrated instrument is formed of a small cylindrical Leyden jar, supported in an inverted position on a glass stem, well covered with lac-varnish, and fixed into a wooden foot, as seen in the figure. The inner coating of the jar is in metallic contact with a brass ball and wire D A; another ball above the former is in contact with the outer coating of the jar, by means of a metallic frame and sliding wire. The brass ball G, and wire B, are also connected with the outer coating. The arrangement of this apparatus, is obviously the same as that of the medical jar, with an attached Lane's discharger, Fig. 73, page 172; for if the wire A D, be connected with the prime conductor, and the wire B with the ground, the charge will proceed till the resistance between the ball D, and that above it, in Fig. 101, is overcome; which accomplished, the jar will discharge spontaneously; and so long as this resistance is constant, and the outside surface uninsulated, similar quantities of fluid will cause corresponding discharges. Now as the spontaneous discharges take place between the two fixed balls, the striking distance is constant, and the discharge through that striking distance will depend upon the *intensity*, and not upon the *quantity* of fluid in the unit jar. For convenience we will call this requisite *intensity* the *discharging intensity*, which would be constantly the same if the striking distance presented a constant resistance, although the *quantity* of fluid required for this *discharging intensity* might vary considerably, according to the facility afforded for displacement of the fluid from its outer surface.

If, for instance, we have two jars, whose figure and extent of coated surfaces were precisely the same, but the thickness of the glass considerably different, that made of the thinner glass would require much more fluid than the thick one to arrive at any given intensity of charge; because of the latter offering a greater resistance to the disturbing force of the accumulated fluid within; and if the resistance were augmented by any means whatever, the standard intensity would be arrived at by a still *less quantity* of electric fluid. Such are the considerations to be attended to in explaining the operations of the unit jar, Fig. 101.

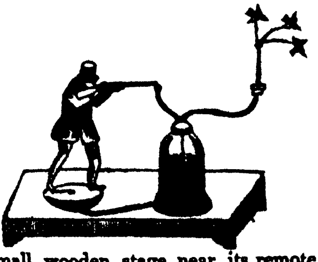
When this instrument is used with a view of measuring the quantity of electric fluid which charges another jar, in all cases much larger than itself, and which for convenience we will call J, the wire O B is connected with its inside, and the wire A D with the prime conductor. When the machine is put into motion, the *unit jar* charges; a portion of the fluid belonging to its outside being driven into the inner surface of J, which, consequently, to a certain extent, charges also by polarization. Now the quantity of fluid driven into the unit jar will depend upon the quantity driven into the jar J, and the quantity driven into J will depend on the thinness of its glass; therefore, the first unit of fluid for the *discharging intensity* depends upon the substance of the glass of the jar J, and however thin that glass may be, the *discharging intensity* will require less fluid in the unit jar than when its coating was connected with the ground.

We now suppose that the first discharge has taken place, and that *nearly* an unit of fluid is thus thrown into J (the *whole* could not be thrown in because of the *initial* part of the discharge partially charging the outer surface in common with the inside of J). The resistance of J against the reception of fluid from the outside of the unit jar is now increased, and the *discharging intensity* will be accomplished by a less quantity of fluid than at first: and this second discharge of the unit jar throws a still *less proportion* of the *diminished* quantity into J than in the previous discharge. And thus it is that each succeeding charge requires less and less fluid for the *discharging intensity*, and a corresponding disproportion enters the jar J.

When the intensity of J becomes considerable, the unit jar will be nearly choaked up, and incapable of receiving any but a very trifling quantity of fluid; and were the resistance of the striking distance not altered during this time, the discharges from the ball D to that above it would take place as if no unit jar were there. This resistance, however, is increased, which requires a higher *discharging intensity*, and consequently somewhat more fluid than if no increase of resistance had taken place. But this increased resistance in the striking distance is that which lessens the *quantity* discharged, which at high intensities of the jar J is very small indeed.

The electrical sportsman is another piece of apparatus which operates upon the principles of Lane's discharging electrometer. Fig. 102 represents this apparatus, which consists of a Leyden jar, a flock of birds, and the sportsman with his gun. From the inside of the jar proceeds a long bent brass wire, with a small wooden stage near its remote end. To the extremity of the wire four or five threads are tied, having artificial birds at their other ends, which rest on the stage. Another wire, terminated with a small ball, also rises a short height from the inside of the jar. The outside of the jar is connected with the table and also with the gun, at the end of which is a small ball, which is brought to within striking distance of the ball of the jar.

Fig. 102.



The inside of the jar being connected with the prime conductor, and the machine put into motion, the charge proceeds, and at the same time the birds rise and fly from one another by repulsion, until the *striking intensity* discharges the jar to the muzzel of the piece, where a flash is seen, and the birds drop as if shot by the discharge.

Whilst on the subject of electrized glass, I will offer to your notice a few curious experiments on flat glass plates. I will first operate with the flat glass disc, and the two metal discs represented by Fig. 51, page 109. I place the glass plates between the two metallic plates, and charge the upper side positively by uniting it with the prime conductor whilst the lower surface is uninsulated. This done I remove the connections with the prime conductor and the table, and then discharge the glass plate by an application of the discharging rod. When the discharging rod has been removed I take up the upper metal plate by its glass handle, and by applying it to my knuckle I receive a feeble spark. I now replace this plate on the glass, and with one hand I touch the other plate: on approaching the upper plate with the other hand I again experience a spark. I now lift up the upper plate by its glass handle and experience another spark on presenting the knuckle, in precisely the same manner as with the electrophorus. But what is very remarkable, the power of these sparks increases to a great extent, and again diminish, and so on for a long time together.

I now employ two square glass plates, each of which is coated on one side only; I place the naked surfaces upon one another, and press them close together. This done, one of the coatings is connected with the prime conductor, and the other with the ground: put the machine in action, a charge takes place, and the two plates are held together by a great force. Indeed, it is difficult to separate them without fear of breaking one or both. Having accomplished their separation, and applied their surfaces to the electroscope, I find both sides of one of the glass plates *positive*, and both sides of the other *negative*. The two plates when together had obviously operated as one plate only. I now again put them together as before, and by applying the discharging rod to the two coatings a discharge takes place, and the plates easily separate.

I charge the two plates when again in close contact, and on trial find they are held fast together. I now turn the negative side upwards, and connect it with the prime conductor, and a moment's action of the machine neutralizes the electrization of the plates, and they are easily separated; but if the action of the machine be continued too long, the plates become electrized the reverse way, and are held together as before.

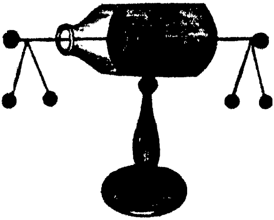
This is an old experiment, first made known by the father Jesuits at Pekin to the academy at St. Petersburg, in the year 1755. It was extensively investigated by Mr. Symmer in this country, and by M. Cigna and Father Beccaria in Italy, who were led to several other interesting experiments in consequence.

To insure success, it is necessary that the glass plates have perfectly flat surfaces, and by being square the corners of the one can be placed across the sides of the other, thus giving a better opportunity of separating them when charged.

Mr. Symmer made a great number of experiments with black and white silk stockings, which, when one of each colour was worn on the same leg for half an hour, and both taken off together without separating them, showed but feeble signs of electric action; but on separating them afterwards, they were found to adhere together with great force, a crackling noise was heard and sparks seen all the time. When quite separated, and one held up in each hand, the repulsion in each stocking was so powerful that it stood out in full shape as if the leg were in it. The attraction between the two stockings was powerful, and a spark was seen as they rushed together. When one stocking was in the other, a force of fifteen pounds was required to separate them. The white stocking was always electro-positive.

The experiments with the two glass plates leads to the explanation of another curious fact attending charged glass generally. When a plate of glass, coated on both sides, is charged to a high intensity, and then brought over the cap of an electroscope, the gold leaves are but little affected, whichever surface be turned towards the instrument, although several sparks have been thrown on the positive surface, each of which, if thrown on a metal surface of the same extent, would have affected the electroscope to a greater degree. The glass is intensely charged, but its accumulated fluid on the positive side presses *inwards* to a much greater extent than outwards, because of the negative surface offering a less resistance than the pressure on the other side; and the forces are principally *engaged* in the substance of the glass, there being but a small portion *disengaged* to operate on external bodies. If, however, either of the coated surfaces be uninsulated for a moment, a portion of the previously engaged force is relieved, and the opposite side of the glass now affects the electroscope much more than before. This doctrine is beautifully illustrated by operating on an insulated Leyden jar, furnished with a pith-ball electroscope on each surface, as represented by Fig. 103. When the jar is charged, and removed from the prime conductor for a few moments, both pairs of balls diverge a little, but not much, for reasons already stated. I now touch the outer coating, and its balls immediately collapse, being uninsulated; but the other pair of balls diverge to a great extent, because my finger has supplied a small portion of electric fluid to the outer surface, and *relieved* a corresponding quantity on the inner surface, which now being *disengaged* in the glass, springs to the balls which it repels.

Fig. 103.



I now take away my finger from the outer surface, and place it on the ball belonging to the inner one. By this means I take away the previously released fluid, and also a little more; and the balance of forces through the glass is again broken, and the negative balls diverge in quest of that portion last taken away from the inside. I again change the position of my finger, and the outside balls collapse, and the inside pair diverge as at first; then by a series of contacts with my finger, first with one coating and then with the other, I gradually discharge the jar.

There are several other methods of discharging a jar gradually and silently, but none more effectually than by a pointed wire. If, for instance, the ball were removed from the stem of a jar it exposes a sharp point, and on this point being applied to the prime conductor the charge is accomplished in the usual way: now remove the jar and place it on the table, and its charge will issue from the point into the air; and in a short time the jar will become perfectly neutral. When this experiment is made in a darkened room, a beautiful purple brush of light is seen issuing from the point, and by close attention the brush appears largest and brightest at first, and gradually grows smaller and feebler till the discharge is complete. When both sides of the charged jar are insulated, and each furnished with a pointed wire, the star will be seen on the negative point during the whole time that the brush appears on the positive point. These are beautiful theoretical facts, though by no means adapted for the lecture-room.

When the discharge of a jar is made in the usual way through a metallic circuit, the velocity of the fluid is too great to allow of measurement: or rather, perhaps, there are circumstances in the way which frustrate all attempts to ascertain its velocity. When, for instance, a discharge is made on one end of a long metallic circuit, the entering fluid disturbs all that belonging to the conducting wire, a portion of which leaves the wire at one end of the circuit at the time the new fluid from the jar enters the other end; and this fact is, perhaps, the most formidable barrier against obtaining satisfactory experimental results. During lightning, however, the electric fluid may be traced by the eye as it traverses the air through long striking distances, and obviously occupies an appreciable period of time.

I have a beautiful experiment to bring forward, which has been often used as an illustration of the great velocity of the electric fluid whilst traversing metallic conductors, but for reasons already explained it is of no value in that capacity.

I have about fifty yards of iron wire chain suspended round the room by silken cords, and through this chain I discharge the battery of jars from a high intensity. The chain, you will have observed, was splendidly illuminated throughout by brushes of scintillating fire, which sprang simultaneously from every link in the circuit. The re[illegible] of experiments of this kind are interesting, if it were on no other account than by their showing that a quantity of the electric fluid is thrown into the air from every sharp point in the circuit. The scintillating of the iron, however, adds much to the brilliancy of the display.

I have already shown in Lecture IV, page 50, that bodies of different kinds have different degrees of susceptibility for receiving the electric fluid, when exposed to the natural electric pressure of the atmosphere, and that Volta's plates of copper and zinc, Fig. 12, when brought into contact, occasion a new distribution of the electric fluid in the pair: the copper parting with some to the zinc; and that when thus in contact the pair is electro-polar.

The polar action of a single pair however, is exceedingly feeble, and requires nice manipulation for its detection; but if we employ a number of pairs of those metals, properly arranged in a group, we accumulate the power to a high degree of intensity, sufficient even to produce sparks and charge glass. When thus arranged, they constitute an instrument called the *dry electric column*; the principles of which I will now attempt to explain.

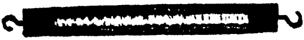
When two pairs of metals, A and B, are placed in such a manner, with respect to each other, that the positive surface of A be directly opposite the negative surface of B, having only a thin film of air between them, the previous electro-equilibrium of each pair will again be disturbed; for the accumulated fluid on the *inner* positive surface of A will polarize the thin film of air, and thus cause it to exert a greater electric pressure on the vicinal *negative* surface of B than that to which it was previously exposed: and no corresponding pressure taking place on the exterior or positive surface of this latter pair, its fluid will be urged in that direction, and consequently the accumulation of the fluid on that surface of B will be increased. The disturbance of the fluid in A arises from the electric pressure on its inner or positive surface being diminished by the vicinal negative surface of B, without any corresponding diminution of pressure on its outer surface, the first effect of which is a movement of the fluid in A towards B. It therefore appears that the fluid, in both pairs, moves in one and the same direction, and that the ultimate result is a new equilibrium in the group, in which a more powerful electro-polarity is established than can be displayed by either pair alone.

It will now appear very obvious that if a third pair C, were to be added to A and B, the electro-polarity at the extremities of the series would become still greater than that displayed by a group of two pairs only; and for the same reason, every additional pair would cause an increase of polarity in the series, which when extended to about one hundred pairs would be sufficiently powerful to affect electroscopes and put light pendulous bodies into motion.

The electro-polarization of bodies may be enhanced either by augmenting the disturbing force, or by lessening the resistance of the surrounding mediums. The latter circumstance is usually resorted to in the construction of the electric column, in which discs of dry paper, instead of films of air, form the intermediate substance between the metallic 1

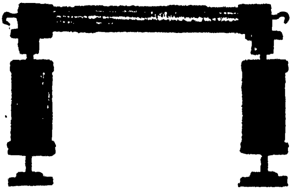
M. Marechaux was the first philopsoher who employed paper in the dry electric column. The metals in M. de Luc's colums were discs of thin zinc, and of Dutch gilt paper of about an inch diameter; the gilt side of the paper being in contact with the zinc in every pair. The series was strung upon a silken thread, which passed through the centre of the whole, and then placed in a glass tube furnished with brass caps and hooks at its extremities, as represented by Fig. 104.

Fig. 104.



When one extremity of the pile is held in the hand, and the other to the cap of an electroscope, the gold leaves immediately diverge, indicating the electric character of the pole in contact with the instrument. Or the column may be placed horizontally on the caps of two gold leaf electroscopes, as represented by Fig. 105. In this case both instruments indicate electric action in the extremities of the column, the one positive and the other negative. By a series of 20,000 pairs the late Mr. Singer was enabled to charge Leyden jars by a moment's contact. By the employment of coated talc, instead of glass, I find that an extensive surface may be charged by a dry pile of 10,000 pairs.*

Fig. 105.



The principal consideration, in this place, is the perpetuity of the action of the dry electric column; which, when properly constructed, and securely guarded against moisture, appears to be possessed of interminable electric powers. At the time when philosophers, especially the chemical philosophers, could form no idea of the changes in the electric characters of bodies but such as emanated from *oxidation*, the most fruitful of all sources of error in this branch of physics, the dry electric column shared the same fate as the wet pile of Volta, in having its action placed to the credit of oxidation. Even when

* The whole process of forming *dry electric columns* with a variety of their interesting applications, will be clearly described "Cyclopædia of Electricity and Magnetism," shortly to

it was found that the dry column would retain its action for several years, a *slow* oxidation of the metals was the only explanation that could be given for the display of its electricity. This idea became so fashionable eventually, that it became the basis of the prevailing hypothesis which, to this day, is strongly contended for by certain philosophers now in controversy on this interesting topic.

To those who have paid attention to the succession of steps that I have hitherto taken in tracing the electric action from metal to metal in each individual pair, and also that action which is due to a series of pairs, as associated in the dry electric column, there can appear no reason whatever for calling into the hypothesis an oxidation of the metals; but, on the contrary, since purity of the metallic surfaces is essential to the development of those peculiar arrangements of the electric forces which I have described, and which form the very soul of the dry electric column, and since the introduction of an oxidizing process would soon pollute those metallic surfaces, and ultimately destroy every particle of their metallic character, nothing can appear more evident in physical science, than that *a perpetuity of electric action in the dry pile, depends upon a continuance of the purity of the metal.*

The inference thus drawn from the simple principles of electricity, is that which alone can direct the *practical* electrician with certainty to the construction of a *permanently* acting electric column. It is conformable with all experience, and, I believe, is now acted upon by those who make the best apparatus of this kind. Every care is taken to insulate the elements of the column from the atmospheric air, and from every kind of moisture; which objects, when properly accomplished, secure the permanency of the electric action.

As the whole action of the column depends upon electric pressures, any change in the external electric state of the atmosphere will necessarily affect the action of the apparatus. It is on this account that it becomes an indicator of those fluctuations of atmospheric electrical pressure which are almost continually going on; and, as these fluctuations are occasioned by change of temperature, humidity, evaporation, winds, barometric pressures, clouds, &c., and frequently by several of these causes at the same time, there can be no astonishment excited at M. De Luc's failures in attempting to apply the electric column as a meteorological instrument. The frequent changes in the activity of this apparatus, first noticed by that ingenious and indefatigable philosopher, are exceedingly curious and interesting. He attached to the upper pole of a vertical electric column, a bent wire, which reached downwards as low as the lowest pole, and terminated in a small brass ball. Between this ball and the lower pole of the column was suspended, by a silken fibre, a light gilt pith ball; the whole being covered by a glass shade, as represented in Fig. 106. The pendulous ball vibrates between the lower pole of the column and the opposite ball, carrying the electric fluid from one to the other continually. When the atmosphere is highly charged with the electric fluid the ball vibrates with great rapidity; it also moves rapidly in a warm room, or any warm unattenuated atmosphere, but languishes very materially in a moist atmosphere.

Fig 106.

When two columns are arranged as in Fig. 107, having a bell attached to each lower pole, the one positive and the other negative, the pendulous brass ball plays between them, and rings both bells; thus warning the observer when any material atmospheric electrical change is taking place. Apparatus of this kind have kept in play for upwards of twenty years, and are still as active as at first, and there can be no satisfactory reason shown why they should ever cease to display their electric forces.

Fig. 107.

The difference of electric action of bodies when under the natural electric pressure, so beautifully illustrated by Volta's copper and zinc plates, and still more so by the dry electric column, is not limited to *different kinds* of metal, for it is manifested on one and the same piece: nor is this difference confined to metallic bodies only. With respect to the metals, their natural electrical character has much dependence on their crystalline structure, and also on the compactness of their particles and polish of their surfaces. On these delicate enquiries I shall have to treat somewhat extensively in my lectures on voltaic electricity, and I will close this course of lectures with a most beautiful experiment illustrative of the difference of the natural electric characters of non-conducting bodies, and also the difference between a *positive* and a *negative* electric action on those bodies.

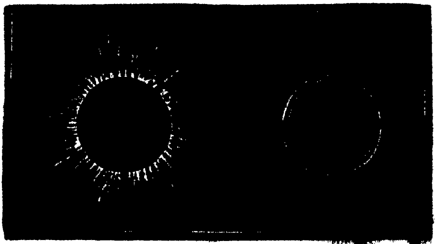
For this purpose I employ a smooth cake of pitch, a Leyden jar, a small cylindrical tin can with a glass handle, and a mixture of sulphur and red lead in a spring puff or bag.

I first place the can upon the pitch cake, and when the jar is charged at the prime conductor, I present its ball to the can, to which it delivers a spark. This electric fluid immediately spreads over the can, and a portion is communicated to the surface of the pitch cake, which renders it electro-positive. The can is now removed by its glass handle, neutralised by a touch with the finger, and then set down on another part of the cake. I next electrise the jar by placing its ball in contact with the negative conductor, and then bring it into contact with the can. In this case the can transfers a portion of its natural share of fluid into the jar, and thus gives an opportunity for a small portion to leave the surface of the cake, and enter the [illegible] rim of the can. Consequently, when the can is removed, the place it left on the cake is electro-negative.

The pitch cake, thus differently electrized on two parts of its surface, is now placed in a vertical position, and whilst standing at some distance from it I project the powder from the puff towards it, until I observe the two electrized specks partly covered; the positive speck with the sulphur, and the negative one with red lead: the two powders being separated from each other by the different electric actions of the two parts of the pitch surface. Hence we learn, in the first place, that although these powders were intimately mixed with each other in the bag, they were absolutely in different electric conditions.

The figures which these powders assume on the surface of the pitch are truly beautiful, and to the theoretical electrician are of the most interesting character. Fig. 106. will give some idea of these figures, but nothing short of real observation of the results of the experiment can convey to the mind, its true beauty and importance. Even to a superficial observer, the ramifications of the sulphur on every side of the electrical nucleus, is highly curious and pleasing; whilst the watchful philosopher observes the particles of sulphur repelled on every side, and creeping outwards in multivious formed radial lines, which expand the electro-stellate picture before his eyes. Inwards, also, the particles of sulphur keep advancing, until the electro-positive forces on opposite sides of the centre balance one another, and then the inward advances cease, and a vacant central speck remains.

Fig. 106.



Turning the eye to the negative ring, it remains the same from first to last, no motions of particles are observed, nor has there been any of those radial shoots such as the sulphur displays. Such results are strictly in accordance with the theoretical principles kept in view during the whole series of illustration in these lectures. They not only demonstrate the different electric actions of different bodies, but stamp the mind with a conviction that the whole series of electrical phenomena are the consequent display of the inherent attributes of a peculiarly active physical agent, perfectly distinct from all other kinds of terrestrial matter.

THE END.

P. GRANT, PRINTER, MANCHESTER.