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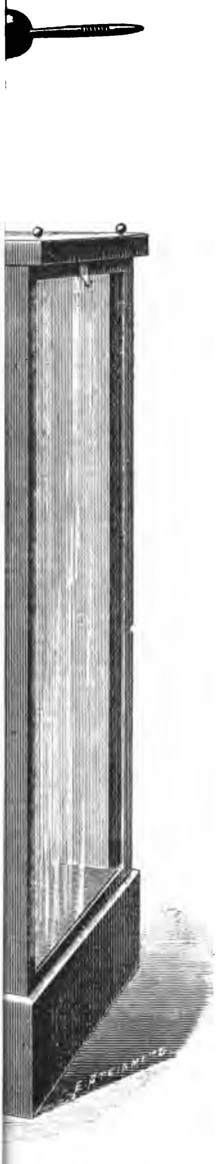
ELECTRICAL INFLUENCE MACHINES.



Frontispiece.

ELECTRICAL INFLUENCE MACHINES.

A FULL ACCOUNT OF THEIR HISTORICAL DEVELOPMENT,

AND MODERN FORMS, WITH INSTRUCTIONS

FOR MAKING THEM.

BY

JOHN GRAY, B.Sc.

ASSOCIATE OF THE ROYAL SCHOOL OF MINES; ASSOC. INST. ELECTRICAL ENGINEERS; MEM. PHYSICAL SOCIETY.

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PREFACE.

ELECTRICITY has now become, in the words of a distinguished physicist "a truly imperial science," in which physics and chemistry may be said to occupy the position of mere subordinate provinces. Clerk Maxwell, Hertz, and others have shown that the medium which transmits the waves of light is identical with that which conveys the waves of electric energy. The waves of light, in fact, differ only in their extreme minuteness, and their extreme rapidity from the electric waves produced by an alternating current dynamo machine or an induction coil, and the flame of a candle or of a gas jet, in which electric oscillations are caused by the impact of atoms has as good a claim to be called electric light, as the glow of the incandescent carbon filament or of the electric arc, in which identical oscillations are generated by the passage of the so-called electric current.

These great generalizations have opened up for the physicist a wide and new field, in which much experimental work of the greatest interest is waiting to be done. Static or high-tension electricity, owing, perhaps, to the prominence which has been given to the dynamical form, by its recent and important commercial applications has not lately received from investigators its fair share of attention. The study of this neglected branch of science ought to receive an additional impulse from the fact that in the latest forms of the Influence Machine, we possess generators of high-tension electricity both simple and convenient, less expensive than the induction coil, and almost equally reliable.

In the present work an attempt has been made to bring together in one volume, all that is useful and interesting about Influence Machines. In the first part is given a sketch of the elements of static electricity sufficient, it is hoped, to make the reader independent of a text-book on the subject, and at the same time, in such a form as will enable those with little mathematical knowledge to understand the nature of electrical quantities. Sir W. Thomson's Electrometers have been described in detail, so that amateurs, and others having the means, may construct them for themselves. This part of the book will be found useful for attaining an exact knowledge of the action of the Influence Machines described in the pages which follow, and may also show makers where they can be improved. In the second part, the history of the Influence Machine, from its earliest known form up to its modern forms, has been given. This, which has been characterized by Professor Ayrton as "a Darwinian development of a Darwin machine," will be found to be a very interesting example of the evolution of machines. The construction and working of all the important machines, have also been described in this part of the book. In the last part, instructions derived from the best available sources have been given how to make the machines most commonly used. It is hoped that this will be found to contain all the information required by instrument makers and amateurs who may wish to make these machines.

For permission to use illustrations from their books, I have to thank Sir W. Thomson and others. I have to thank Mr. Wimshurst for much valuable practical information, and for drawings with dimensions of his excellent machines. I have also to acknowledge my indebtedness more especially to the following works:—"Die generatoren hochgespannter Elektricität by Wallentin"; "Die Lehre von der Elektricität by Wiedemann"; "Papers on Electrostatics and Magnetism, by Sir W. Thomson," and a "Lecture on Influence Machines in the proceedings of the Society of Telegraph Engineers, by S. P. Thompson."

January, 1890.

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GENERAL SKETCH OF THE PHENOMENA AND LEADING PRINCIPLES OF STATIC ELECTRICITY.

ELECTRICAL INFLUENCE MACHINES.

CHAPTER I.

THE EXPERIMENTAL DATA OF STATIC ELECTRICITY.

If a glass rod be rubbed with a piece of flannel held in front of a fire till it is warm and dry, it will be found that the glass rod has acquired the property of attracting any small light bodies, such as bits of paper, which may be in its neighbourhood; and it will be further observed, that the small bodies, after adhering for a short time to the glass, will be repelled. If a stick of sealing wax be rubbed with the dry flannel, precisely similar phenomena will be observed; that is to say, the bits of paper near which it may be brought will be first attracted to the sealing wax, and after a little repelled.

A further experiment, however, will show that the properties that have been acquired by the glass rod and the sealing wax when rubbed by the flannel are not identical.

Two pith balls *A* and *B*, which are preferably covered with tinfoil, are suspended by silk threads from a stand, as shown in Fig. 1. A third pith ball *C* is carried on the end of a glass rod. If we touch the pith ball *A* with a piece of glass excited as explained above, and the pith ball *B* with a piece of sealing wax similarly excited, and, finally, the pith ball *C* with the excited piece of glass, then it will be found that *C* will repel *A*, but will attract *B*. If, on the other hand, *C* be touched with a piece of excited wax, it will attract *A* and repel *B*.

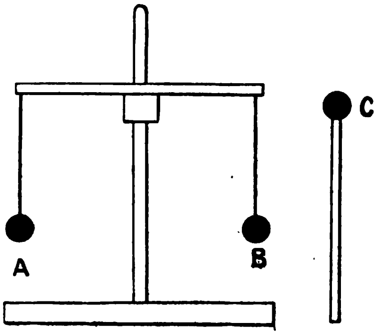


FIG. 1.

Pieces of glass or sealing wax excited in this way are said to be *electrified*, and the pith balls which by contact have acquired properties similar to those of the originally electrified bodies are said to be *electrified by conduction*.

The experiment just described appears to show that glass and sealing wax when rubbed with flannel are differently electrified; having opposite properties, which they communicate to the bodies with which they are brought in contact. A body which has a similar electrification to a piece of glass rubbed with flannel is said to be *positively* electrified, a body which has a similar electrification to a piece of sealing wax rubbed with flannel is said to be *negatively* electrified. The law of electrical attraction and repulsion may be deduced from the above experiment, and is usually stated as follows:—

Bodies similarly electrified, whether positively or negatively, repel one another.

Bodies oppositely electrified attract one another.

If we electrify one of the two pith balls suspended from the stand in Fig. 1 with a positive charge, the other ball being without any charge, then touch both simultaneously with a piece of thin metallic wire supported on a glass handle, it will be found after removing the wire that both the balls are charged positively. This may be tested by imparting a charge, positive or negative, to the carrier *C*, and noting the attraction or repulsion.

The success of the experiment will be found to be independent of the length or shape of the wire, and will be equally good with copper, iron, lead, or any other metal. But, if we make use of a thread of glass or of shellac to connect the balls, it will be found that no electrification will have been transferred from the first ball to the second.

Bodies may therefore be divided into two classes: *conductors*, or those which transmit the electric discharge, and *non-conductors*, or those through which the electric discharge does not take place. In electrical experiments, those conductors the charge of which we wish to maintain constant must be supported by non-conducting materials. Pillars of glass, ebonite or gutta percha may be used as supports, or the conductor may be suspended by a white silk thread. Solid non-conductors, when employed for this purpose, are called insulators. Copper wires are sometimes lapped with silk, and sometimes inclosed with a sheath of gutta percha, in order to prevent them being in electrical communication with other bodies. They are then said to be *insulated.*

The metals are good conductors; air, glass, resins, gutta percha, caoutchouc, ebonite, paraffin, are good insulators; but all substances resist the passage of electricity, and all substances allow it to pass, though in exceedingly different degrees.

The class of substances which we have called non-conductors or insulators are sometimes denoted by the name of *Dielectrics.* They are called insulators because they do not allow a current of electricity to pass through them. They are called dielectrics because certain electrical actions can be transmitted through them. This function of insulators or dielectrics will be explained more fully when we come to treat of Influence and Electrical Theory.

Besides the attractions and repulsions of electrified bodies for one another, we find by experiment that an electrified pith ball, whether electrified positively or negatively, will attract a neutral pith ball. The usual explanation of this is that the originally neutral body becomes itself electrified in presence of the electrified body. By using a long cylindrical conductor we can show that it is not, as in ordinary cases of electrified conductors, uniform, but that the electrification is of different kinds in different parts. In Fig. 2 *A* and *B* are insulated conductors. The body *A* is positively electrified. If the neutral body *B*, which is of a long cylindrical shape, be brought near to the body *A*, without touching it, on testing with an electrified pith ball, (employing an apparatus like that in Fig. 1), it will be found that there is negative electricity at the end next to *A*, and positive electricity at the other end. The experiment points to a law for electricities, similar to that which we have already shown to hold for electrified bodies, viz., unlike electricities attract, and like electricities repel one another.

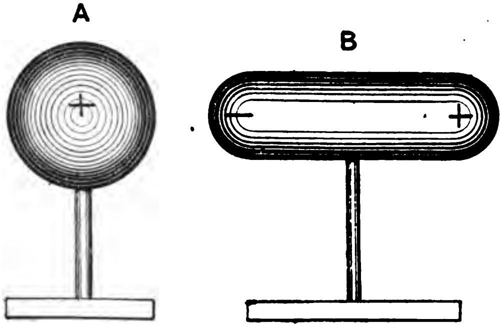


FIG. 2.

The distribution or density of the electricity at different parts on the surface of insulated conductors is a matter of the greatest interest, and has been the subject of numerous experiments. In order to carry out experiments on the distribution of electricity on conductors, we require some means of measuring the electric density, that is, the quantity of electricity on a unit surface, for example, on a square inch or centimetre, at any particular part of the surface of the conductor. The *proof plane* was invented by Coulomb for the purpose of removing a small charge from any part of the surface of a conductor. It consists of a small circular metallic plate *B*, Fig. 3, mounted on a handle *A* of glass or other insulating material. The plate *B*, which may be of unit area, is applied so as to coincide with any particular part of the surface of the conductor where the density is to be tested. On removing the proof plane, it brings with it a quantity of electricity proportional to the density of the charge at that point. To measure this quantity, or at least to compare it with other charges, Faraday's cage method may be used. A hollow insulated conductor *C*, Fig. 3, is mounted on an insulating stand. The outside of *C* is connected with one electrode of a Thomson's quadrant electrometer, *E* (to be described further on). On introducing the plane *B* with its charge into the hollow conductor *C* to a sufficient extent, the deflection of the needle of the electrometer becomes constant, and is a measure of the charge on the proof plane. One or more additional charged planes may be introduced into the cage at the same time, and each will independently pro-

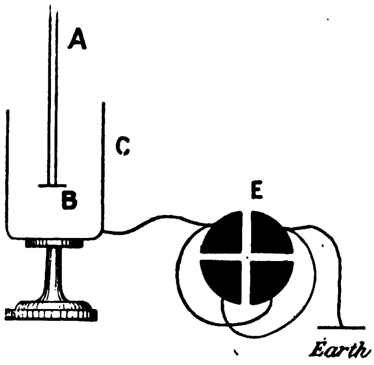


FIG. 3.

duce its effect. It is obvious that by this apparatus electrical densities at different parts of a conductor may be compared.

Gray and White concluded from an experiment with two cubes of oak, one hollow and the other solid, that it was only the surface of the cubes that attracted. These experiments pointed to the conclusion that electricity resides entirely on the surface of the conductors. To verify this principle Coulomb made the following experiment. A hollow sphere of metal, Fig. 4, with a perforation large enough for the insertion of a proof plane, was insulated and electrified. He found by means of the proof plane no sensible trace of electricity inside, except near the edges of the opening, and hence we may conclude that if the sphere had been completely closed there would have been no electricity inside the sphere.

FIG. 4.

The classical experiment of Biot confirms the result obtained from Coulomb's experiment. An electrified spherical conductor *A*, Fig. 5, is supported on an insulating stem *D*. Two hollow hemispheres *B* and *C*, fastened to insulating handles *E* and *F*, are made to fit on each side of the sphere *A*, so that when

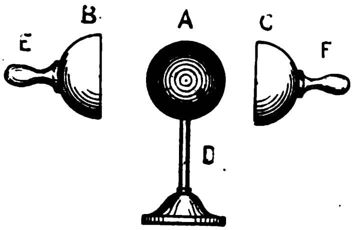


FIG. 5. BIOT'S EXPERIMENT.

brought together they completely envelop the sphere *A*. If *A* is strongly electrified, so that when placed in the electrical cage it will give a considerable deflection, and the hemispheres *B* and *C* are then closed upon it and removed, it will be found on again testing in the cage that all the electricity has left *A*, and passed on to *B* and *C*.

The density of the electricity at different parts of the surface of a conductor depends on the shape of the conductor. If we electrify a sphere, and test the electrical density at two points of its surface, experiment will show, as would be expected from the symmetry of the sphere, that the electrical density is the same at any two points. But if we test an ellipsoid or egg-shaped conductor, we shall find that the density is not the same at different points, as in the case of the sphere, but greater at the sharp ends than at the equator, (as shown by the dotted line in Fig. 6) and the ratio of the densities increases indefinitely as we make the ends of the ellipsoid sharper and sharper. This leads us up to a principle of great importance in electrical distribution, namely, that the electrical density is very great at any pointed part of a conductor. If we double the charge on any conductor, the densities at all different points will increase in the same proportion. The density at any point of a conductor is proportional to the whole charge on the conductor, or, what is the same thing, to the

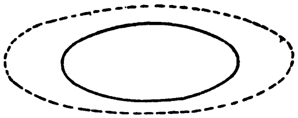


FIG. 6.

average density. Electric force is the force with which electricities or electrified bodies attract or repel each other, and Coulomb has done for its laws what Newton has done for the laws of gravitation. Coulomb's experiments were made with the torsion balance. It is unnecessary here to describe these experiments in detail; it will be sufficient to give the statement of the law which he deduced from his experiments. The Law of Electric Force is as follows: If we have two points, one having a charge of electricity whose amount is q, and the other a charge whose amount is q^1, and situated at a distance d from one another, the force between them acts in the straight line joining the points, and is proportional to $\frac{qq^1}{d^2}$.

It is important to observe that the above law holds for points, not planes.

By means of this law the unit of electric quantity can be defined in a satisfactory and practical manner. This unit may now be stated to be that quantity of positive electricity which, when collected in a point, repels with unit of force an equal quantity similarly collected into a point at unit distance from the former. If we take the centimetre, gramme, and second as our units of length, mass, and time, the unit force will be that force which in a second generates in a gramme of matter a velocity of a centimetre per second.

CHAPTER II.

A WORKING HYPOTHESIS OF THE ELECTRIC FIELD.

IT is of the greatest importance that a student of any branch of electrical science should have correct and clear ideas of the various electrical magnitudes he may meet with, and of their relations to one another. This object is best attained, we venture to think, not by means of the ordinary mathematical definitions, but by means of some physical analogy or working hypothesis of the nature of the Electric Field. For example, one may have at one's finger ends the mathematician's definition of the potential at any point in an electric field, viz., the amount of work done on unit of electricity in bringing it from an infinite distance to the given point, and yet have such hazy notions on the subject as to be unable to explain simple electrical phenomena, such as the well-known fact that points fixed on an electrified conductor will discharge it, though they are at the *same* potential as flatter parts of its surface from which no discharge takes place. The distinction between potential and electromotive force, and between quantity, density, and capacity, may be cited as further illustrations of the difficulties to be met with in the study of this subject. To diminish or to remove these difficulties we shall endeavour in this chapter to furnish a mental representation of a physical condition of the dielectric medium, which will account for the results of experiment; but readers must be on their guard against allowing it to prepossess the mind as to what may be the complete ultimate explanation.

According to modern views, electric forces on bodies are accounted for by the action of a medium called the *dielectric*, in which the bodies acted upon are immersed, the theory of action at a distance being now considered untenable. Our object is to picture such a structure of this medium as will account for observed electrical phenomena, and to point out what corresponds to electric potential, quantity, capacity, and other electric magnitudes. It will be advisable first to describe the method of subdividing the electric field by tubes of force and equipotential surfaces employed by Faraday, Maxwell, and others.

A *line of force* is a line drawn in the electric field whose tangent at any point indicates the direction in which the electric force acts upon an electrified particle placed at that point.

If we suppose that an insulated electrified spherical conductor is placed at the centre of a spherical chamber, an electric field is produced in the air space between the conductor and the walls of the chamber. In this case radial lines drawn from the centre of the conductor to the walls of the chamber will represent lines of force. If the surface of the sphere be subdivided into a number of small areas of such size that each of such units of area contains a unit quantity of electrification or electricity, and lines of force be drawn from every point of the periphery of the unit area, *a tube of force* will be produced. The number of tubes of force will evidently denote the quantity of electrification on the surfaces which they cut.

The potential of the conductor we will assume to be higher than that of the surrounding space. Let a number of surfaces be drawn in the electric field, such that every point in a given surface is at the same potential, and the potential of each differs from that of the surface next to it by one unit, these surfaces will cut the tubes of force at right angles, and the whole field will be divided up into small cells, between the ends of which there will be a difference of one unit of potential, and on the ends of which there will be unit quantity of electrification. These surfaces are called equipotential surfaces. In the case we have assumed the tubes of force will be conical, and the equipotential surfaces will be spheres, concentric with the spherical conductors; with less symmetrical arrangements the shape and dimensions of the tubes of force and equipotential surfaces will be less regular. Each of the *electric cells* contains one unit of the total energy in the electric field, and the number of the cells will denote the total amount of energy, or work stored up in the electric field.

We are now in a position to form a picture of the structure of the electric field which will account for the observed phenomena of statical electricity. Imagine the tubes of force to be material elastic tubes. Across each of these tubes is fixed a number of elastic diaphragms, each diaphragm coinciding with the equipotential surface where it cuts the tube. The mathematical electrical cells are now material electric cells with elastic walls; the sides of the tubes are, however, supported by the adjacent tubes, so that only the elastic diaphragms or ends of cells can be displaced. Each of these cells is now filled with an incompressible fluid, and the structure of our dielectric medium is complete. The incompressible fluid corresponds to what we call *electricity*, which, however, must be carefully distinguished from *electrification*, which is the electricity displaced at the terminal surfaces or poles of the electric field when under the influence of electrical stress. The term *electricity* or *charge of electricity* is, however, often used to denote electrification in treating of static electricity. This electrical fluid or electricity would appear not to be the luminiferous ether, but some fluid of a higher degree of tenuity. The substance of the elastic tubes and diaphragms would appear to correspond to a combination of the dielectric substance or material with the luminiferous ether.

A *dielectric* or *insulator*, as we have seen, is a substance in which electricity is capable of receiving a small displacement, but which does not permit of its free passage except by rupture of its elastic diaphragms. A *conductor*, on the other hand, is a body in which there are no elastic diaphragms, or, if there are any, they have so weak an elastic resistance as to allow the electric fluid to pass through the body with little or no resistance. The insulated electrified spherical conductor is filled with the electric fluid, which can flow freely through any part of its substance. According to the principles of hydrostatics, the pressure of electricity at all points in a conductor will be the same. It is proved by experiment that the potential at any point inside or on the surface of a conductor is the same; hence we naturally assume that potential corresponds to pressure in our hypothetical electric fluid. The further development of the theory will be found to support this view.

Potential.

Assuming that potential is the pressure of the electric fluid or electricity in the elastic cell as just described, we shall endeavour to establish a few propositions about it. In the first place we shall consider the mechanical laws which govern the changes of a single electric cell. The relation between the distortion or amount of bending produced in an elastic body by a force applied to it is regulated by a well-known law called Hooke's law, which stated shortly is: *The distortion produced in an elastic body is proportional to the force which produces it.* We have a good example in the common spring balance. If one pound stretches the spiral spring one inch, two pounds will stretch it two inches, and so on.

Let *A*, Fig. 7, be a cylinder in which is fitted a piston *B*, whose area is one square inch. The piston *B* is supposed to work without friction, but is connected with a crossbar *D* on the top of the cylinder by a spiral spring *C*. Now suppose that this cylinder is immersed in an ocean of incompressible fluid, and that through the opening *E* in the side liquid is pumped into the cylinder. The spring will be compressed by the rise of the piston, and the movement of the piston will be a measure of the difference of pressure per square inch between the fluid inside the cylinder and the fluid outside the cylinder. The amount of work done in forcing the fluid into the cylinder will be equal to the displacement of the piston multiplied by the average pressure, *i.e.*, half the final pressure, [since the pressure starts from zero and increases uniformly to a maximum]. This will be found to be a useful rule for calculating the energy stored in the dielectric.

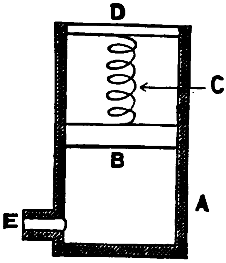


FIG. 7.

If, in investigating the laws of potential, in any case we require a cylinder with a piston of larger area, we are to consider it made up of the required number of these unit cylinders, each square inch of area having its spiral spring of unit strength. On this assumption a given difference of pressure per square inch on the opposite sides of the piston will always produce the same displacement of the piston, whatever its area. The strength of the unit spring will be the elastic strength of the piston or diaphragm.

We are now in a position to describe the unit electric cell. Let *A A*, Fig. 8, represent the sides of a tube of electric force; B_1 B_2 elastic diaphragms corresponding to the pistons supported by a spiral spring on each square inch, as already described, and coinciding with the equipotential surfaces.

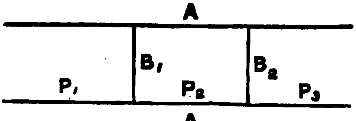


FIG. 8.

Now let us suppose that the pressure at P_1 is greater than the pressure at P_3; the diaphragms will be displaced as diagrammatically represented at Fig. 9. The fluid between the diaphragms B_1 and B_2 being incompressible, the displacement of B_2 must be equal to that of B_1.

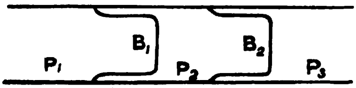


FIG. 9.

The pressure in the cell P_2 will be the pressure in P_1 minus the elastic force of B_1, and that in P_3 will be the pressure in P_2 minus the elastic force of B_2. Thus we see that the pressure in each cell is less than that in the one preceding it, by the elastic force of the diaphragm which separates them. The potential at any point in an electric field or strained dielectric is the pressure in the cell in which the point lies. It may be well to explain here that the elementary electric cell, or what corresponds to it, is probably of exceeding smallness, and it may be assumed that the unit cell which we have found it convenient to use for the purpose of mathematical investigation is made up of a very large number of these.

A *conductor*, as we have already explained, is a body through which the electric fluid can flow with little or no obstruction. Its bounding surface will be the first skin of elastic diaphragms in the dielectric surrounding it. The conductor may, therefore, be looked upon as an elastic bag filled with the electric fluid. If a conductor should be brought into such a position as to inclose any number of cells of a dielectric, the pressure of the fluid in all the cells inclosed will be equal, though formerly unequal, because the fluid can now flow freely from one to the other.

Let us now consider what will take place if we place an insulated electric conductor in an electrically strained

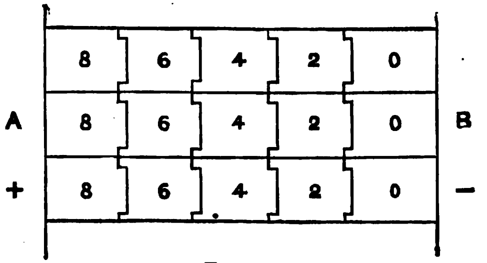


FIG. 10.

dielectric. We shall assume, in the first place, that the conductor is cylindrical in shape, and that its axis is placed in the direction of the lines of force. We shall also assume that the lines of force are parallel, and that the conductor is of such a length as to annihilate one half the number of elastic diaphragms between the poles (*i.e.* the terminal conducting surfaces) of the electric field.

Fig. 10 is a diagrammatic representation of such a field as we have been describing before the conductor has been introduced. *A* is the positive pole of the field, at a potential represented by 8; *B* the negative pole, assumed to be at zero potential. The potential is assumed to fall uniformly; the figures in each cell representing the potential in that cell, and the stretch on the diaphragms the *E. M. Fs*, between the cells.

Fig. 11 represents the condition of the same field when a conductor *C* is introduced into the middle tube of force, so as to annihilate two of the diaphragms. As two diaphragms instead of four have now to sustain the

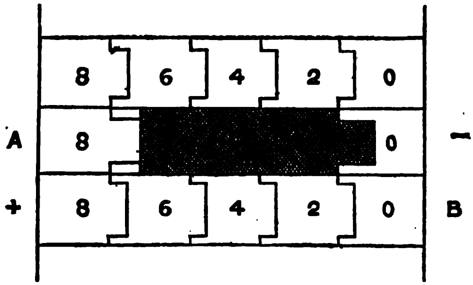


FIG. 11.

whole difference of potential, they will be stretched to double the extent. The potential of the conductor, it will be observed, is now 4. Let us compare its potential with that of the surrounding field. At the end nearest *A* (the positively electrified pole) it is lower than the surrounding field, and therefore will exhibit negative electrification; at the end furthest from *A* it is higher than the surrounding field, and therefore will exhibit positive electrification. We have here the explanation of the well-known phenomena of *Electric Influence*, or, as it is sometimes called, *Electrostatic Induction.* It is often stated in text-books on Electricity that under the influence of an electrified conductor a separation of the electricity or electricities in a neutral conductor takes place. It will be obvious, if the above explanation is correct, that no such separation takes place. The potential throughout the conductor is the same, the difference, or separation so-called, is in the dielectric which surrounds it. Another diagram may be given, which will exhibit more accurately the condition of the electric field.

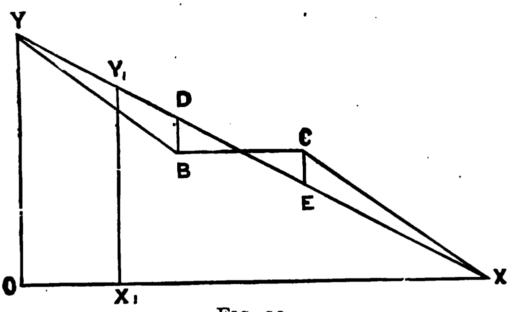


FIG. 12.

Let *O X*, Fig. 12, represent a line of force drawn between the two poles *A* and *B* (see Fig. 11) of the electric field; *O Y* drawn at right angles to *O X* represents the potential of the plate *A*; the potential of the other pole *B* being zero. A straight line *Y X* is the diagram of potential between the two poles; the potential at X^1, for example, is represented by $X^1 Y^1$. The diagram of potential in the tube of force containing the conductor *C* is *Y B C X*, the part *B C* in the conductor being parallel to OX. If a pair of pith balls be suspended from the end B of the conductor, they will take the potential of B. The potential of the field unaffected by the conductor will be greater than that of B by an amount represented by the line BD; therefore the pith balls will diverge as if charged with negative electricity of a potential equal to BD. In the same way, pith balls suspended at C will diverge with positive electricity of potential represented by CE. In fact, the so-called separation of the electricities under *influence* will appear to have taken place. Positive and negative electrification is simply positive or negative electro-motive force with reference to the surrounding field.

Discharging Effect of Points.

The diagram of potential, Fig. 12, is for parallel tubes

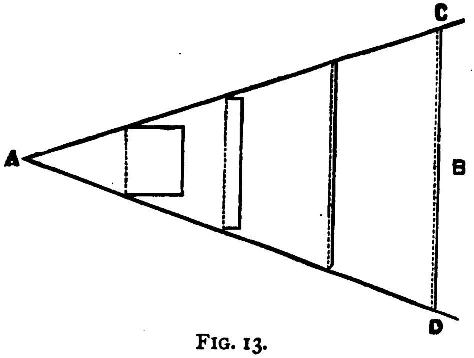


FIG. 13.

of force, *i.e.*, for a field where the decrease of potential is uniform, and YX is therefore a straight line; the YX, however, will usually be a curve. Take the case of a conical tube of force, Fig. 13, where a point forms one pole of the electric field and a plane or spherical surface the other pole. Owing to the smaller area of the elastic diaphragms near the apex, the distortion will be proportionally greater, as the same quantity of electricity has to be displaced at each diaphragm. Fig. 13 roughly indicates the distortion of diaphragms at different distances.

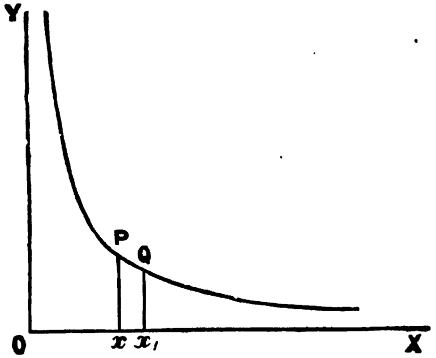


FIG. 14.

It can easily be seen that the distortion of the diaphragm will be inversely proportional to the square of its distance from the apex *A* of the cone, the areas being proportional to the square of their distances from the apex. The curve of potential *F C*, Fig. 14, will in this case be a rectangular hyperbola. The following considerations will show that this is the curve. The steepness of the curve, or the inclination of a line tangent to it at any point, is represented by the difference of height between two successive ordinates, say $P x$ and $Q x_1$, divided by $x x_1$, the distance between them. This inclination of the tangent in the diagram represents, therefore, the rate at which the potential decreases, *i.e.*, the *E. M. F.* which, as we have seen, is the stretch on the elastic diaphragm of the electric cell. The stretch on any diaphragm in a conical tube of force has been shown to be inversely proportional to the square of its distance from the electrified point; therefore, in the diagram of potential for this case, the inclination of the tangent of the curve must be inversely proportional to the square of its distance from the origin *O*. This is known to be a property of the rectangular hyperbola.

If the apex of the cone, Fig. 13, be a mathematical point, the *E. M. F.* at *A* will be infinite. This explains the *discharging effect of points* on a conductor, for the diaphragms of the dielectric will burst if the distortion, *i.e.*, the *E. M. F.*, exceeds a certain limit, and the electricity will flow away in the form of the well-known *brush* discharge.

Equation of Potential.

The equation for determining the potential due to an electrified point at any given distance from the electrified point may be deduced from the curve or diagram of potential shown at Fig. 14. Let *P* be the given point, at a distance $A x$ from the electrified point. The potential at *P* is $P x$. By a well-known property of the hyperbola $P x \times A x =$ constant, therefore $P x$ [potential at $P] = \dfrac{\text{constant}}{A\,x}$, *i.e., the potential at any point is inversely proportional to its distance from the electrified point.*

Attraction and Repulsion.

Under certain circumstances it is found, as we have seen, that certain bodies are attracted or repelled by electrified conductors. We shall now attempt some explanation of this in terms of the elastic cell hypothesis. First, we shall consider the case of a neutral conductor placed in an electric field, in which there is a uniform *E. M. F.*; such a field, for instance, as will be produced between two parallel plates of large size, of which one has a positive charge and the other is connected to the earth. Fig. 11 shows a diagrammatic section of such a field; the positive plate *A* is charged to a potential of say 8; the negative plate *B*, is supposed to be connected to the earth, and is therefore at zero potential. The *E. M. F.*, or stretching force on the diaphragms, is 2. Three tubes of force are shown, a conductor *C* being placed in the central tube. This conducting body, as we have previously explained, imparts its conducting property to the two diaphragms, thereby increasing the *E. M. F.*, or stretch on the diaphragms in the central tube.

In this theory it is necessary to assume that diaphragms, when just outside the conducting substance of the conductor, adhere to it as a schoolboy's sucker adheres to the wet stone on which it is pressed. It may help us to see the necessity for this assumption if we remember that as a conducting body advances and comes in contact with a stretched diaphragm, it imparts its conducting property to it, the pressure on both sides of the diaphragm becomes equalized, and the diaphragm must consequently seek to return to its neutral position. It cannot in doing so leave the conducting body behind it, as otherwise its pores are closed up; it becomes again non-conducting, and the difference of pressure established between its opposite sides prevents its further movement. Hence we are driven to the conclusion that it adheres to the end of the conductor and exercises a mechanical pull upon it. We shall suppose that the conductor in Fig. 11 is advancing towards *A*. The diaphragm in front of the conductor is under tension, and when it is perforated, or becomes conducting by its absorption into the conductor as it advances, the tension of the diaphragm pulls the body forward. At the same time the posterior end of the conductor is sealed by a diaphragm which is leaving it, but not in a stretched condition, as its pores are not closed till it leaves the substance of the conductor. There is thus the tension of the diaphragm representing a force of 4, pulling the conductor forward, and there is the difference of potential between the conductor and the following cell, also represented by a force of 4, pulling it back. The resultant force acting upon the conducting body will therefore be zero. From this it would appear that there will be no *electric force* on a neutral conductor placed in an electric field of uniform electro-motive force, which, however, we shall see is only true when the body is in the centre of the field. The law, however, may be inferred from the above theoretical explanation, that the *electric force*, or mechanical push or pull, on a body in an electric field is determined by the difference of the *E. M. Fs.* at its two ends. It is not proportional to the difference of the *E. M. Fs.*, but more strictly speaking, to the difference of their squares.

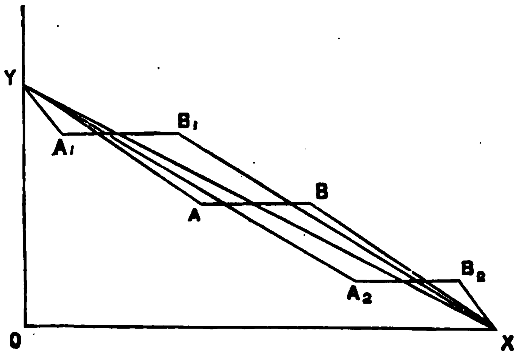


FIG. 15.

Fig. 15 is a diagram which gives a more accurate representation of the conductor placed in the field of uniform *E. M. F.* than that shown in Fig. 11. *O* represents the position of the pole-plate *A*; *X* that of *B*. *O Y* represents the potential at *O*, and the potential at *X* is taken as zero. The straight line *Y X* represents the potential in the field between the two plates, except in the particular tube of force in which the conductor *A B* is placed. The diagram for this tube is *Y A B X* when the conductor is in the middle of the field, $Y A_1 B_1 X$ or $Y A_2 B_2 X$ when $A B$ is near one or other of the poles of the field. There is no resultant force acting on the body $A B$ when the conductor is placed in the middle of the field, because the steepness or inclination of $A Y$ is equal to that of $B X$, these inclinations representing the electro-motive forces at the opposite ends of $A B$. When the conductor is in the position $A_1 B_1$ the inclination of $A_1 Y$ is greater than

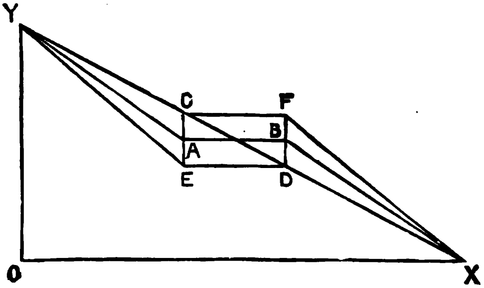


FIG. 16.

that of $B_1 X_1$, and there will be a resultant force towards the positive pole of the field. By similar reasoning, it would appear that when the body is in the position represented by $A_2 B_2$ it will be attracted to the negative pole of the field. With the help of a diagram similar to that in Fig. 15, it is easy to show the effect of giving a positive or negative charge to a conductor, or, what is equivalent, raising or lowering its potential.

Fig. 16 is a potential diagram of an electric field with parallel tubes of force, in which a conductor $A\ B$ is placed, as already described in Fig. 15. Let us assume that the potential of $A\,B$ is increased by an amount $B\,F$ by imparting a positive charge to it ($B\,F$ has been taken so as to bring C to the potential of the surrounding field, merely to simplify the diagram), the potential diagram for the tube of force containing the conductor will now be $Y\,C\,F\,X$. It can easily be seen that the inclination $F\,X$ is greater than the inclination of $Y\,C$, *i.e.*, the *E. M. F.* at F is greater than that at C. The conductor, therefore, when positively charged, will be repelled from the positive pole of the field. This explains the well-known law that *similarly electrified bodies repel one another.* On the other hand, let us suppose that the potential of the conductor is reduced by an amount represented by the line $B\,D$, by imparting a negative charge to it. $Y\,E\,D\,X$ will then represent the potential diagram for the tube of force containing the conductor. In this case we see that the inclination of $Y\,E$ is greater than that of $D\,X$, *i.e.*, the *E. M. F.* at E is greater than the *E. M. F.* at D, consequently the negatively electrified conductor will be attracted towards the positive pole of the field. This explains another well-known law, that *bodies when oppositely electrified attract one another.*

Hitherto we have considered the case of parallel tubes of force; let us now consider the case of conical tubes of force, such as will be produced by an electrified point placed at the centre of a spherical conductor, or at an infinite distance from all conductors. The diagram of potential, as previously shown in discussing the discharging effect of points, will be in this case a rectangular hyperbola. Referring back to Fig. 14, if a small neutral conductor is placed in a field due to an electrified point, it will be seen from the diagram that the *E.M.F.* at the end nearer to the electrified point will always be greater than at the other end. Or if we return to the conception of the elastic conical tube of force shown in Fig. 13, it will be evident that the end of the conductor nearest to the apex of the cone will be in contact with a diaphragm having a greater stretch or distortion than that in contact with the end of the conductor furthest from the apex of the cone, that is, the electrified point. Hence neutral bodies will be always attracted to an electrified point, and obviously the attractive force will be greater the nearer the neutral body is to the electrified point.

Capacity.

A Leyden jar, as is well known, consists of a glass bottle or jar coated inside and outside with conducting substances, such as sheets of tinfoil. It is charged or filled with electricity by connecting the outer coating to the earth and the inner coating to the electric machine, or other source of electricity. It is found that a much greater charge of electricity can be imparted to the inner coating of the jar than if the same surface of tinfoil were placed on an insulating stand at a distance from all other conductors. To understand the explanation of this, we must fix our minds on the dielectric, that is, the glass forming the substance of the sides of the Leyden jar. When a charge is given to the inner coating of the jar, parallel tubes of force pass across the glass to the outer coating, which, being in connection with the earth, is at zero potential. The whole difference of potential has thus to be sustained by the diaphragms of the tubes passing between the inner and outer coatings. These tubes are very short compared with those from a conductor placed, say, in the centre of a room. Hence there is a much smaller number of elastic diaphragms to resist the whole difference of potential, or pressure due to the electric machine, and each of the diaphragms will be stretched to a much greater extent. Now the extent to which the first sheet of diaphragms is stretched is a measure of the total amount of free electricity or electrification on the conducting surface. The diagrammatic sketches, Fig. 17, will show more clearly how the charge in a Leyden jar depends on the thickness of the glass. The thickness of the glass in *B* is double that in *A*. The tube of force in *B* will therefore, as illustrated, have double the number of elastic diaphragms that *A* has. The same difference of potential between the two coatings will have to be supported by two diaphragms in case of *A*, and four diaphragms in case of *B*. Each diaphragm will thus be stretched to double the amount in *A* that it is in *B*. The following law can easily be deduced from the above

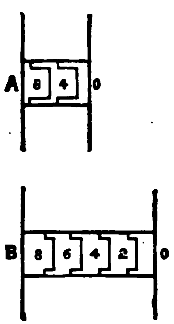


FIG. 17.

explanation: *The charge of a Leyden jar is proportional directly to the potential of the charge, and the superficial area of the coating, and inversely to the thickness of the glass.*

The *capacity* of a conductor is proportional to the displacement of the elastic diaphragms close to the surface of a conductor produced by one unit difference of potential between the two poles of the dielectric. It is propor-

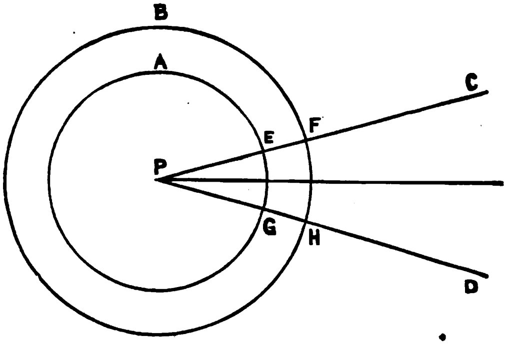


FIG. 18.

tional to the whole charge on the conductor divided by the potential, or, in the Leyden jar, to the surface divided by the thickness of the glass. The *capacity* of a Leyden jar is very large, for the reasons given above.

Consider now the electric capacity in some other simple cases. First we shall investigate the electric capacity of a spherical conductor at an infinite distance from all other conductors. Let *A*, Fig. 18, be the section of such a sphere, neglecting for the moment the other sphere B. The tubes of force of such a sphere will be truncated cones $C\ E\ G\ D$, each extending in the direction of its base to infinity, and springing from an apex situated at P, the centre of the sphere. The capacity of the sphere will be inversely proportional to the elastic resistance of the frustum of the cone extending outwards from $E\ G$ to infinity. To find that elastic resistance, suppose a quantity of electricity placed at the point P. The potential on the surface of A is the pressure due to the elastic resistance of the frustum of the cone extending outwards from $E\ G$. But we have shown by the diagram at Fig. 14 that the potential on A is inversely proportional to its radius, say $= \frac{1}{R_1}$. The capacity is inversely proportional to this, that is, it is proportional to the radius of the sphere. By assuming that the quantity of electricity on a sphere of unit radius with unit potential is the unit quantity, we may state that *the capacity of a sphere at an infinite distance from other conductors is equal to its radius.*

Referring again to Fig. 18, we may calculate the capacity of two concentric spheres, A and B, of radii R_1 and R_2 respectively. We have now to find the elastic resistance of a slice of the cone of the thickness $E\ G$ or $G\ H$. This can be found by subtracting the elastic resistance of the frustum $C\ F\ H\ D$ from the elastic resistance of the frustum $C\ E\ G\ D$. The elastic resistance of $C\ F\ H\ D = \frac{1}{R_2}$ and of $C\ E\ G\ D = \frac{1}{R_1}$, therefore the elastic resistance of the slice $F\ E\ G\ H = \frac{1}{R_1} - \frac{1}{R_2}$ $= \frac{R_2 - R_1}{R_1\ R_2}$. The capacity will be the reciprocal of this, that is, $\frac{R_1\ R_2}{R_2 - R_1}$.

We have discussed above how the capacity of a conductor is modified by the dimensions of the electric field. It has been found by experiment that the capacity of a conductor depends on the nature of the substance of the dielectric. For instance, if glass be substituted for air between two conducting surfaces, the same difference of potential between the two surfaces will impart more than three times the quantity of electricity to the charged conductor. This means in our theory that the elastic diaphragms in glass have only one-third the elastic resistance of those in air, and that consequently the same pressure will produce three times the amount of displacement or stretch of the diaphragms. The displacement of the elastic diaphragms of any substance, compared with that produced in air by the same difference of potential, corresponds to what is called the *specific inductive capacity* of the dielectric.

Quantity and Density.

It only remains now to give the explanation of the terms quantity and density in terms of our hypothesis to complete the list of important magnitudes we meet with in the study of statical electricity. We have assumed in this theory that electricity is an incompressible fluid with which the pores of all bodies are always filled. When an insulated conductor has received a positive charge of electricity, however, the amount of the charge will not be the total quantity of electricity in it, but the excess which is added to it. This excess will be represented by the total volume swept through by the elastic sides of the skin of diaphragms, which is supposed to form its bounding surface. When a negative charge is imparted to a body a certain quantity of the normal charge is abstracted, and the elastic skin of the conductor is pressed inwards from its normal position, the quantity of the charge being represented by the volume swept through by the skin when it is pressed inwards.

The density of an electric charge is the quantity of free electricity or electrification on a unit area of the surface of the conductor. This density will evidently be proportional to the displacement of the elastic skin over the given area.

Electrostatic Units.

Every magnitude is measured by ascertaining the number of certain standard magnitudes, or, as they are usually called, units, which it contains. We shall briefly explain the units in which the electric quantities we have been discussing are measured. In what is called the Electrostatic system of units, they are derived from the force exerted between two electrified points. As the units of length, mass, and time employed are the *centimetre*, *gramme*, and *second*, this system is sometimes called the *C. G. S.* system of units. The unit force in this system is called the *dyne*, and is that force which acting for one second on a mass of one gramme gives to it a velocity of one centimetre per second. The *unit quantity* of electricity is that quantity which, when placed at a distance of one centimetre from a similar and equal quantity, repels it with a force of one *dyne*. The quantities of electricity must be on very small bodies, or, strictly speaking, they must be concentrated at points. The unit quantity of electricity may be defined in another way as the quantity on a sphere of one centimetre radius, at an infinite distance from all other conductors, and charged to unit potential. In our hypothesis we have usually taken the volume of displacement of the elastic diaphragms as the measure of the quantity of electricity. The volume of displacement on a sphere of unit radius = $4 \pi x$ displacement. If the displacement be equal to the density, the density on the unit sphere at unit potential will be $\frac{1}{4\pi}$. The quantity on a sphere of 1 centimetre radius is taken as unit quantity when the charge is at unit potential. It thus follows that to find the quantity of electricity on any surface at an infinite distance from all conductors we multiply the area of the surface by the potential and divide by 4π.

The *unit of potential* is the pressure on the surface of a sphere of unit radius when the quantity of electricity on the surface is unity, or, to state the same thing in another way, when the displacement or density is $\frac{1}{4\pi}$.

The mathematical definition of unit potential is the quantity of work required to bring a unit quantity of positive electricity from an infinite distance up to another unit of positive electricity. This second unit can be derived from the first.

The *unit of density* is the unit quantity of electricity on unit area.

The *unit of capacity* is the capacity of a sphere of unit radius charged to unit potential, and at an infinite distance from other bodies.

CHAPTER III.

ELECTROMETERS.

THE difference of potential between any two electrified bodies is measured by means of instruments called electrometers. We shall describe some of the instruments of this class designed by Sir W. Thomson.

Quadrant Electrometer.

The quadrant electrometer may be used to measure very small differences of potential; for example, the difference of potential between the poles of a Daniell cell will in some instruments produce a deflection of 100 divisions on the scale.

It will be convenient first to describe the essential parts of this instrument, and afterwards to describe it more in detail.

A light aluminium needle *u*, Fig. 19, is suspended by two silk fibres *x* and *y*, so as to be able to turn on a vertical axis of platinum wire inside a shallow cylindrical brass box, made up of four separate and distinct quadrants, *a*, *b*, *c*, *d*. The opposite quadrants are connected by conductors, but are otherwise insulated. One of these quadrants *b* is removed to show the aluminium needle and its suspending wire. The position of the needle when in equilibrium is such that one end is half in the quadrant *a* and half in the quadrant *c*, and the other is half in *b* and half in *d*. The terminal *l* is connected with the quadrants *a* and *d*; the terminal *m* with *b* and *c*. The needle *u* is always kept at a high potential, generally positive. To test the difference of potential between any body and the earth, one of the terminals, say *m*, is connected to the earth, and the other *l* to the body to be tested. The deflection of the needle will be proportional to the difference of potential, and may be shown on a scale by a beam of light reflected from a small mirror attached to the axis of the needle. The needle is kept at a constant potential by means of a small influence machine and a Leyden jar. The figure shown is only diagrammatic.

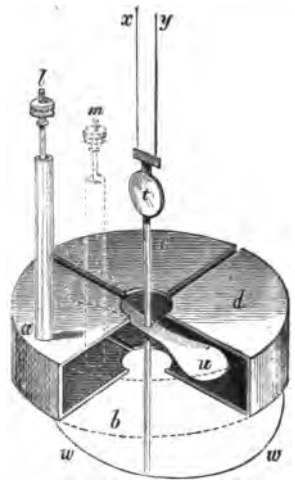


FIG. 19. DIAGRAM OF QUADRANT ELECTROMETER.

A more detailed description of the instrument may now be given. In the form illustrated below the directive force is given to the needle by means of magnets, but it has been found in recently constructed instruments that the bifilar suspension as just described is preferable.

Fig. 1, Plate I., represents the front elevation of the instrument. The outer shell of the instrument is made up of a jar of white glass (flint), supported on three legs by a brass mounting, cemented round the outside of its mouth, which is closed by a plate of stout sheet brass, with a lantern-shaped cover standing over a wide aperture in its centre. In what follows these three parts will be called the jar, the main cover, and the lantern.

Fig. 5 represents the quadrants as seen from above; they are shown in elevation at *a* and *b*, Fig. 1, and in section at *c* and *d*, Fig. 2. They consist, as already described in the general sketch, of four quarters of a flat circular box of brass, with circular apertures in the centres of its top and bottom. Their position in the instrument is shown in Figs. 1, 2, and 6. Each of the four quadrants is supported on a glass stem passing downwards through a slot in the main cover of the jar from a brass mounting on the outside of it, and admits of being drawn outwards for a space of about $\frac{3}{8}$ of an inch from the position occupied when the instrument is in use, as shown approximately in the drawings. Three of them are secured in their proper positions by nuts *e*, *e*, *e*, on the outside of the chief flat lid of the jar shown in Fig. 6. The upper end of the stem carrying the fourth is attached to a brass piece *f*, Fig. 6, resting on three short legs on the upper side of the main cover, two of these legs being guided by a straight V groove at *g* to give them freedom to move in a straight line inwards or outwards, and to prevent any other motion. This brass piece is pressed outwards and downwards by a properly arranged spring *h*, and is kept from sliding out by a micrometer-screw *i* turning in a fixed nut. The opposite quadrants are connected in two pairs by wires as shown in Fig. 5; and two stout vertical wires, *l*, *m*, called the chief electrodes, passing through holes in the roof of the lantern, are firmly supported by long perforated vulcanite columns passing through those holes, and serve to connect the pairs of quadrants with the external conductors whose difference of potential is to be tested. Springs *n*, *o*, at the lower ends of these columns, shown in Figs. 1 and 2, maintain metallic contact between the chief electrodes and the upper sides of two contiguous quadrants *a* and *b*, when the lantern is set down in its proper position, but allow the lantern to be removed, carrying the chief electrodes with it, and to be replaced at pleasure without disturbing the quadrants. The lantern also carries an insulated charging rod *p*, or temporary electrode, for charging the inner coating of the jar to a small degree to be increased by the replenisher, or for making special experiments in which the potential of the interior coating of the jar is to be measured by a separate electrometer, or kept at any stated amount of difference from that of the outer coating. When not in use, this temporary electrode is secured in a position in which it is disconnected from the inner coating.

The main cover supports a glass column *q*, Fig. 2, projecting vertically upwards from its central aperture, to the upper end of which is attached a brass piece *r*, which bears above it a fixed attracting disc *s*, to be described later; and projecting down from it a fixed plate bearing the silk fibre suspension of the mirror *t*, needle *u*, etc., seen in Figs. 1 and 2, and fixed guard tubes *v*, *w*, to be described presently. To the main cover is also attached the circular level, Fig. 6, which is adjusted to indicate the position of the instrument in which the quadrants are level, and the guard tubes just mentioned vertical. Its lower surface, which rests on the cover, is slightly rounded, like a convex lens, so as to admit of a slight further adjustment by varying the relative pressure of the three screws by which it is fastened down to the cover.

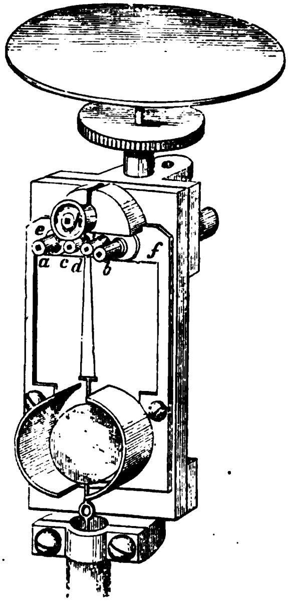


Fig. 20.
Bifilar Suspension.

The movable conductor of the instrument consists of a stiff platinum wire about $3\frac{1}{8}$ inches long, with the needle rigidly attached to a plane perpendicular to it, and connected with sulphuric acid in the bottom of the jar by a fine platinum wire hanging down from its lower end, and kept stretched by a platinum weight under the level of the liquid. In the instrument illustrated in Plate I., Figs. 1 to 6, a small magnetic needle is fixed to the aluminium needle, and a permanent magnet is fixed outside to give directive force. It has been found that the bifilar method of suspension is superior to this. Fig. 20 illustrates this method of suspension. The stiff platinum wire which carries the mirror and needle has a cross-piece at its upper end, to which are attached the lower ends of the suspending silk fibres; the other ends being wound upon the two pins *c*, *d*, which may be turned in their sockets by a square pointed key to equalize the tension of the fibres and make the needle hang midway between the upper and under surfaces of the quadrants. The pins *c*, *d*, are pivotted in blocks carried by springs *e*, *f*, to allow them to be shifted horizontally when adjusting the position of the points of suspension. The screws *a*, *b*, which traverse these blocks, have their points bearing against the fixed plate behind, so that when *a* or *b* is turned in the direction of the hands of a watch the neighbouring point of suspension is brought forward, and conversely. The needle may thus be made to turn through an angle till it lies in a symmetrical position as represented in Fig. 5, Plate I., when all electrical disturbance has been guarded against by connecting the quadrants with the inside and outside of the jar. The conical pin *h* passes between the two springs and screws into the plate behind; by screwing it inwards the points of suspension are made to recede from each other laterally, and the sensibility of a needle to a deflecting couple is diminished, and conversely.

The method employed to test the symmetry of the suspension is suggested by the consideration that, if the tension be equally distributed between the two fibres, the sensibility of the needle to the same deflecting couple will be less than if the whole or the greater part of the weight were supported by one fibre ; also, the sensibility being a minimum, a small deviation from the conditions which make it so will produce the least change of sensibility by the known property of a maximum or minimum. To test whether these conditions are attained, raise one side of the instrument a little (one turn of the foot-screw on that side is usually sufficient), and then produce an equal deviation in the opposite direction from the position marked by the attached level; and in each position of the instrument observe the deflection of the image on the scale produced by some constant difference of potentials, as that between the poles of a Daniell cell. This deflection ought to be nearly equal in the three positions, but exactly equal in the two disturbed positions, and somewhat greater in these than in the middle or level position. When the instrument is far out of adjustment, the deviation will be greater in one of the disturbed positions, and less in the other than in the middle or level position. When it is slightly out of adjustment, the deflections in the disturbed positions may both somewhat exceed that in the middle position, but to different degrees. An approximation to symmetry thus far, at least, should be obtained by merely turning the pins *c*, *d*, in their sockets, as already directed, through the minutest angles sensible to the operator, without altering the adjustment of the spirit level on the cover. When that has been done, the level on the cover ought to be adjusted by successive trials to indicate the position of the instrument, such that, when equally disturbed from it in opposite directions, the deflections obtained are equally in excess of the deflection obtained in the indicated position.

The needle *u* is of thin sheet aluminium, cut to the shape seen in Figs. 5 and 6, Plate I.; the very thinnest sheet that gives the requisite stiffness being chosen. Its area is $4\frac{1}{5}$ square centimetres, and weight ·07 of a gramme. If the four quadrants are in a perfectly symmetrical position round it, and if they are kept at one electric potential by a metallic arc connecting the chief electrodes outside, the needle may be strongly electrified without being disturbed from its position of equilibrium; but if it is electrified, and if the external electrodes be disconnected, and any difference of potential established between them, the needle will clearly experience a couple turning it round its vertical axis, its two ends being driven from the positive quadrants towards the negative, if it is itself positively electrified. It is kept positive rather than negative in the ordinary use of the instrument, because it is found that when a conductor with sharp edges or points is surrounded by another presenting everywhere a smooth surface, a much greater difference of potentials can be established between them without producing disruptive discharge if the points and edges are positive than if they are negative.

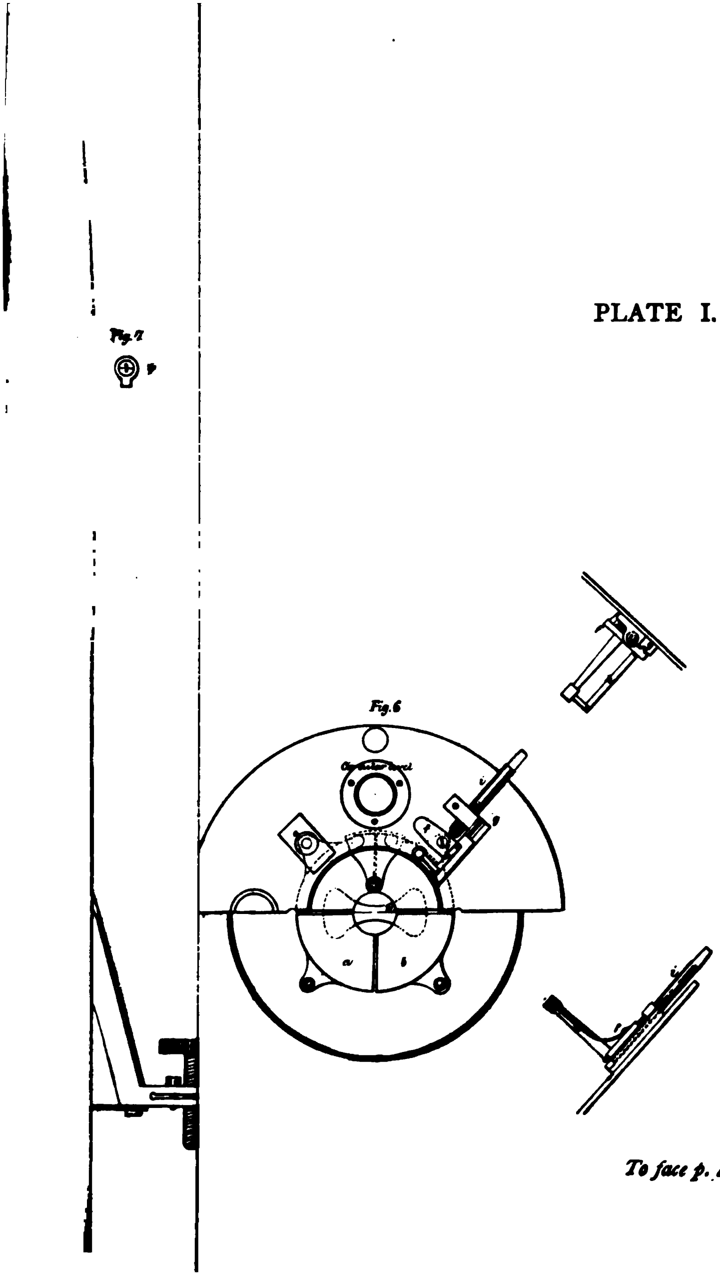
The mirror *t* serves to indicate, by reflecting a ray of light from a lamp, small angular motions of the needle round the vertical axis. It is a very light concave, silvered glass mirror, being of only $\frac{1}{3}$ inch diameter and 22 milligrammes ($\frac{1}{3}$ grain) weight. Mirrors may be produced by cutting out and silvering a large number of circles of the thinnest microscope glass, fixing and testing for the image. Out of fifty tried, ten or fifteen are generally found satisfactory. The focus for parallel rays is about 20 inches from the mirror, and thus the rays of the lamp placed at a distance of 40 inches are brought to a focus at the same distance. The lamp is usually placed close behind the vertical screen, a little below or above the normal line of the mirror, and the image is thrown on a graduated scale extending horizontally above or below the aperture in the screen through which the lamp sends its light. When the mirror is at its zero position, the lamp is so placed that its image is, as nearly as may be, in a vertical plane with itself, and not more than an inch above or below its level, so that there is as little obliquity as possible in the reflection, and the line traversed by the image on the screen during the deflection is, as nearly as possible, straight. The distance of the lamp and screen from the mirror is adjusted so as to give as perfect an image as possible of a fine wire, which is stretched vertically in the plane of the screen across the aperture through which the lamp shines on the mirror. It is easy to read the horizontal motions of the dark image to an accuracy of the tenth of a millimetre. In the ordinary use of the instrument a white paper screen, printed from a copper-plate, divided to fortieths of an inch, is employed, and the readings are commonly taken to about a quarter of a scale division.

The charge of the needle remains sensibly constant from hour to hour, and even from day to day, in virtue of an arrangement by which it is kept in communication with sulphuric acid in the bottom of the jar, the outside of the jar being coated with tinfoil and connected with the earth, so that it is in reality a Leyden jar. The whole outside of the jar, even where not coated with tinfoil, is in the ordinary use of the instrument kept virtually at one potential through conduction along its surface. This potential is generally by connecting wires or metal pieces kept the same as that of the brass legs and framework of the instrument. To prevent disturbance by the presence in the neighbourhood of strongly electrified bodies, a wire is either wrapped round the jar from top to bottom, or a cage or network of wire, or any convenient metal case is placed round it; but this ought to be easily removed or opened at any time to permit the interior to be seen. White glass is found to retain the charge better than green.

A small influence machine called a replenisher, Figs. 16, 17, and 18, is used to restore the charge in the jar when it falls off through leakage. As this machine will be described in detail in its proper place further on, we shall say no more about it at present than that by turning a milled head attached to the axis of the machine any required quantity of electricity may be imparted to the jar.

A gauge is fitted on the instrument to enable the replenisher to charge to a fixed potential. This gauge is constructed on the same principle as the attracted disc electrometer to be described further on. The movable attracted plate *a*, Fig. 4, Plate I., is made of aluminium, and supported by a stretched platinum wire passing through its centre of gravity. Fig. 3 shows the manner in which the platinum wire $\beta\beta$ is attached to the movable plate, viz., by passing it through two holes in the sheet and over a central ridge of bent sheet aluminium. The ends of the wire are passed through holes in curved springs, as shown in Fig. 4, and are bent round them so as to give a secure attachment without solder, and without touching the stretched part of the wire. The ends of the platinum wire are attached to the springs by cement, (solder being found to render the ends of the wire brittle,) care being taken to obtain metallic contact between the wire and the brass springs. The springs keep a constant tension on the platinum wire. The brass pieces carrying the springs are adjustable to give a certain stretch to the wire, and pins are fitted in them to give the necessary torsion to the wire. The movement of the long end of the aluminium plate is limited by stops; this end is shaped like a stirrup, of which a black hair forms the transverse piece. Between the fork of the stirrup a white enamel plate with two black dots in close proximity is fixed, so that when the black hair is between the two dots the aluminium disc is in the neutral position. By means of a plano-convex lens the position of the hair may be fixed more accurately. A side view of the attracting plate, the brass roof of the lantern, the aluminium balance, the sight plate, the hair, and the plano-convex lens is given in section (Fig. 2); also of a glass upper roof to protect the gauge and the interior of the instrument below from dust and disturbance by air currents. The fixed attract-

PLATE I.



To face p. 48.

ing disc is mounted on a vertical screw, which screws into the brass mounting *z*, Fig. 2, connected with the inner coating of the Leyden jar through the guard tubes, etc., and is secured in position by the jam nut shown in the drawing at *z*, Fig. 2. The disc *s* is about $1\frac{1}{2}$ inches in diameter, and is placed horizontally, with its centre under the centre of the square aperture in the roof of the lantern. The distance of the fixed disc from the movable plate is about $\frac{1}{10}$ to $\frac{1}{5}$ of an inch, but will have to be adjusted according to the torsion of the platinum wire to give the maximum sensibility. The sensibility is increased by diminishing the distance from the attracting to the attracted plate, and increasing the amount of torsion on the wire. If the needle is electrified to too high a potential, the position of equilibrium becomes unstable. The torsional resistance of the fibres that suspend the needle should be adjusted so that a single Daniell cell gives a deflection of about 100 scale divisions (each division being about $\frac{1}{40}$ of an inch).

These instruments may be relied upon to measure the electro-motive force of a Daniell cell with an accuracy amounting to one quarter per cent. In using the quadrant electrometer several different degrees of sensibility may be obtained, according to the way in which the connections are made. The instrument is most sensitive when the two chief electrodes are connected with the two bodies whose difference of potential is to be measured, and one of them with the case of the instrument. A lower grade of sensibility is obtained by simply raising, so as to disconnect it from the quadrant, the electrode connected with the case. Several still lower grades are obtained by placing an insulated induction plate over one of the quadrants, but we do not consider it necessary to describe this for our present purpose.

The Absolute Electrometer.

The quadrant electrometer, just described, does not give an absolute measure of potential, but only measures relative to some standard such as the Daniell cell. It is best suited for measurements of density and quantity by Faraday's cage method, as described in Chapter I., but for measuring the high potential differences found in influence machines the attracted disc electrometer, which we are now about to describe, is better suited.

By measuring the force of attraction between two electrified plates, the difference of potential between them may be calculated without the use of a standard of potential such as a Daniell cell. It is necessary that the distribution of electricity on the surface of the attracting discs should be uniform, and this is effected in Sir W. Thomson's attracted disc or absolute electrometer by making the fixed disc larger than the movable disc, and surrounding the movable disc by a ring called the guard ring. This ring has its surface in the same plane as the movable or suspended disc, and obviates any want of uniformity in the distribution of the electricity at the edge of the suspended disc.

The guard ring is connected with a metal case surrounding the back of the attracted disc and all its suspending apparatus, and thus the electrification of the back of the disc is rendered impossible, as it is part of the inner surface of a hollow conductor. The fixed disc is horizontal, and mounted on an insulating stem. Its distance from the guard ring can be adjusted by

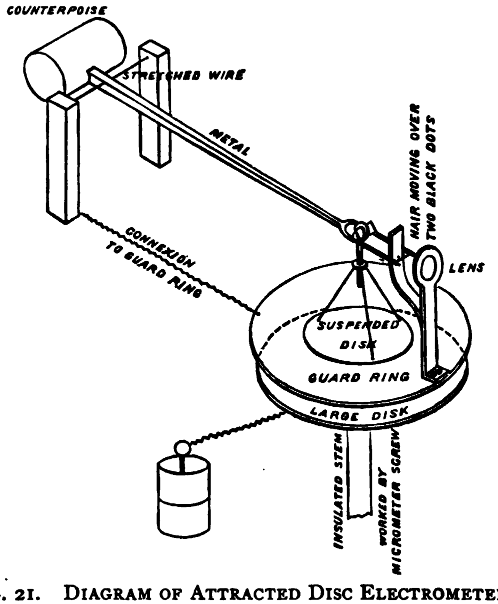


FIG. 21. DIAGRAM OF ATTRACTED DISC ELECTROMETER.

means of a micrometer screw. The guard ring is at least as large as the fixed disc, and its lower surface is truly plane and parallel to the fixed disc. A delicate torsion balance is mounted on the guard ring, to one end of the beam of which a light movable disc is suspended. This disc almost fills the circular aperture in the guard ring, without rubbing against its sides. The lower surface of the suspended disc must be as flat as possible, and a contrivance has to be fitted for ascertaining when it coincides exactly with the lower surface of the guard ring, so as to form a single plane, interrupted only by the narrow interval between the disc and its guard ring. The lower disc must be screwed up till it lies closely in contact with the guard ring, and the position of the end of the balance noted with respect to a plate or other suitable mounting erected on the guard ring. It is usual to fix a black hair across a fork on the end of the beam of the balance, and mark two black dots on the white surface of the plate, so that the black hair just lies between them when the suspended disc is in the proper position. A lens may be mounted in front of the hair and dots, so that the point of bisection may be determined more accurately.

To measure a difference of potential, a known weight is placed on the suspended disc sufficient to bring it into the sighted position; the weight is then removed and the two discs connected with electrified conductors between which the difference of potential is to be measured. The large disc is now adjusted by the micrometer screw till the suspended disc is in the *sighted* position. If W be the numerical value of the weight, g the force of gravity, A the area of the suspended disc, D the distance between the discs, and V the difference of potentials of the discs, then

$$Wg = \frac{V^2 A}{8 \pi D^2}$$

$$V = D\sqrt{\frac{8\pi g W}{A}}$$

If the suspended disc is circular, of radius R, and if the radius of the aperture of the guard ring is R_1, then

$$A = \tfrac{1}{2}\pi(R^2+R_1^2), \text{ and } V = 4D\sqrt{\frac{gW}{R^2+R_1^2}}.$$

The detailed construction of Sir W. Thomson's absolute electrometer is shown in Fig. 22. In this electrometer an auxiliary charge besides the one to be measured is used; but for measuring large differences of potential that is not necessary. The Leyden jar, which forms the case of the instrument, is a white (flint) glass cylinder, coated inside and outside with tinfoil to nearly the height of the circular plate A, apertures being left to admit the requisite light to the interior and allow the indications of the vertical scale r and divided circle t to be read. Round the upper rim of the jar a brass mounting is cemented, to which the cover of stout sheet brass C is screwed to close the jar at the top. By another brass mounting round its lower rim the jar is fastened down to the cast-iron sole plate D, which closes its lower end, and is supported on three legs. The cover C supports the replenisher E and the aluminium balance lever of the gauge, both similar to those already described in connection with the quadrant electrometer, but on a larger scale. The air inside is kept dry by the aid of pumice stone soaked with strong sulphuric acid contained in glass vessels placed in the bottom of the jar.

The movable disc *c* hangs in a circular aperture in the plate *A*, which rests on three fixed supports *z z z*, cemented to the interior surface of the jar, and in metallic connection with the inside coating; the manner of support is that of the hole, slot, and plane. This perforated plate or guard plate supports on a brass pillar the attracting plate *F* of the gauge, which thus tests the potential of the guard plate, balance, and inside coating. This potential is kept constant by the replenisher, which has metallic contact with the guard plate through the spring *e*. The jar is charged by an insulated charging rod let down for the occasion through a hole in the cover.

The balance *c* is a light aluminium disc, about 46 millimetres in diameter, strengthened by an elevated rim and radial ribs on its upper surface, but having its lower surface plane and smooth. It nearly fills the aperture in the guard plate, sufficient clearance being left (·75 of a millimetre all round) to allow it to move up and down without risk of friction. It is supported by three delicate steel springs, each of which consists of two parts; the upper end of the upper part is attached to the lower extremity of a vertical insulating stem *i* directly above the centre of the disc where the corresponding end of the lower part is fixed. The opposite ends, which project considerably beyond the circumference of the disc, are rivetted together. One of the springs *s* is shown in the figure. Their general form may be compared to that of coach springs. The insulating stem *i* is attached to a brass tube *a*, which slides up and down in V guides by the action of a micrometer screw. The micrometer

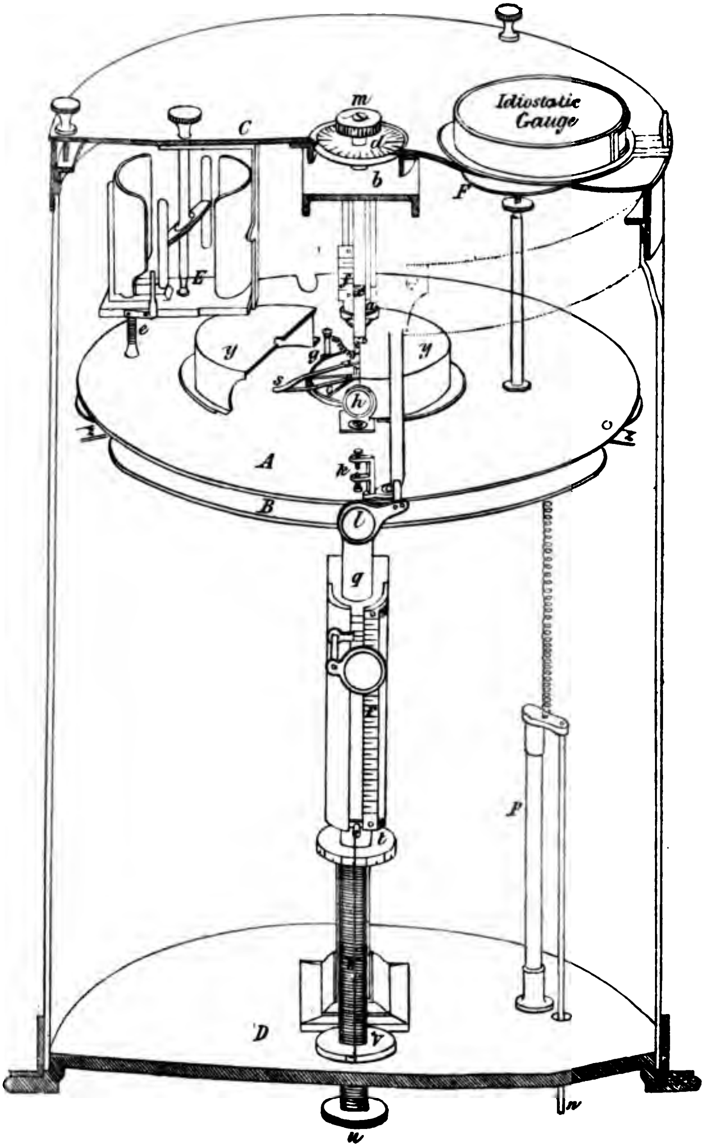


FIG. 22. THOMSON'S ABSOLUTE ELECTROMETER.

screw is worked by means of the milled head *m* projecting above the cover *C*; there are guides to prevent the tube *a* turning round, and an index *x*, which moves up and down with the tube, to show the amount of movement. These are rigidly attached to a strong brass plate *b*, lying across the mouth of the jar below the cover, and resting upon the flange of the brass mounting to which it is fastened by screws. The plate *b* is so adjusted that the balance may hang concentric with the perforation in the guard plate. The micrometer screw carries a horizontal circular disc *d*, graduated by 100 equal angular divisions. An aperture is left in the cover, through which its indications can be read off by reference to a fixed mark on the sloping edge of the aperture. This, together with the scale *f*, each division of which corresponds to one full turn of the micrometer screw, measures the vertical distance through which the tube *a* and the points of attachment of the springs are moved.

Metallic communication between the balance and the guard plate is maintained by a light spiral wire attached to the pillar *g*, and to the upper support of the springs, which is a brass piece cemented to the insulating stem. An arm not seen in the figure projects from the guard plate over the disc, so that its extremity is between the centre of the disc and the upper end, bent horizontally, of an upright fixed to the disc, thus serving as a stop to confine the motion of the disc between certain limits. A very fine opaque black hair is stretched between two small uprights (one of which is seen in the figure, standing in the centre of the disc). An achromatic convex lens *h*, fixed on the guard plate, stands opposite, and produces an image of the hair in the conjugate focus, which is just over the outer edge of the guard plate. The two opposed screw points *k* are adjusted to touch each side of the image thus thrown by the lens, which, on the principle of the astronomical telescope, is observed through an eye-lens *l* attached outside of the jar to the upper brass mounting. By this arrangement the error of parallax in observing the position of the hair relatively to the two points is avoided; the position of the eye may be varied in any direction without causing any change in the apparent relative position of the hair (image) and points. In adjusting these different parts, it is arranged that when the image of the hair is exactly between the two points, or in what is called the sighted position, the under surfaces of the balance and guard plate may be as nearly as possible in one horizontal plane.

In the use of the instrument the balance and springs are protected from disturbing electrical forces by a brass cover in two halves *yy*, one of which is represented displaced in the figure to show the interior arrangements. The two halves when placed together form a circular box, with an aperture in front, in which the lens *h* stands, and another aperture behind to admit light from the sky, or from a lamp placed outside the jar in the line of the hair, lens, and points.

The electrical part of the instrument is completed by the continuous attracting plate *B*, under and parallel to the guard plate and spring balance. This is a stiff circular brass plate, with parts cut out to allow it to move freely past the fixed supports *z z z* of the guard plate. An electrode *n*, projecting through a hole in the sole plate from an insulating stem *p*, is kept in metallic communication by a spiral wire with an arm projecting from the centre of the continuous plate. The plate *B* is supported by a brass pillar *q*, from which it is insulated by a short glass stem. It is moved vertically by the micrometer screw *w* (pitch $\frac{1}{50}$ of an inch), and this motion is measured by a vertical scale *r* and horizontal graduated circle *t* attached to the screw. The screw projects below the sole plate, and is worked by the milled head *u*, the nut *V* being fixed in the centre of the sole plate. The pillar *q* moves in V or ring guides, and rests upon the upper end of the screw.

Before this instrument is available for absolute electrometer measurements, the force required to move the balance through any fixed vertical distance (the point of suspension being unmoved) must be known. This is ascertained by weighings conducted in the following manner: The cover *C* is removed, and all electrical force in the balance is guarded against by putting the electrode *n* in metallic connection with the guard plate. The balance is then brought by turning the micrometer circle *d* to the sighted position, and the reading on the scale *f* and graduated circle *d* is noted. A known weight is then distributed symmetrically over the disc ($\frac{6}{10}$ of a gramme has been used hitherto), which displaces it below the sighted position. It is now raised to the sighted position by turning the disc *d*, and the altered micrometer reading is noted. The difference between the two readings measures the distance through which the given weight displaces the balance in opposition to the tension of the springs; and conversely, when the balance has been displaced through the same distance by electrical attraction between it and the continuous plate below it, this known weight is the measure of the force exerted upon it. It has thus been found by repeated weighings that a weight of $\frac{6}{10}$ of a gramme displaces the balance through a distance corresponding to two full turns of the micrometer screw, and a fraction of one division of the circle in the instrument belonging to the laboratory of the Glasgow University. This distance having been ascertained with all possible care, and at different temperatures, in view of the possible effect of temperature on the elasticity of the springs, the plan of proceeding to absolute electrostatic measurements is as follows, the weights being removed, and covers *y y C* replaced.

All electrical influence having been removed by a wire led from the electrode *n* through the hole in the cover *C* to the guard plate, the balance is brought to the sighted position. Starting from this point, it is raised by the micrometer screw through any distance which has been ascertained to correspond to a known weight, *e.g.*, the distance just mentioned. This corresponds exactly to the removal of the weight in the general sketch of the electrometer given above. The jar is then charged, and the potential is kept constant during the experiments by using the replenisher according to the indications of the gauge, which, as already said, has been made extremely sensitive for the purpose. The attracting plate B is connected by its electrode n alternately with the outside coating of the jar (which may be either connected with the earth or insulated) and with the body the difference of whose potential from that of the outside coating is to be measured. In each case the balance is brought to the sighted position by moving the plate B up or down by the micrometer screw w, and the reading on the vertical scale r and graduated circle t is noted. The difference of the two readings gives the difference of the two distances between balance and attracting plate, from which the difference of potentials is deduced by the formula

$$V^1 - V = (D^1 - D)\sqrt{\frac{8\pi W g}{A}}.$$

From the descriptions given above, electrometers of sufficient accuracy to make interesting experiments on influence machines may be constructed by an amateur possessing engineer's tools. For example, the distribution of electricity on the plates of influence machines may be measured by the proof plane, Faraday's cage, and a quadrant electrometer; while the great differences of potential between the poles of influence machines may be measured by the attracted disc electrometer. To determine the electric energy developed by an influence machine, it is necessary to have also the means of measuring the current, or quantity per second, flowing between the poles of the machine when it is in action, and this can be done by means of an instrument called a galvanometer.

Galvanometer.

The currents from the very largest influence machines are very small when compared with currents obtained from dynamos or batteries. The galvanometer most suitable for measuring these small currents is one having a coil made up of a great length of very fine wire. The galvanometer designed by Sir W. Thomson for measuring potential difference in electric lighting and similar applications of voltaic electricity is very well suited for our

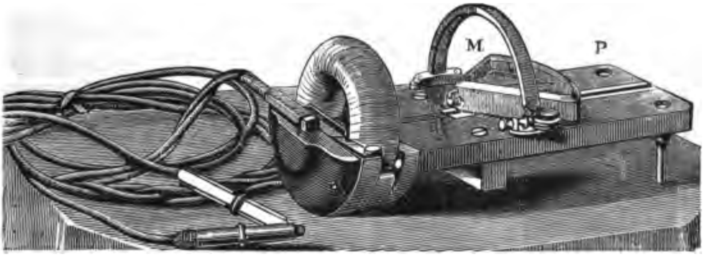


FIG. 23. THOMSON'S POTENTIAL METER.

purpose. This galvanometer belongs to the class of tangent galvanometers, the tangent of the deflection produced in a magnetic needle being proportional to the current flowing in the coil. The coil should contain two or three miles of German silver wire, having a resistance of four to five thousand ohms. The wire should be double silk covered, and each layer insulated with paraffin. The coil is fixed in a vertical plane on the baseboard. The magnetic needle, which must be very short, is suspended by a silk fibre in a line with the axis of the coil at some distance in front of the coil. A long pointer of glass or aluminium is fixed to the needle and moves over a tangent scale. The box *M*, carrying the needle with its scale, etc., may be made to slide on the baseboard *P*, and by moving it nearer to or further away from the coil, in the line of its axis, a deflection of 10, 20, or any required number of degrees may be obtained when a Daniell cell is placed in the circuit of the coil. The electro-motive force of a Daniell cell is known to be as nearly as possible one volt, and if this unit be divided by the known resistance of the coil in ohms (say 5,000 ohms), the result $\frac{1}{5000}$ will be the fraction of an ampere of current which gives the deflection of say 10 degrees on the tangent scale of the magnetic needle. An instrument such as this would thus measure a current as small as the $\frac{1}{50000}$ part of an ampere, and this will be found sufficiently delicate to measure the currents usually obtained from influence machines.

The terminals of the galvanometer are to be connected to the poles of the machine, but sparks must not be sent through the galvanometer coil. Instead of the galvanometer, Leyden jars of known capacity may be used and the number of sparks per second counted.

PART II.

DESCRIPTION OF INFLUENCE MACHINES.

CHAPTER I.

HISTORICAL DEVELOPMENT OF THE INFLUENCE MACHINE.

IT is a popular but erroneous belief that great inventions have sprung, full grown and completely equipped, from the brains of their inventors, like Minerva from the brain of Jupiter. A closer examination into the history of these inventions generally shows that the machine which impresses us so much by its ingenuity and apparent originality is the result of many small steps taken by many investigators, each starting from the position attained to by his predecessors. The history of the electrical influence machine is no exception to this rule, but is in fact a very fine example of what may be called the evolution of machines.

The phenomena of electrical influence appear to have been observed by Otto von Guericke, Hawksbee, Gray, and other physicists in the first half of the last century; but Canton, about 1750, was the first to describe them in detail, and to a certain extent explain them by the theory of "electrical atmospheres" prevalent at that time. Wilke, and especially Æpinus, were the first to thoroughly establish and explain, as far as it was possible at that time, the phenomena of electrical influence. The name of *electrical influence* appears to have been applied to such phenomena by the latter, and thus we see that this name is of much earlier date than that of electrostatic induction, which has been frequently applied to these phenomena in recent times.

In 1762 Wilke described a simple apparatus which may be looked upon as the forerunner of the first apparatus in which electricity was produced by influence, viz., the electrophorus. Wilke's apparatus consisted of a glass table, to the opposite surfaces of which metal covers could be applied. He showed that when the table had been electrified, it was capable for many days of giving a charge to the metal covers when they were applied to its two surfaces.

The greatest credit, however, for the invention of the electrophorus belongs to Alexander Volta, the Italian scientist, who, in 1775, gave it the form in which it is generally made, even at the present day. He also established the true theory of its action.

The Electrophorus.

The electrophorus, or, as it was called by Volta on account of the persistence of the electricity in the resinous plate, the "perpetual electrophorus," generally consists of a disc of an insulating or dielectric substance *H* (Fig. 24), called the *cake*, which is placed on a metal plate *M*, or in a metal dish. Upon the dielectric cake a conducting plate *D*, usually called the *cover* of the electrophorus, is placed, and can be easily lifted off the cake by an insulating glass handle *G*, or by silk strings. The cake may be made of various materials; we may use shellac to which wax or turpentine has been added in such quantity that the resulting mass has slightly passed the point of brittleness, or we may use a mixture of resin, turpentine, and white pitch, or equal parts of colophonium and black pitch. Cakes have been made of gutta percha and vulcanite, but the former substance very soon loses its electrical properties, while the latter, though it supplies more electricity than the resinous cake is liable to warp, and under the influence of the oxygen of the atmosphere to undergo chemical changes on its surface, the effects of which, however, may be removed by washing with water or an alkaline solution. Vulcanite cakes owe their efficiency in great part to the fact that their surfaces can be made very flat, a point which is of the greatest importance in the construction of the electrophorus.

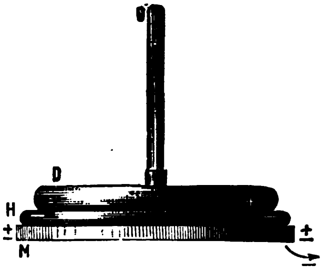


FIG. 24. THE ELECTROPHORUS.

The cover of the electrophorus is a circular disc rounded on the edge, and made of brass, tin, or wood covered with tinfoil. Its lower surface, which rests upon the cake, must be as flat as possible, and its diameter slightly less than that of the cake.

To set the electrophorus in action, the cake is, after, it has been thoroughly dried by warming, rubbed with fur (such as a catskin). The cake thus becomes negatively electrified, and to such a degree that, if, a knuckle is brought near, a crackling noise is produced and sparks can be seen in the dark. If the cover be now placed on the cake, it will by influence exhibit positive electrification on its lower surface and negative electrification on its upper surface. If the cover be then touched, it will be reduced to the same potential as the earth, and will consequently show positive electrification all over, though still chiefly on the lower surface. When the cover is raised by its insulating handle, the positive electrification becomes practically equal on both sides, and the cover, being now in a field of higher potential than when covering the negatively electrified cake, will discharge sparks of positive electricity to any conductor connected with the earth if it be brought sufficiently near.

Lichtenberg was able to draw sparks sixteen inches in length from one of his electrophori, the cover of which was five feet in diameter, and was placed on a cake six feet in diameter.

After the cover has been once discharged it is only necessary to place it again on the dielectric cake to touch and raise it in order to accumulate upon it a fresh charge of electricity. To obviate the necessity of touching the cover of the electrophorus every time, a variety of arrangements has been devised. The positive electricity may be allowed to flow from the earth into the cover through the tin case or dish by glueing on the surface of the cake a short piece of tinfoil of sufficient length to connect the cover to the tin case when the cover is placed on the cake; or a metallic peg may be fixed to the bottom of the case, so as to pass up through the centre of the cake. The case or base plate on which the cake is placed plays an important part in the action of the electrophorus. It forms, in fact, one pole at zero potential of the electric field existing in the dielectric cake, the upper surface of the cake forming the other pole. Owing to the proximity of a zero pole, the capacity of the dielectric is very great. If the case were absent, it would be equivalent to removing the zero pole to a greater distance, when the capacity would be proportionally reduced.

As we have seen, when discussing the theoretical part of the subject, great capacity means great electrical displacement, and consequently great strain on the so-called elastic diaphragms of the dielectric, and this may result in partial rupture and a consequent penetration of the negative charge for short distances into the surface. This action is supposed to account for the property which the cake of the electrophorus is found to possess of retaining for a long time the electric charge when once it has been imparted to its surface.

An explanation of the action of the electrophorus in terms of the elastic cell hypothesis may be interesting. The metallic *cover* *A*, Fig. 25, supported on an insulating handle *B*, is represented by an elastic bag filled with the incompressible electric fluid. The resinous cake *C* being a dielectric is supposed to have a number of elastic diaphragms in its substance in the manner we have already explained in Chapter II. When the cake is excited by friction its elastic diaphragms, as represented by the dotted lines, are strained inwards. This produces an electric vacuum or negative potential in the dielectric air above the cake. The elastic bag *A*, when placed on the cake, is surrounded by this vacuum, and when a communication is established between the inside of the bag and the earth by means of the tube (*i.e.* the

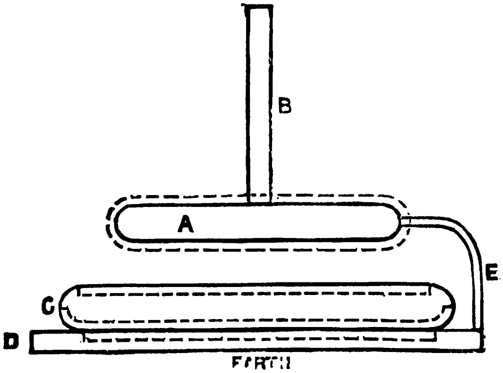


FIG. 25.

conductor) *E*, which is connected to the metallic plate or dish *D* resting on the earth, then the electric fluid will flow from the earth into the bag, and expand it till equilibrium is established. If the connection *E* be now broken, and *A* be removed till it is surrounded by a neutral field, the full pressure of the stretched elastic bag will be exerted on the fluid inside the bag, and will drive it through any channel which may lead it to the earth.

The Double Electrophorus.—The cake of the electrophorus which we have just described, though it retains its electrical charge for a considerable time, ultimately loses it, and has to be re-excited by rubbing with the fur. The necessity for re-exciting the cake may be obviated by using two electrophori. We will call the cake of one electrophorus *A*, and that of the other *B*. To start with, a small negative charge is communicated to *A* by rubbing with the fur. The cover is then placed on it, touched, and removed with a positive charge. This positive charge is now to be communicated to the cake *B*. This can be done by placing the edge of the cover where the density of the electric charge is greatest, on the cake *B*, and rolling it or sliding it on the surface. The cover is now placed flat on the surface of *B*, touched and lifted, when it will exhibit negative electrification in the ordinary way. This negative charge is now communicated to *A* by contact with the edge of the cover, and reinforces its original negative charge. The operation may be continued to any required extent, till *A* has acquired a strong negative charge and *B* a strong positive charge. The multiplying of small charges of electricity by this method was described in detail by Lichtenberg in 1778. We find it again mentioned by Volta in the "Collezione delle opere," 1816.

The double electrophorus is too troublesome in its working to be of practical value, but it is of great interest as involving the same principle as the multiplying influence machines which we shall describe presently, viz., the multiplying by mechanical manipulation of a small initial charge of electricity till electricity of very high tension is produced.

Condensers.

In the early days of electrical science, when there existed no instrument for testing electrical charges more delicate than the gold leaf electroscope, it was found difficult with weakly electrified bodies to communicate to the gold leaves and their supports a sufficient charge to deflect the leaves. Volta's condenser, described in 1782, was a contrivance to obviate this difficulty by increasing the capacity of the part of the electroscope to which the charge was to be communicated. It consisted, Fig. 26, of two metal plates rounded on the edges, and carefully lacquered to prevent them coming into conducting contact. One of these plates was fixed on the top of the rod carrying the gold leaves of the elec-

FIG. 26. VOLTA'S CONDENSER.

troscope, and the other was furnished with an insulating handle. When a weak charge was to be communicated to the electroscope, the electrified body was placed in conducting contact with the fixed plate; the movable plate was then placed above it and touched. The capacity of the fixed plate was limited only by the extremely thin layer of shellac between it and the earth plate. Practically the whole of the charge on the weakly electrified body would thus be communicated to the upper surface of the fixed plate, and when the movable plate was withdrawn the charge flowed in great part down to the gold leaves and deflected them.

Nicholson in 1797 described an apparatus which he called a *spinning condenser*, in which a glass disc carrying on its lower face two insulated tinfoil segments revolves on a vertical axis immediately over a fixed glass disc with corresponding tinfoil segments. The capacity of each of the movable segments becomes alternately of maximum and minimum value by the opposition of a fixed segment having respectively an opposite and similar charge. In the former case the movable segment takes up the charge from the electrified body to be tested, and in the latter delivers it to the electroscope. A point of great interest about this apparatus is the use of tinfoil carriers fixed on a glass plate, an arrangement almost invariably adopted in modern influence machines.

Doublers.

In 1786 the first of the so-called doublers was invented by the Rev. Abraham Bennet of Wirksworth. The object of this and all the earlier influence apparatus was the same as that of Volta's condenser, viz., to multiply small charges of electricity and render them visible on the electroscope. For this purpose they were afterwards found to possess a serious defect, which, however, eventually proved to be one of the most useful characteristics of their descendants, the modern influence machines.

Bennet's apparatus will be easily understood by supposing that another similar metallic disc with an insulating handle is added to the two already described in connection with Volta's condensing electroscope. This additional disc

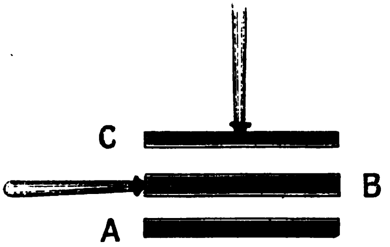


FIG. 27. BENNET'S DOUBLER.

is carefully shellaced on both sides, the insulating handle being fixed in the plane of the disc to a point on its circumference. The additional disc above mentioned we shall call *B*, the other two *A* and *C*, as in Fig. 27. A body charged with electricity of a low potential (say positive) is placed in contact with the lower unvarnished side of the disc *A*. *B* is placed on *A* and touched, then removed with its negative charge and placed on *C*, which is now also touched. *C* when removed by its insulating handle has a charge similar to that originally communicated to *A*. If *C* is now put in contact with *A*, in the place of the original electrified body, and *B* be placed on *A* and touched as before, an additional positive charge will be communicated from *C* to *A*, as the electricity will flow to the upper surface of *A*, where it is nearest to the surface of *B*, in contact with earth.

The name of doubler was given to this apparatus by Cavallo, and he says that the multiplying operation may be repeated any number of times, though Bennet mentions only once.

In 1788 Cavallo, while experimenting with one of Bennet's doublers, made a very important discovery, which constituted the defect, we have already mentioned, of the apparatus as a doubler. His discovery, however, brought to light one of the most useful functions of the apparatus as a generator of high potential electricity, viz., the function of *self-excitement.* He found that insulated plates almost without exception retain a very small charge of electricity. This of course might mask any small charge which was to be multiplied for testing purposes, but it also enables the apparatus as a generator of electricity to start without any external excitement. The principle thus discovered by Cavallo was taken advantage of in Nicholson's machine, which was invented in the same year and is usually looked upon as the first influence machine, the operations performed by hand in Bennet's doubler being here effected by mechanism.

In 1787, the year previous to Nicholson's invention, a mechanical arrangement was devised by Erasmus Darwin for effecting the operations of Bennet's doubler. It appears to have been a very imperfect apparatus, and its exact construction does not appear to have been anywhere published. A rough sketch of an apparatus was found amongst Darwin's papers, and shown by Prof. S. P. Thompson in a lecture delivered before the Society of Telegraph Engineers; and Nicholson mentions an instrument devised by Dr. Darwin which was lent to him. The instrument was actuated by wheelwork, but in certain positions had to be touched by hand. This latter circumstance would appear to establish Nicholson's claim to be the inventor of the first influence machine in which the operations were performed entirely by mechanism.

Nicholson's Revolving Doubler.—In the Philosophical Transactions for the year 1788 is described what we may fairly call the first influence machine, in the sense that it produced electricity by turning a handle, without the intervention of the hand to effect any of its operations. The inventor of this machine was William Nicholson of London, a teacher of mathematics and writer on chemistry and natural philosophy. The paper just referred to is entitled "A description of an instrument which by the turning of a winch produces the two states of electricity, without friction or communication with the earth."

The history of the invention of the doubler is given by Nicholson himself. He says: "In the month of December, 1787, Mr. Partington lent me an instrument contrived by Dr. Darwin, and consisting of four metallic plates, two of which were movable by wheelwork into positions which required them to be touched by hand in order to produce the effect. It appeared to me that the whole operation, including the touching, might be done by a simple combination without wheelwork, by the direct rotation of a winch. This was soon afterwards effected and communicated to the Royal Society in 1788. Mr. Bennet and Mr. Cavallo observed, soon after the discovery of the doubler, that it never fails to excite an electrical state by the mere operation, without any communication of electricity having been previously made." Nicholson also says that the first instrument that he made was given to Van Marum of Haarlem.

It is very difficult to get an electric charge from the machine as described by Nicholson, and the reason appears to be that its capacity is small owing to the absence of "communication with the earth." We shall here describe a form of the instrument

FIG. 28. NICHOLSON'S DOUBLER.

constructed by Wimshurst, which differs from the original machine only in the one detail of having an earth connection. After a few turns this machine will show sparks at its brushes, and give very decided indications on an electroscope. *A* and *B*, Fig. 28, are two fixed brass or copper discs fitted on the ends of horizontal glass rods, which are attached to the top of an insulating pedestal *C*. *D* is a movable disc attached to the end of a glass radius arm *F*, which is attached to and turns with the axes *E E*. A metallic rod *G* projects from the back of the disc *D*, coming in contact once in every revolution with a small wire brush on the end of the brass pedestal *H*, which is in conducting communication with the earth. When the disc *D* is opposite *A*, a small wire brush on the end of a bow-shaped piece of brass wire *M* touches the stud *K* and puts the plate *A* in communication with the earth through the winch handle *W* and the body of the operator. A small initial charge of, say, positive electricity on *D* would thus induce a small charge of negative electricity on *A*. When *D* in the course of its rotation comes opposite the other fixed disc *B*, a brass bow *L L* with a small brush at each end touches the two pegs *L* and *K*, thus connecting the two discs *A* and *B*; this contact, however, owing to the unequal distance of *L* and *K* from the centre, does not take place when *D* is opposite *A*. The peg *G* at the same time comes in contact with the brush on the end of the pedestal *H*, and thus communicates with the earth. The negative electricity which was developed on *A* now flows across the bow *L L* to the plate *B* and develops on *D* a positive charge. By the continued rotation, the connection of *B* with *A*, and of *D* with the earth, is broken. The negative charge is thus left isolated on *B*, and *D* moves again in front of *A* with its positive charge. *A* is again connected with the earth through *M*, and another negative charge is developed on *A*. This after another half revolution will be transferred to *B*, through *L L* as already described, thereby doubling the negative charge already on *B*. The positive charge which this produces on *D* will now be doubled, and so the increase will go on in a geometrical ratio till a spark passes, say, between *B* and *D*. The law of the increase of the charge may also be described as the same as the law according to which the principal increases at compound interest. The initial charge on *B* is the principal. The ratio of the charge on *A* to the charge on *B*, by which it is produced through the intervention of the movable disc *D*, is the rate of interest. The charge produced on *A* is the total amount of the interest, and this is added to the principal on *B*, through *L L*, at every revolution (which period corresponds to the year or other period on which interest is calculated). If the rate of interest were 100 per cent., the charge on *B* would be *doubled* every revolution, and it was on this assumption, doubtless, that the name of *doubler* was given to this and similar machines. A little investigation in these cases will show that the rate of interest is less than 100 per cent., and therefore the name doubler is not strictly applicable. We shall, however, retain the original name for the purposes of description. A more appropriate name, viz., *multiplier*, has been employed, and this term we shall preferably use hereafter for machines working on this principle.

Cavallo's "Multiplier."—Cavallo, in 1795, in his "Treatise on Electricity," described an influence machine, which, however, did not work on the compound interest principle. The movable disc had imparted to it a reciprocating instead of a revolving movement, as in the Nicholson doubler. The initial small charge to be multiplied was imparted to an insulated metal disc *A*, Fig. 29. A movable disc *B* was supported on a glass rod on the lever *E K*, the fulcrum of which was at *K*. A bent wire *M* fixed on *B* made an earth connection by touching the metallic pillar *N* when *B* was facing *A*, and a charge of the opposite kind of electricity was thus imparted to *B* by the

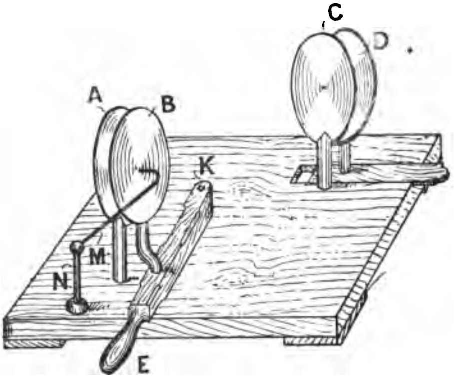


FIG. 29. CAVALLO'S MULTIPLIER.

influence of the charge on *A*. By swinging round the lever *E K*, the disc *B* with its attached wire *M* was brought opposite a third insulated disc *C*, in which position the bend on the wire *M* made contact with *C* and imparted a proportion of its charge to *C*. This proportion was made as great as possible by the contiguity of an earth-connected plate *D* to the opposite face of *C*. This machine was called by Cavallo a "multiplier." It will easily be seen that the charge on *C* was increased simply by successive additions. This would be more appropriately called an *addition machine.*

In 1798 considerable attention was given to the doublers, in France by Hachette and Desormes, and in Germany by Bohnenberger. The improvements were principally in the details of construction.

Hachette and Desormes' Machine.—Hachette and Desormes mounted the movable disc of the Nicholson doubler so that its distance from the fixed discs could be altered, with a view mainly to adapt it for experiments on atmospheric electricity. They found, as had been previously noticed by Cavallo, that the machine would start without any external charge. They thought that if machines were made on a large scale they would give sparks, thus probably giving the first suggestion of the modern use of the influence machine.

In 1804 Hachette and Desormes devised a form of Nicholson doubler, having earth contacts to touch the movable disc while under the influence of one of the fixed discs, as in the improved Nicholson we have already described. The discs were about 3 inches in diameter, and the total length of the instrument was about 15 inches.

Bohnenberger's Machines.—Bohnenberger, in a small volume devoted chiefly to the subject of electrical doublers, describes a great variety of improved Bennet's and Nicholson's doublers. In the Bennet's doublers the discs are mounted to work mechanically, and resemble in construction Cavallo's "multiplier," already described. In one form of the Nicholson type of machine the line joining the centres of the fixed plates is vertical, instead of being horizontal, as in the original machine. In another form the axis of rotation is a vertical pillar, and one disc is fixed, while two are made movable.

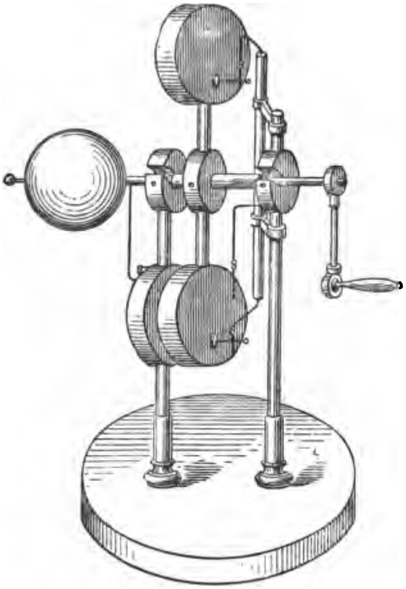


Fig. 30. BOHNENBERGER'S MACHINE.

One of Bohnenberger's machines is shown, Fig. 30. It was constructed very simply of pieces of wood, cork, and glass rods.

In 1804 Wilson made an improvement in Cavallo's apparatus, which converted it from being an addition machine into a genuine multiplier. There were in this apparatus, two movable plates, *B* and *D*, Fig. 31, which were carried on reciprocating levers, as in Cavallo's machine. The initial (positive) charge to be multiplied was communicated to an insulated plate *A*. The plate *B*, when brought close to *A*, made earth connection by touching the wire *P*, and received a negative charge. This negative charge was communicated

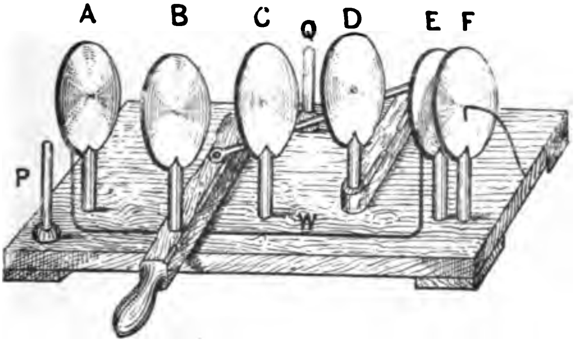


FIG. 31. WILSON'S MACHINE.

to *C* by moving *B* up to *C* till it touched it. The disc *D* being at the same time close to the other face of *C*, and earth-connected through the rod *Q*, received a positive charge, which it communicated by contact to *E*, in conducting communication by means of a wire *W* with the disc *A*. The original charge on *A* was thus increased, and in the next operation all the induced charges will be proportionally increased, and so on for succeeding operations.

Ronalds' Pendulum Doubler.—This instrument was devised in 1823 by Sir F. Ronalds for telegraphic purposes. The principle of its action is exactly analogous to that of Nicholson's, the movable disc forming the bob of a pendulum. *A* and *B*, Fig. 32, are two fixed discs, and *C* is the movable disc which swings backwards and forwards

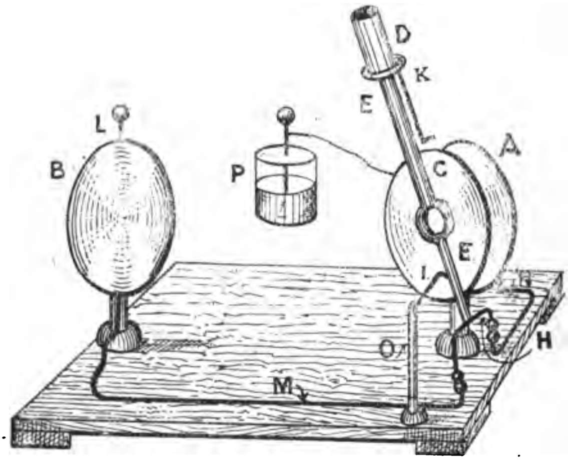


FIG. 32. RONALDS' PENDULUM DOUBLER.

in front of them. Let us assume that *C* has a small initial charge of positive electricity, which is prevented from escaping by the insulating portion *E* of the pendulum rod. When *C* is in front of *B*, *B* is put to earth through the contact of a wire *L* fixed on *B* with a wire *K* connected to a conducting part of the pendulum rod *D*. A negative charge will thus by influence be produced on *B*. *C* now swings in front of *A*, the bent wire *H* on the pendulum connects *B* to *A* by touching simultaneously the wires *M* and *N*, and the negative charge is drawn from *B* to *A*. *C* is at the same time put to earth through the wires *I* and *O*, thereby slightly reducing [illegible] the charge on *C*. *C* again swings in front of *B*, producing another charge somewhat smaller than the last, on *B*, which, at the end of the next swing in front of *A*, is transferred to *A*. *C* now receives a larger charge of positive electricity which increases the negative charge of *B*, and so on—the potential of *A* finally becoming high enough to produce a spark. A Leyden jar may be connected to *A* to store up the charge. The oscillations of the pendulum are produced by the usual arrangement of clockwork. The apparatus might be very convenient where a constant discharge of spark for a considerable length of time was required.

[illegible]

in Fig. 33, consist of two pieces of metal bent into a semi-cylindrical form and supported on insulating pillars. The movable parts or carriers consist of two metal discs about $1\frac{1}{2}$ inches diameter, carried on a glass stem, mounted transversely on an axis which is fitted with a winch handle for turning. A neutralizing rod is mounted

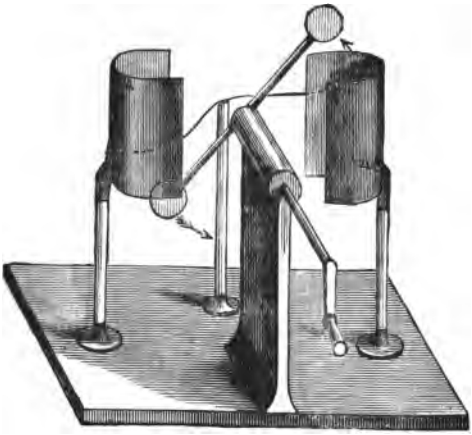


FIG. 33. BELLI'S MACHINE.

on a pillar fixed at the back of the apparatus, its ends being so situated that they touch the carriers just before they leave the inductors or field plates. Two springs are soldered inside at the opposite ends of the inductors, and so arranged that they touch the carriers just after they have entered the inductors.

In this machine, as in the doublers, the field plates will usually have a small charge to start with. We shall assume that the right-hand field plate has a small positive charge. The carrier just before leaving this field plate touches the end of the neutralizing rod, and thus acquires by influence a negative charge. The carrier in the course of its revolution passes round with this negative charge to the left-hand field plate, and just after entering comes in contact with the receiving spring and communicates its charge to the field plate. This field plate is now negatively charged, and imparts by influence a positive charge to the carrier when it is in contact with the neutralizing rod just before leaving the field plate. The positive charge is transferred by the carrier to the right-hand field plate when it comes in contact with its receiving spring. The positive charge in this field plate is thus increased. The carrier on the other end of the transverse rod acts in an exactly similar way. The result of the continued operation of the machine is that negative electricity accumulates in one field plate and positive electricity in the other field plate, and if suitable discharging rods are connected to the field plates sparks will be obtained. The action of this machine differs from that of the doubler in the fact that its action depends on the direction of rotation of the carriers. Rotation in one direction will increase the difference of potential between the field plates, in the other direction it will reduce the difference of potential, even though it was very high to start with.

Another machine of Belli's consists mainly of a glass disc rotating inside a box. The glass disc rotates on a vertical axis, Fig. 34, and on its upper surface are glued three tinfoil sectors *N*, the edges of which are not in contact. The box is made in two halves $A\ A_1$, having double walls of iron plate carefully insulated from each other by resin. The inner walls are connected to the two metal wires $l\ l^1$, which are insulated from the outer walls by glass tubes. Insulated wires $p\ q\ r$ and $p^1\ q^1\ r^1$ pass through small holes in the top walls of

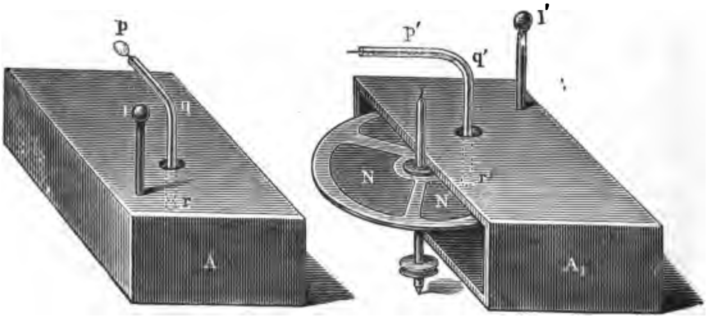


FIG. 34. BELLI'S MACHINE.

the two halves of the box, and have fixed to their lower ends fine wire brushes which rub against the tinfoil sectors on the glass disc. To start the machine the inner wall of *A* has a very small positive charge imparted to it (for example, from a silver coin held in a damp hand and placed in contact with the knob l^1). If the sector inside is put in contact with the earth by means of the wire $p\ q\ r$, a negative charge is induced upon it. On turning round the disc the negative electricity is communicated to the inner coating of *A* by

$p^1\ q^1\ r^1$, which is temporarily connected to it. A negative charge of electricity is thus accumulated in the second half of the box. The brush connections are now exchanged, one being put to earth and the other to the inner wall of the other half of the box. The two inner walls are insulated, and one wire, say $p\ q\ r$, is

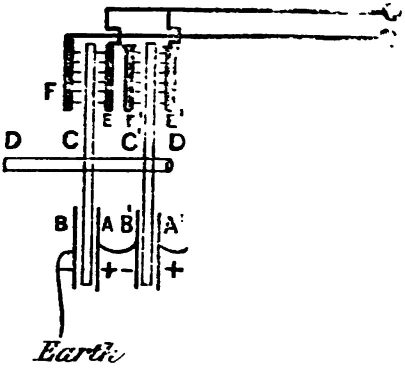


FIG. 35. GOODMAN'S MACHINE.

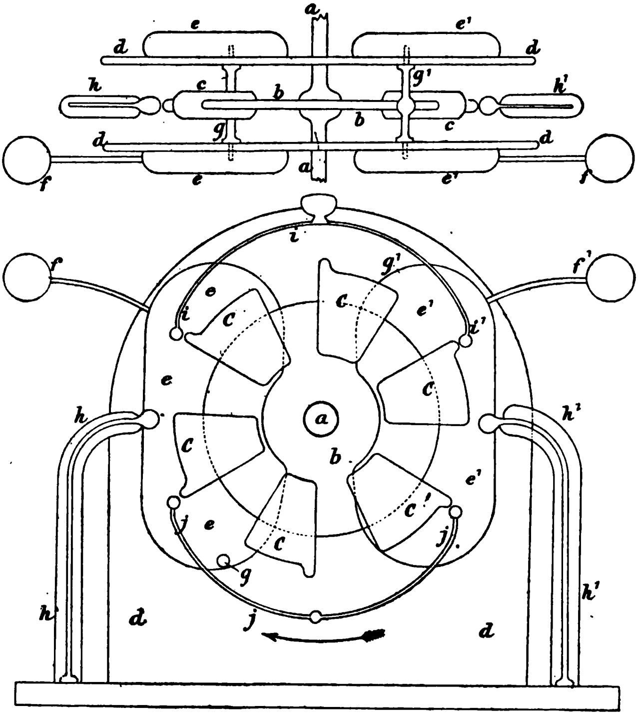
connected with the earth, while the other is connected with the body to be electrified.

Positive or negative electricity may be obtained according as one wire or the other is connected to the earth.

Goodman.—In 1840 Goodman of Birmingham described a machine which, if not very efficiently designed, involved one important principle, which was afterwards employed in the Holtz machines and considered one of their most important characteristics, namely, the use of the surface of the glass without metallic coatings for conveying the electric charge from the field plates to the collecting combs. Goodman's intention was to imitate in his machine the experiment with a Leyden jar with movable coatings, in which it is shown that the positive and negative charges are left on the surface of the glass after the metallic coatings have been removed. Two fixed metallic plates represent the coatings of the Leyden jar; one of these, *A*, Fig. 35, is insulated, and receives a charge from an external source, the other, *B*, is connected to the earth. A glass disc *C* rotates on an axis *D D*. As its periphery passes between the plates *A B* the two surfaces of the glass receive opposite charges, which they carry round and deliver to the combs *E* and *F* at the opposite side of the disc. Goodman constructed multiple plate machines on this principle, by fixing additional discs, such as C^1, on the same axis, with field plates A^1 B^1 and collecting compounds E^1 F^1, arranged on the same principle as in the single machine.

of testing them on the electroscope or electrometer, but in perfection and simplicity of design it has

Plan.



End.

Fig. 36. Varley's Machine.

scarcely been excelled by the most modern types of the influence machine.

The machine was patented by C. F. Varley in 1860.

In the specification of his patent he states so clearly the principle underlying the design of modern influence machines that his words are worth quoting. He says, "I placed an insulated plate or conductor near or between two other suitable conductors; these being charged statically induce in the former the contrary state, the inner plate being momentarily connected to earth to give or to take positive electricity. This plate is then moved and placed between two other plates, and then allowed to touch them, by which it gives them its acquired charge; then moved out of contact, but while between them it is made to touch the earth, by which it acquires through induction a charge of the opposite kind to the former one; it is then taken back to the first pair, to which it gives up its new charge; then moved out of contact, but while between them it touches earth, which renews the first charge, but a little stronger; thus by continuing the process the charge rapidly augments to the required amount."

This principle was developed in his machine. Metallic carriers *c*, Fig. 36, were mounted on the periphery of a glass disc *b* turning on an axis *a*.

On each side of the disc were fixed glass plates *d d*, on the outer surfaces of which field plates $e\,e^1$ (four in all) were mounted, and connected by metallic transverse rods $g\,g^1$. Small projections on the carrier plates *c* touch the transverse rods $g\,g^1$ as they pass them, and also the knobs on the end of earth-connected wires $h\,h^1$ covered with insulating substance. The electrodes $f\,f^1$ are connected to the field plates $e\,e^1$. Neutralizing rods *i* and *j* are shown in the drawing "to increase the power of the machine," though it is difficult to see how it would do so. A multiple plate machine on this principle is also described in the same specification. It should be noted that Varley's machine differed from the doublers in being symmetrical.

About the year 1865 the subject of influence machines was taken up with great energy in Germany by Toepler and Holtz. Their first machines appear to have been invented almost simultaneously.

We shall first deal with Toepler's machines.

Toepler's Machines.

In 1865 Toepler, requiring a supply of high potential electricity for some experiments on which he was engaged, designed a machine which appears to have had its origin in an attempt to construct a continuous electrophorus, though it contained an appliance for replenishing the field plate, through the influence of which the main charge was produced.

Before describing the actual machine we shall first discuss the principle of its construction with the aid of a diagrammatic sketch, in which for clearness discs in the actual machine are represented by cylinders. *A*, Fig. 37, represents a cylindrically curved fixed field plate, in front of which two similarly curved plates *B* and *C*, insulated from one another, rotate about the axis *P*. A similar apparatus, called by Toepler the "Regenerator," consists of a field plate *H* and two plates *K* and *L* rotating about the axis *Q*. Brushes *D E* and *M N* are fixed so as to rub on *B C* and *K L* respectively as they pass under them; *F* and *G* are electrodes between which the sparks pass. Connections are made as shown in the sketch. *B C* and *K L* are rotated in the directions shown by the arrows at equal angular velocities, *i.e.*, the same number of revolutions per minute. Neglecting for the moment the action of the regenerator, we shall suppose that a small negative charge is imparted to the field plate *A*. The carrier *C* in the course of its rotation comes first in con-

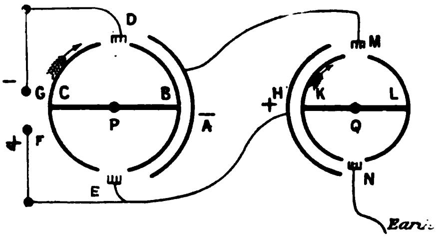


FIG. 37. DIAGRAM. OF TOEPLER MACHINE.

tact with the brush *D*, and then passes in front of the field plate *A* till it occupies the position of *B* in the diagram. The negative electricity in *A* induces negative electricity in the electrode *G* and positive electricity in the carrier *C*. The carrier *C* now breaks contact with the brush *D*, and makes contact with the brush *E*. No transference of electricity to the brush *E* takes place till *C* is sufficiently removed from the influence of *A*, and just before it breaks contact with the brush *E* and returns to its initial position, the last of its positive charge will be discharged through the brush *E* to the electrode

L. The carrier *B* goes through an exactly similar cycle of operations, adding to the charges of positive and negative electricity on the electrodes *F* and *G* respectively, till the difference of potential is sufficient for sparks to pass.

The object of the regenerator is to maintain the charge in the field plate *A*. Its action is exactly similar to that part of the machine just described, but instead of sending its positive and negative charges to electrodes it sends its negative charge to the field plate *A* and its positive charge through the brush *N* to earth. The field plate *H* of the regenerator is excited reciprocally from the brush *E* of the main machine.

The actual machine as constructed by Toepler is shown in Fig. 38.

The field plates A_1 consist of plates of glass covered on the lower side with tinfoil. On the under side of the main disc are glued two tinfoil sectors *A* and *B*, separated from each other by a sufficient distance to secure good insulation; similar sectors *a* and *b* are glued on the under side of the regenerator disc. The main disc and regenerator disc are fixed on the same vertical axis and set in rapid rotation by a belt and pulley gear, as shown in the illustration. The brush *f* is in connection with the electrode *i*, the brush *e* with the electrode *k*, and also with the field plate a_1 of the regenerator; the brush *f* is in connection with the earth, and the brush *e* with the field plate *A*. The action of the machine will be easily understood on comparing these connections with the diagrammatic sketch in the last figure. An

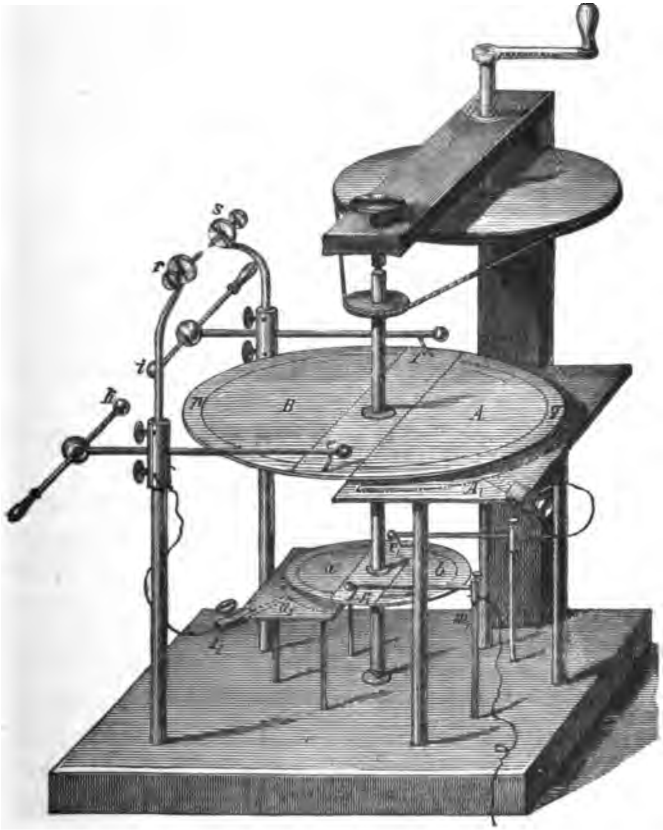


FIG. 38. TOEPLER MACHINE.

extra pair of pointed electrodes *r s* are fixed to prevent the difference of potential becoming so great as to cause internal sparking in the machine.

Toepler has shown that it is not necessary to electrify the field plate A_1 to start the machine. Different causes have been assigned for the self-excitement, such as the friction of the air or the brushes, or the hypothesis that a small difference of potential always exists between opposing conducting surfaces.

These machines, as well as all others with conducting carriers, have the advantage over other machines in which non-conducting carrying surfaces are used, that they are less sensitive to the influence of atmospheric moisture; but, on the other hand, they have the disadvantage that they supply less continuous currents.

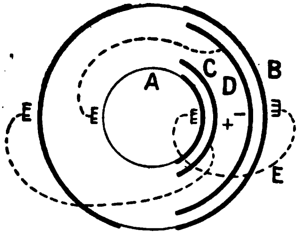


FIG. 39.
DIAGRAM OF TOEPLER MACHINE.

In 1866 Toepler made a comparison between machines having glass plates without metal carriers and corresponding machines with metal carriers. In connection with his experiments on this subject he described a machine which was a step in advance of his first machine. The two rotating discs *A B* (which are represented in Fig. 39 by cylinders) are of equal size and mounted on a horizontal axis, though at some distance apart. Between them, and both at the same side of the shaft, are two fixed field plates *C D*, consisting each of a plate of glass coated with tinfoil on the side furthest from the rotating disc. The field plates are close to their respective rotating discs, and are charged with opposite kinds of electricity; they are regenerated by supplies taken from charges induced in the rotating disc beyond the influence of the field plate. There is a neutralizing circuit *E*, consisting of a conductor joining together two brushes which stand outside the two discs exactly opposite the two field plates. The arrangement of the machine is symmetrical.

In 1867 a machine, Fig. 40, was described in which both field plates were placed behind a single rotating disc, and on the opposite sides of its axis the charges on the field plates were, as in the last machine, replenished or regenerated by bringing round from the field plates cross conductors terminating in brushes which touched the carriers as they came opposite the field plates.

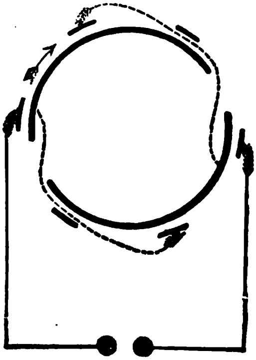


FIG. 40. DIAGRAM OF TOEPLER MACHINE.

Toepler exhibited at Cassel in 1878 a machine constructed on this principle. It consisted, Fig. 41, of a fixed polygonal glass plate in two parts, *A* and *C*, on each of which is fixed at the back a metallic field plate. On the face of the glass disc *D*, which rotates in front of the fixed plate, a number of tinfoil carriers are glued, while to the centre of each carrier is fixed a projecting semi-cylindrical piece of metal upon which the brushes of the machine may rub. Two brushes are fixed on wooden knobs *G* and *H*, on the ends of an oblique glass rod, and each is connected to the field plate on the opposite half of the fixed plate by conductors passing round its edge. Combs *K* and *L* are fixed in front of the rotating disc at opposite ends of the horizontal diameter, one

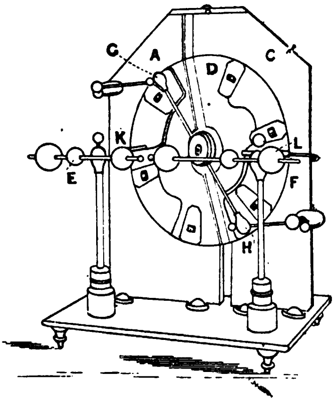


FIG. 41. TOEPLER MACHINE.

tooth in each comb being replaced by a brush which as the disc rotates comes in contact with the projection on the centre of each carrier. The comb *K* is connected to the electrode *E*, and the comb *L* to the electrode *F*,—the whole arrangement being supported on insulating pillars.

According to Toepler's investigations an increase of the charge is obtained by a combination of the brush and comb. The self-excitement of the machine is probably assisted by the brush fixed on the comb, as the electrode circuit in this machine takes the place of a device which we shall find in later machines, called the *neutralizing fork*, the function of which is to equalize the potential of two diametrically opposite carriers. The diagram, Fig. 42, may help to explain the action of

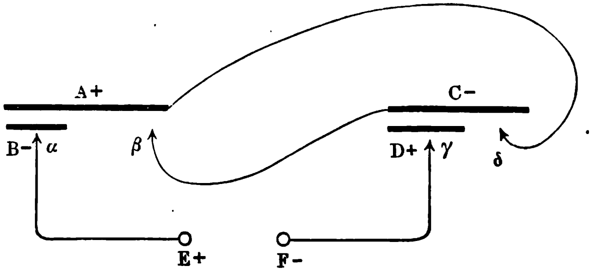


FIG. 42. DIAGRAM OF TOEPLER MACHINE.

the machine. *A* and *C* represent the two field plates; *B* and *D* two carriers passing in front of the field plates. *E* and *F* are the electrodes, which are placed in contact before starting the machine. If *A* has a small positive charge, by influence a negative charge will be imparted to *B*, and a positive charge to *D*, which is connected with *B* by the electrode circuit and the brushes α and γ. As *B* and *D* move across the field plates they leave the brushes α and γ, and come in contact with the brushes β and δ, which are connected respectively to the field plates *C* and *A*. The potential of *C* will be always somewhat higher than that of *B*, owing to the arrangement of the surrounding electrified bodies. Positive electricity will pass from *C* to *B*, and leave the field plate *C* with a negative charge. For a similar reason, positive electricity will pass from *D* to *A*, thereby increasing the charge on *A*. The charges on *A* and *C*, and consequently their positive and negative potentials, will go on increasing in geometrical progression, or according to the law of compound interest, till the limit fixed by leakage is reached. A correspondingly great difference of potential will be induced between the carriers *B* and *D*, which pass in front of the field plates, and if the electrodes are separated powerful sparks will pass between them. As there will always be a certain difference of potential between *A* and *C*, it is not necessary to impart any charge to the machine to start it. In criticising the design of this machine, we may point out that it would greatly facilitate the transference of the electricity from *B* to *C* if *B* were entirely removed from the influence of *A* before it touched the brush *B*, that is to say, it should make contact with *B* in a position much closer to *C*. The same holds for *D* with respect to *A*. It will be found that this improvement has been carried out in a later machine—the Voss.

The glass pillars which carry the conductors of the machine just described are glass tubes set in porcelain cups. The latter are coated outside and inside with tinfoil, so as to form conductors. Metal wires fixed to the electrodes pass down the centre of the tubes, thus forming condensers in connection with the electrodes.

To obtain larger quantities of electricity, Toepler has made machines on the above principle, with a considerable number of plates. He has exhibited two machines at the Paris Exhibition, with twenty and sixty rotating plates respectively. At the Vienna Exhibition, the Mechanical Institute of the Royal Polytechnic of Dresden exhibited one machine with twenty rotating plates and another machine with thirty, constructed by Oscar

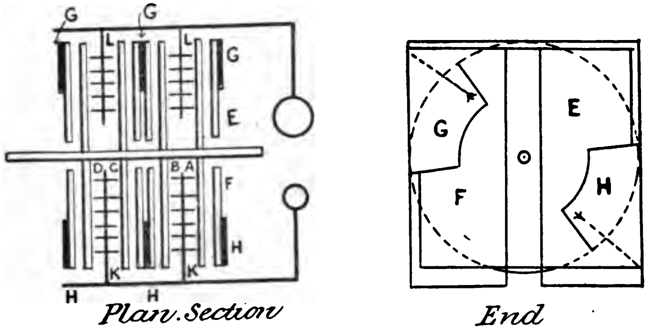


FIG. 43. DIAGRAM OF GREAT TOEPLER MACHINE.

Leuner on Toepler's system, and driven either by hand or a motor.

The arrangement of these multiple machines will be understood from the adjacent figure, Fig. 43. A number of discs *A*, *B*, *C*, *D*, &c., are fixed on the same axis. The field plates *G H* are carried on glass plates made in two halves (as *E F*), to clear the axis of the discs. Carriers are mounted on the rotating discs, as in the single machine, and the electricity is drawn off by forks

K and *L*, passing between the rotating discs and connected to the electrodes as shown in the figure. The arrangement of the regenerating brushes is shown on the end view, Fig. 43; these are fitted on the first and last

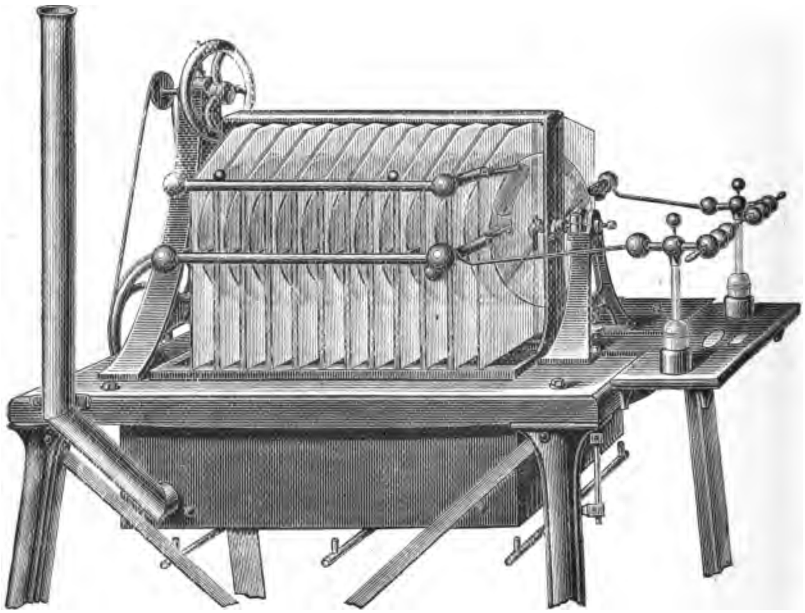


FIG. 44. GREAT TOEPLER MACHINE.

plates only; and all the field plates on one side are connected together by rods parallel to those which connect the forks. Only the end discs have metallic carriers glued upon them, the other discs being uncoated as in the Holtz machine.

The complete machine is illustrated in Fig. 44. The electrodes of this machine rest upon two glass tubes inserted in porcelain cups. The cups are coated inside and outside with tinfoil, and thus serve as Leyden jars. To connect them with the electrodes, wires furnished with knobs at the top are dropped through the glass tubes till they touch the bottom of the cups.

The whole apparatus stands on a very firm table of cast iron. The axis can be set in rotation by a system of belts and pulleys by hand power or motor (for example, a small electric motor). The discs are covered with a glass case, inside which a dish of linseed oil is placed to absorb the ozone, and out through which the electrodes project. From below, the table which carries the apparatus can be heated by gas-flames contained in a sheet-iron box with a chimney. Such a machine, with 20 discs, each 26 cm. diameter, the axis of which made 22 revolutions per second with an expenditure of 4 kilogrammetres of work, supplied a current of electricity of 0·0081 absolute units, when measured by passing the current through a U-formed glass tube filled with water and a tangent galvanometer. The strength of the current was found to be proportional to the number of revolutions per second.

With an increased striking distance, or length of spark, amounting to 55 mm., with electrode balls of 8 mm. diameter, and a regular stream of sparks, the strength of the current decreases.

With insulated electrodes connected to Leyden jars, the striking distance, with a regular stream of sparks, may amount to as much as 130 mm.

By measurement it was determined that when the length of spark was 55 mm., the current was such that the energy developed per second was equal to 0·8 kilogrammetres per second.

A battery of eighteen large jars furnished every 0·6 seconds a discharge which heated a platinum wire of 0·12 mm. thickness to a dark red.

According to these experiments these machines furnish very considerable quantities of electricity. They are not, however, suited for technical application, owing to the delicacy of the parts and the great speed of rotation required. Moreover, dust is liable to collect on the discs, in spite of the protecting glass case, and the shellac coating, owing to its destruction by the sparking, has to be frequently renewed. For scientific purposes the machines are to be highly recommended.

Toepler's Non-regenerative Machines.—In another series of machines which he devised, Toepler appears to have taken a retrograde step from the principle of those just described—the field plates receiving initial charges which were not regenerated or replenished during the operation of the machine. A machine of this class is illustrated in Fig. 45. Upon the back of a fixed plate are glued two paper field plates, *A* and *C*, called the "distributors." In front of this a glass disc rotates, upon which a number of tinfoil carriers are glued, having each a semi-cylindrical projection of brass in the centre for the brushes to touch. The electrodes *E* and *F* have brushes of silver wire, which rub on the carriers as the disc rotates.

If the field plates *A* and *C* are oppositely charged, for example, *A* positively and *C* negatively, the carriers *B* and *D* opposite to them will, by influence and contact with the electrodes, through the brushes receive charges

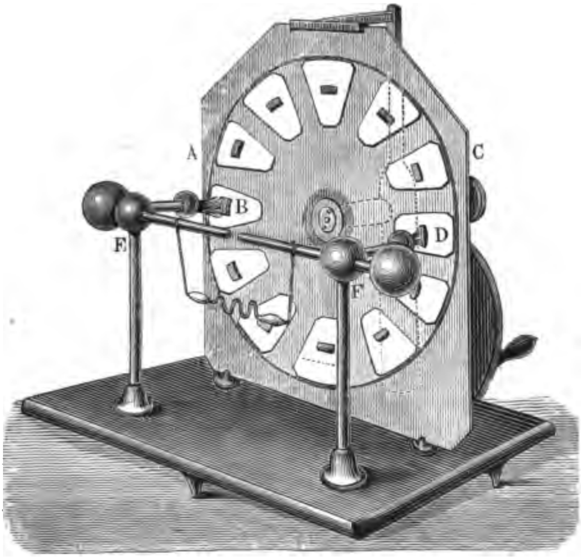


FIG. 45. TOEPLER MACHINE.

of the opposite sign to their respective field plates, while the electrodes *E F* will receive charges of the same name as their respective field plates. If the disc be now turned till the negatively charged carrier *B* comes in contact with the brush of the negative electrode *F*, under the influence of the negative field plate *C*, an additional negative charge will be imparted to *F*. A similar cycle of operations takes place owing to the transfer of *D* to a position in front of the electrode *E*, whereby the positive charge of *E* is increased. All the carriers act in a similar manner, and a continued discharge is produced between the electrodes as long as the fixed charges last.

CHAPTER III.

MODERN MACHINES (CONTINUED): HOLTZ MACHINES.

THE first machine devised by Holtz in 1865 was on the principle of the mechanical electrophorus, and belonged to what we have called the addition class of machines.

It consisted of a fixed glass disc, on one side of which an even number of tinfoil sectors was pasted, and charged alternately positive and negative from a small electric machine. In front of this disc, opposite the glass side, was mounted, so that it could be put in rapid rotation, another glass disc, having the same number of tinfoil sectors pasted on its outer surface. As the disc rotated the movable sectors passed alternately in front of the positively and negatively charged fixed sectors. By influence a negative and positive charge would thus be alternately induced in each of the movable sectors, and when sectors in which similar charges were generated were connected together, the charges could be drawn off by collecting combs.

In the same year Holtz described a machine of the type which is now generally associated with his name. This belonged to the multiplying class of machines, the field plates being replenished by the machine itself, and not separately excited.

A disc of thin flat plate glass is mounted on a horizontal spindle, which can be set in rapid rotation by means of a belt and pulleys. Opposite this disc is fixed another, Fig. 46, of slightly larger diameter, and at a short distance (say $\frac{1}{8}$ inch) from the first disc. In the edge of this disc are two notches *A* and *B*, and near their edges, at the back of the disc, are pasted two paper field plates *C* and *D*. One side of each of the field plates has toothed projections *c* and *d* formed upon it, and these protruding through the notches in the disc bend forward till their points almost touch the surface of the rotating disc in front. The field plates are also sometimes bent round the edges of the notches and pasted on the front surface of the fixed plate. When considered with reference to the direction of rotation of the movable disc, a notch always precedes a paper field plate. In front of the rotating disc are placed the *collecting combs*, which consist of a series of pointed wires attached to a radial bar as the teeth are attached to the back of a comb. These collecting combs are placed opposite the paper field plates at some distance back from the toothed edge, and supported on rods parallel to the axis of the disc, leading to the discharging electrodes.

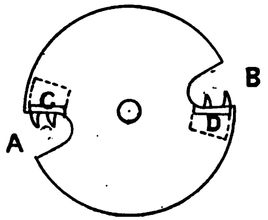


FIG. 46. PLATE OF EARLY HOLTZ MACHINE.

As the operation of this machine is the same as in a later form of the Holtz machine which we shall next describe, it is unnecessary at present to describe it. The principal point of interest about this is that it was the first form of the present type of the Holtz machine. The chief difference between it and the present machine is in the fixed plate shown in Fig. 46. In this, as we have seen, the openings *A B* are notches cut in the edge of the plate; in later machines these openings were holes cut in the glass disc near its edge. These holes would be much more difficult to cut than the notches, and it is questionable whether they improve the action of the machine.

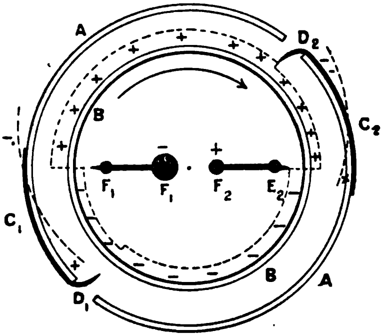


FIG. 47. DIAGRAM OF HOLTZ MACHINE.

The operation of the Holtz machine will be understood from the diagram shown in Fig. 47. As in previous diagrams to show the action of the machine more clearly the glass discs will be assumed to be cylinders. The fixed glass disc is represented by the cylinder *A A*, the glass disc which rotates in front of it by the cylinder *B B*. On the back of the fixed disc are glued two paper field plates, or, as they are sometimes called, armatures, C_1 and C_2. From one end of each of the field plates, tongues or teeth D_1

and D_2 project through apertures cut in the fixed disc, bending towards but not touching the movable disc *B B*. Collecting combs E_1 and E_2 are fixed in front of the rotating disc, and opposite the ends of the field plates furthest removed from the tongues D_1 and D_2. The collecting combs are connected by metal rods to the electrodes or discharging knobs F_1 and F_2, between which the sparks pass when the machine is in action.

To start the machine a charge, say of negative electricity, is communicated to one of the field plates, say C_1, and the disc *B B* is set in rotation in the direction shown by the arrow. By the influence of this charge negative electricity is driven through the collecting comb E_1 to the electrode F_1, and a charge of positive electricity is left on the surface of the revolving disc, by which it is carried round till it comes opposite the tongues D_2 on the other field plate C_2. By means of points the greater part of the positive charge is communicated to the field plate C_2, which now in its turn by influence repels positive electricity through the collecting comb E_2 to the electrode F_2, and leaves a negative charge on the surface of the disc. This negative charge is carried round by the disc and communicated by means of the points D_1 to the field plate C_1, increasing the charge originally imparted to it. This action will go on till C_1 and C_2 have acquired the maximum charge they are capable of retaining. This increase takes place according to the law which we have already found to hold for all multiplying influence machines, that is, the compound interest law.

In the diagram Fig. 47 we have endeavoured to indicate roughly the distribution of electricity on the machine when it is in full action. The exact distribution has not yet been determined. The distance of the dotted lines from the glass surfaces indicates the intensity of the electrification, or the electro-motive force at any particular part of the surface. When the dotted line is on one side of the glass surface it indicates positive electricity, and when it is on the other, negative electricity, the + or − signs marked under the dotted line showing which of the two is indicated. With these explanations we can see that the charge on the surface of the revolving plate from the collecting comb E_1 round in the direction of rotation to the points D_2 is positive. After passing D_2 this positive charge is slightly reduced by the amount necessary to supply the leakage from the field plate C_2. At the collecting comb E_2 the charge is changed from positive to negative under the influence of the charge on C_2. From the collecting comb E_2 round to the points D_1 the charge on the plate is negative. At D_1 a certain proportion of the negative electricity is communicated to the field plate C_1, and the negative charge on the plate from D_1 to the collecting comb E_1 is somewhat less. At E_1, under the influence of the charge on C_1, the negative charge is changed to a positive charge, and we arrive at the point we started from.

To determine the distribution of electricity on the field plates we must consider the effect of all the charges in the neighbourhood of a field plate. Let us consider the field plate C_1. The negative charge on the surface of the plate *B*, extending from opposite D_1 to opposite E_2, may approximately be looked upon as a negatively charged long conductor placed in line with C_1 opposite the end D_1, as in the actual machine the plates *B* and *A* are much closer together than in the diagram. Secondly, the positive charge on the surface of the plate *B*, extending from opposite E_1 to opposite D_2, may be similarly looked upon as a positively charged long conductor placed in line with C_1 opposite the upper end of C_1. Lastly, the negative charge on the surface of the plate *B* between D_1 and E_1 may be looked upon as a negatively charged conductor placed parallel with C_1. The first and second electrified surfaces have the same effect on C_1, that is to say, they induce by influence positive electricity towards D_1 and negative electricity towards the other end. If C_1 were symmetrical the neutral point would be in the centre of C_1, but owing to the existence of the points at D_1 it would, other things being equal, be nearer D_1. The effect of the parallel charge from D_1 to E_1 is to displace the curve of distribution on C_1 in a lateral direction, and so as to move the neutral point towards D_1.

The above diagram can only be taken to indicate approximately the distribution of electricity in the Holtz machine, as a sufficient number of experiments has not yet been made to settle the question finally.

To start the machine it is necessary to impart a charge to one of the field plates and put the electrodes in contact; then after a few turns they may be separated, and sparks will pass between them. If a Leyden jar be connected to each of the electrodes, they will be charged and discharged rapidly between the knobs. It is found, by gradually increasing the distance between the knobs, that at a certain point the sparks will cease, the direction of the current in the electrode circuit will be reversed, and the jars pumped out; then if the electrode circuit be quickly closed, the jars will be charged in the opposite direction. If the electrodes are not quickly closed after reversal the excitement will die out. A consideration of the diagram will show the probable cause of this phenomenon. If no discharge takes place between the electrodes the sign of the electricity will not be reversed at the collecting combs. Consequently negative electricity will pass round from E_1 to D_2, and positive electricity from E_2 to D_1. The field plates will thus receive an opposite charge from what they originally possessed, and the action of the machine will be reversed or die out.

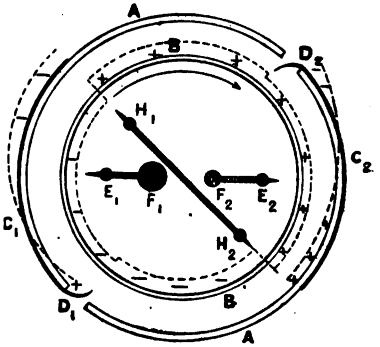


FIG. 48. DIAGRAM OF HOLTZ MACHINE WITH NEUTRALIZING ROD.

To prevent this reversal Holtz has introduced a device called the *neutralizing rod.* Fig. 48 is a diagram of a Holtz machine fitted with a neutralizing rod H_1 H_2. The neutralizing rod consists of a transverse conductor furnished with collecting combs at each end. All the other parts of the machine are marked with the same letters as in Fig. 47, and are the same, except the field plates C_1 C_2, which are extended so that their extreme ends lie opposite the collecting combs of the neutralizing rod. The electrodes F_1 and F_2 are supposed to be so far removed that sparks will not pass between them. In consequence of this the sign of the electricity on the surface of the rotating plate will not be reversed on passing the collecting combs E_1 E_2. The charge on the surface of the plate will thus remain the same till it reaches the collecting combs H_1 H_2 of the neutralizing rod, when a complete reversal will take place in consequence of there being practically no resistance in the rod. In the ordinary working of the machine, when sparks are passing between F_1 and F_2, the neutralizing rod will have no work to do, except to complete the reversal of the charge which has already been more or less perfectly effected at E_1 and E_2. Having now explained the operation of the Holtz machine, we shall proceed to describe the machine as usually constructed. The machine is illustrated in Fig. 49. A disc of thin glass, lacquered on both sides, is mounted on a vulcanite tube which turns on a fixed steel axis. A rapid rotation can be imparted to the disc by a belt and pulley arrangement. Behind the rotating disc another disc is fixed between two ebonite holders. The fixed disc has a hole in the centre for the passage of the axis of the rotating disc, and is perforated in two places at opposite ends of a horizontal diameter with oval holes which become narrower towards the centre of the disc. Upon the side of the fixed disc turned away from the rotating disc the

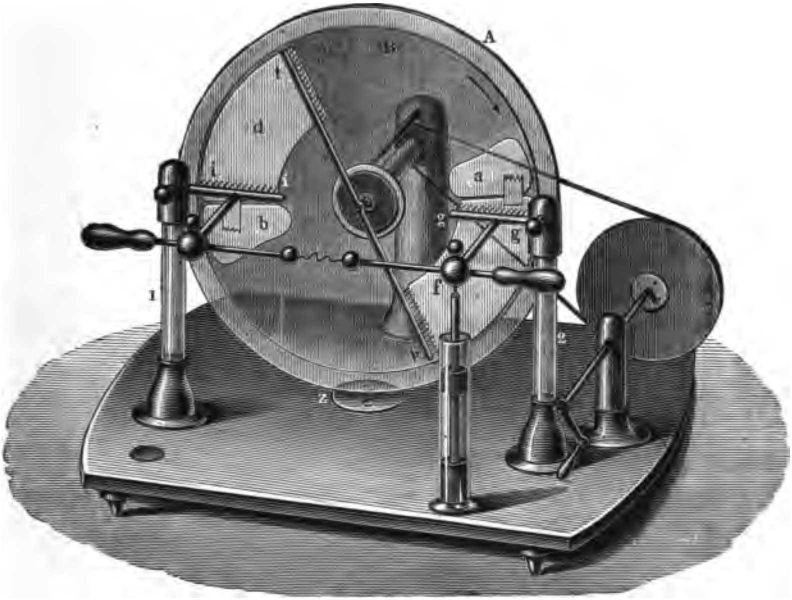


FIG. 49. HOLTZ MACHINE.

field plates, consisting of paper sectors with a central angle of 60°, are glued are. They in connection with small paper strips glued upon the front side of the disc opposite to them, and close to the holes, which strips carry two thin metal plates bent forward towards the revolving plate and sharpened to one or more points or to an edge. The fixed disc stands in a slit in an ebonite plate, which can be moved nearer to or further from the revolving plate. Above the axis of the revolving disc, it hangs by the upper edge of the central perforation, in a slit in an ebonite rod, with which it can also be moved nearer to or further from the revolving disc. On both sides it is held by ebonite knobs. In front of the rotating disc, opposite the horizontally placed strips, there are two collecting combs, which are attached to metal rods parallel to the axis and furnished at one end with perforated metal balls. These rods stand on carefully lacquered glass rods mounted on the baseboard of the machine. Through the perforated balls slide two discharging rods, each fitted at one end with an ebonite handle, and at the other with a discharging knob. By sliding one or both of the rods longitudinally in the perforated balls the length of the spark may be adjusted. The discharging knobs, which are preferably of different sizes, are removable, so that they can be interchanged if necessary. Since it has been found that leakage from the discharging rods takes place most readily at their exit from the ebonite handles, the latter are hollowed out in hemispherical form, so that the line of intersection of the brass and ebonite is almost completely inclosed by the ebonite cup. All the settings or unions are of vulcanite, which is carefully varnished to prevent deterioration by atmospheric influence.

In front of the rotating disc the neutralizing rod is mounted on the end of the fixed steel axis, so that it can be turned on its central point into the most effective position. At each end it is furnished with metal points or combs turned towards the surface of the revolving disc, and is so arranged that the combs stand nearly over the edge of the paper sectors of the fixed disc furthest removed from the perforations in the disc. Under the collectors of the electrode circuit are placed two Leyden jars, whose central wires pass into holes in the collectors, and whose outer coatings are connected by a strip of tinfoil. In another arrangement these jars may have a glass tube passing down the centre, through which passes a metal rod to make contact between the bottom of the jars and the conductors.

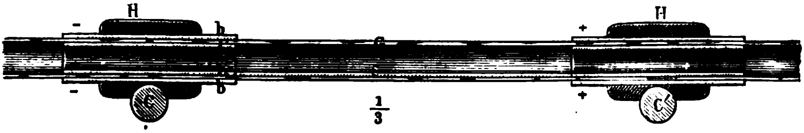


FIG. 50. HOLTZ TUBE CONDENSER.

A substitute for the Leyden jars has been devised by Holtz, and is illustrated, Fig. 50.

A glass tube *G*, about ½ inch in diameter, is coated near its ends inside and out with tinfoil rings *b b* and b_1 b_1. The outer tinfoil rings are surrounded by wooden rings $H H_1$, which are attached to the conductors C C_1 of the two electrodes. The inner coatings are connected by a small strip of tinfoil.

To understand the operation of the machine it is only necessary to compare it with the diagram Fig. 48. The cylinder *A A*, Fig. 48, corresponds to the fixed glass disc; C_1 C_2 represent the paper sectors or field plates glued on the back of the fixed disc. In the actual machine as described above small paper strips are also glued upon the front side of the disc, close to the edges of the holes in the glass, and connected to the paper sectors at the back; or the ends of the sectors may be bent through the holes and pasted along the inner edge. The object of these inside strips is to prevent an accumulation of the opposite kind of electricity on the inner surface of the fixed disc, for this would neutralize the influence of the charge of the sectors on the movable disc. The points or tongues are attached to this inner strip. The machine will work, however, without these inner strips; it is only necessary that the serrated ends of the sectors be bent through the holes so as to point towards the movable disc without touching it.

The collecting combs, which consist of a row of pointed wires fixed in a backing of brass tube or rod, are represented by E_1 E_2 in Fig. 48. The neutralizing rods represented by H_1 H_2 have similar combs at each end, also with points turned towards the surface of the revolving disc.

It will be observed that there are no metallic carriers on the surface of the rotating disc of the Holtz machine. The surface of the glass plate performs the same function as the metallic carriers in the Toepler and similar machines. The plain surface of the glass plate evidently does not retain a charge of electricity so long as a surface furnished with metallic carriers, as it is found that the Holtz machine, if left at rest for a short time, loses its charge, and requires to be re-excited from an external source.

For the *field plates* or sectors Holtz recommends a material, such as paper, of a resistance midway between that of a good non-conductor and a good conductor. According to Poggendorff, if a good non-conductor is used, the charge communicated to the points will not flow to the other end of the field plate where it is required to exercise its influence on the revolving plate. If the sectors are good conductors, for example made of metal, the charge originally communicated to them escapes too readily from their points on to the rotating disc, thus reducing the action of the machine. For the same reason blunt points on the paper coatings give better results than one or more very sharp ones. Poggendorff recommends a single point as being better than a greater number.

Some experiments made by the author do not altogether confirm Poggendorff's statements. It was found that a Holtz machine will work very well with tinfoil sectors if the collecting combs are placed opposite a part of the sector further removed from the serrated end than in the case of the paper sectors. A pair of sectors of paper and another pair of tinfoil were fixed successively with shellac varnish on the back of the fixed plate of a Holtz machine. The length of each sector subtended an angle of about 60°, and one end was notched so as to form teeth in the usual way. When the sectors were fixed on the disc, the serrated or pointed ends projected through the openings so as almost to touch the revolving plate. With paper sectors it was found that the collecting combs could be brought, without reducing the action of the machine, opposite a point much closer to the teeth of the sector than with tinfoil sectors. The tinfoil was found to answer quite satisfactorily, however, when the collecting combs were placed sufficiently far back from the serrated ends of the sectors. Tinfoil sectors subtending an angle as small as 20° were found to answer, while it was found that the machine would work with paper sectors of about one-half that length.

The fixed glass disc, besides acting as a support for the field plates, serves to prevent the dissipation of the charge on the surface of the revolving disc while it is being carried across from one pole of the machine to the other. For Reiss has found that if the paper sectors are mounted on two separate strips of glass, the machine will work, but its action very soon falls off. When a fixed glass disc covering the whole surface of the revolving disc, as in the machine described, is used, each part of its surface acquires an opposite charge of electricity to that on the surface of the revolving disc, and binds it in the same way as the charge on the outer coating of a Leyden jar is said to bind that on the inner coating.

Instead of openings of considerable width, as usually employed in the Holtz machine, Poggendorff tried narrow diametrical slits through which the pointed ends of the paper sectors projected towards the rotating disc. The machine was found to work, but its action was weaker. It has been suggested that this is due to the fact that the nitrous acid or ozone formed by the discharge is not readily removed, and conducts away the electricity.

Recently, however, machines have been constructed without any openings in the fixed disc. To avoid the difficult and dangerous operation of cutting openings in the disc, Pouchkoff glued the sectors on the back of the disc and the points in front, and connected them by a strip of paper passing round the edge. He found that a machine constructed in this way gave quite as good results as a machine constructed in the ordinary way.

The Holtz machine is very sensitive to atmospheric moisture. In damp weather it is generally not possible to start it. To get over this difficulty it is necessary to place the machine in a current of hot air from a suitable stove, or, to completely enclose it in a glass case, having a double bottom of sheet iron heated from beneath. To dry the air inside the case anhydrous phosphoric acid or concentrated sulphuric acid may be placed in shallow vessels inside the case. To remove the ozone and nitrous acid, which conduct away the electricity, a saucer containing linseed oil should be placed inside the case.

It is necessary to see that the glass plates and other parts of the machine are free from dust, since dust is found to disperse the electricity. The layers of shellac varnish on the discs are in time deteriorated by the action of the sparks from the combs, and have consequently to be renewed at intervals.

To excite the Holtz machine, we have seen that it is necessary to communicate to it a charge from an external source of electricity; it is not self-exciting. The method which is usually adopted is to communicate the starting charge to one of the field plates; but other methods have been adopted. One method is to allow electricity from Leyden jars to stream from the combs on to the surface of the rotating disc; another is to touch the field plates, thereby inducing in them a charge by the influence of the opposite electricities on the top or bottom halves of the movable disc (see Fig. 47), remaining from the previous operation of the machine. The latter method, it will be seen, is only applicable within a limited period of time from the stopping of the machine.

The Leyden jar method of exciting the machine, is of great interest, and throws considerable light on the theory of the Holtz machine. The discharging knobs of the machine are first separated beyond striking distance; the inside coatings of two oppositely charged Leyden jars (the outer coatings of which are connected), are connected one to each electrode of the machine. The machine is then turned.

In the first place we shall suppose that there is no neutralizing rod on the machine. Referring back to Fig. 47, let us assume that the positively charged jar is connected to the electrode E_1 F_1, and the negatively charged jar to the electrode E_2 F_2. From the comb E_1 positive electricity will be poured on the surface of the rotating disc, and carried round to the points D_2, where it imparts a positive charge to the field plate C_2. In the same way negative electricity will be discharged from the other jar, through the comb E_2, on to the surface of the rotating disc, and carried round to D^1, where it imparts a negative charge to the field plate

C_1. The field plates being thus electrified, the action of the machine will be the same as in Fig. 47, that is to say, positive electricity will be supplied to the electrode F_2, and negative electricity to the electrode F_1. Remembering the way in which they were connected up, we can see that the jars will be pumped out and charged in the opposite direction; care however must be taken to bring the electrodes within striking distance at the proper moment.

In the second place we shall assume that the machine is fitted with a neutralizing rod. Referring back to Fig. 48, we may suppose that the negatively charged Leyden jar is connected to the electrode E_1 F_1, and the the positively charged jar to the electrode E_2 F_2. Positive electricity is now discharged on the surface of the rotating disc from the comb E_2, is carried round by the rotating disc to the comb H_2 of the neutralizing rod, flows to the other end of the neutralizing rod, where it is discharged again by the comb H_1 on to the surface of the rotating disc, and carried round to the points D_2, through which a positive charge is imparted to the field plate C_2. In a similar way the other jar will impart a negative charge to the field plate C_1. When the field plates have received a sufficient charge, positive electricity will be supplied to the electrode E_2 F_2 to which the positively charged Leyden jar is connected, and negative electricity to the electrode E_1 F_1, to which the negatively charged Leyden jar is connected.

From these theoretical considerations we should expect to find, when there is no neutralizing rod, that with proper precautions the Leyden jars will be completely pumped out and charged in the opposite direction; when there is a neutralizing rod, that a small quantity will first be pumped out of the jars, then the current in the machine will be reversed, and the jars charged in the same way as they were originally, to as high a potential as the machine is capable of producing. Experiment shows that this is exactly what takes place.

Another arrangement of the neutralizing rod was introduced by Riess in 1870. The two field plates *a* and *b*, Fig. 51, were glued on the fixed disc in the usual way, while a third sector *c* was fixed at an angular distance of 90° from the other two, and connected by a conductor with *a*. Opposite each of these sectors, and in front of the rotating disc, three collecting combs

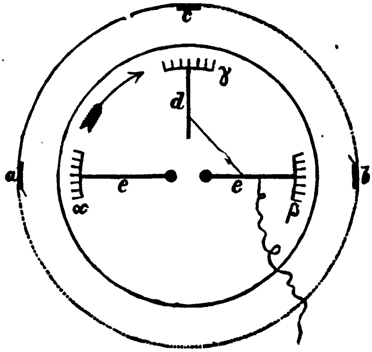


FIG. 51. RIESS'S MACHINE.

are situated. Those which are opposite *b* and *c* are connected together, and to the earth. If the sector *a* is positively charged, and the sector *b* negatively charged, when the discharging knobs are separated beyond the striking distance, positive electricity will be carried past the collecting comb *α*, without being reversed, but will be taken up by the comb *γ*, and discharged to earth, before it reaches the negative field plate *b*. The reversal of the charges in field plates is thus prevented as in the case of the ordinary neutralizing rod already described.

Kundt's Machine.—In 1868 Professor Kundt introduced a form of Holtz's machine, in which the reversal of the discharge was prevented by other means than the neutralizing rod. This machine is a combination of the old Frictional machine with the Influence

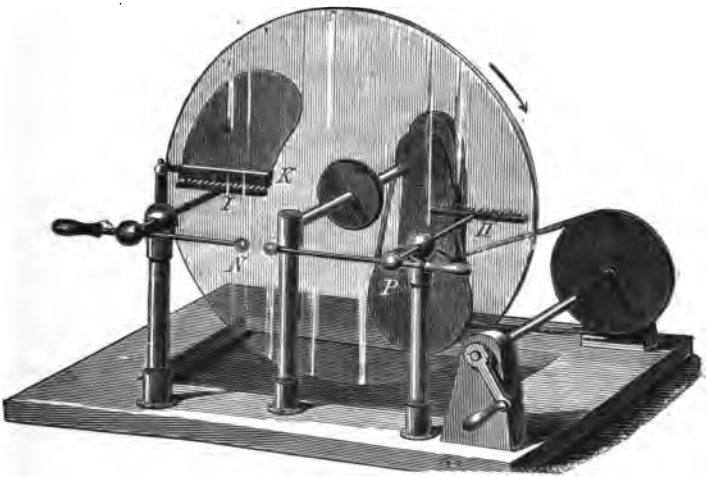


FIG. 52. KUNDT'S MACHINE.

machine. A rotating disc is mounted on a horizontal axis as in the Holtz machine, but there is no fixed disc. Behind the disc, and opposite one of the collecting combs *I*, is fixed on a suitable support a cushion rubbed with amalgam, and furnished with a silk flap, as in the ordinary frictional machine. The friction of the cushion against the back of the disc produces positive electricity, which is carried round by the movement of the disc to the other collecting comb *H*.

By the influence of the positive charge on the back of the disc, positive electricity flows into the electrode *P*, and the front side of the disc is left with a negative charge. By the further rotation of the disc this negative charge is brought opposite the other collecting comb, and imparted to the electrode *N*. By the continuation of these operations, positive and negative charges will accumulate in the electrodes *P* and *N* respectively, and sparks will pass between them. The influence of the negative charge on the cushion also assists in charging the electrode *N* with negative electricity.

It is necessary that the rubbing cushion should be supported on an insulating support; when it is earth-connected it is found that the action of the machine is considerably reduced. The explanation of this is that when the cushion is earth-connected, its negative charge escapes, and the positive charge on the back of the glass disc to a great extent neutralizes the negative charge on the front, and thus reduces the amount of negative electricity imparted to the electrode *N*.

A machine of this sort with a disc 20 inches in diameter will give a continuous stream of sparks of 1 to 1½ inches in length, and with two Leyden jars sparks of 5½ inches in length. One great advantage of the Kundt machine is that it is less sensitive to moisture than the Holtz machine.

A great many modifications have been introduced in the construction of the Holtz machine by different inventors. We shall describe a few of the most important of these machines.

The Lepper Machine.—This machine is of very simple

Fig. 55. Lepper's Machine.

construction and is easily taken to pieces and put together again. It can be seen from the illustration, Fig. 55, that there is a movable disc *E*, rotated in the usual way by belt and pulleys. There is no fixed disc, but instead, a rectangular plate of glass *F* is fixed between ebonite supports, behind the rotating disc. The field plates are pasted on the back of this fixed plate, and are shaped like right-angled triangles with two rounded corners. They are made of silvered paper, the silver side of which is placed next the glass, and connected by paper strips to two paper combs *a* and *b* fixed on the edge of the rectangular fixed plate, and bent towards the rotating plate, without however touching it.

On the pillar *S* are fixed two brass collecting combs *c* and *d*, which lie almost in the same vertical plane as the vertical edges of the field plates. The two combs are connected by a metallic wire passing through the pillar *S*, and are mounted so that they can be slightly displaced parallel to the axis of the machine. The conductors are connected to two collecting combs *e* and *f*, which in this machine have a special construction. They are made of semi-circular brass plates, protected by a bead on the curved side, and brought to a very sharp edge on the straight side, which stands opposite the disc.

To start the machine, a piece of vulcanite, excited by friction, is held near the rotating disc, at a point opposite the paper collecting comb *a*, while the disc is turned in the direction shown by the arrow. Leyser's machine, which was constructed in 1873, is very effective; sparks of 6 inches in length can be easily got from a medium-sized machine.

The principle of the action of this machine will be readily understood. When the disc is turned in the direction shown by the arrow in the illustration, the combs *a*, *d*, and *e* will show positive electricity, while negative electricity will flow out of the combs *b*, *c*, and *f*, as may be readily seen by working the machine in a dark room. The charge on the surface of the disc will be positive on one side of the neutralizing combs, and negative on the other side. It is evident that the polarity of the machine will be reversed if the excited ebonite be held opposite *b*.

Holtz Influence Machines of all sizes have been made. One of the largest machines of this kind was made a short time ago by J. and H. Berge, of New York. It had two rotating discs, each 45 inches in diameter, and was fitted with separate starting machine. The length of spark obtained from this machine was as much as 26 inches.

The Bleekrode Machine.—A machine of the Holtz type, in which the discs were made of vulcanite, was constructed in 1875 by Bleekrode. In experimenting with this machine, he discovered several peculiarities of great interest. Paper sectors were pasted on the back of the fixed disc, with points projecting through openings in the disc, as in the ordinary Holtz machine. Collecting combs and a neutralizing rod were also mounted in the usual way. The machine may be started in any of the ordinary ways, or simply by the friction of the hand on one of the vulcanite discs. Contrary to the usual practice, the electrodes of the machine must not be in contact when the machine is started. But the most interesting points are in connection with the neutralizing rod. It has been found that a machine such as this, having vulcanite discs, will not work at all without the neutralizing rod; the Holtz machine, with glass plates, as we know, will work with or without the neutralizing rod. If when the Bleekrode machine is in full action, the neutralizing rod be removed, the machine will cease to act, and all electricity will apparently disappear from it. This machine, however, is not really discharged; for when the neutralizing rod is again brought into position, the machine will commence to act as before. It will start even if the neutralizing rod is held in the hand at a distance of 1 to 1½ inches from the rotating plate in its proper position opposite the field plates. If the machine should accidentally lose its charge, it may be started by giving a to-and-fro motion to the neutralizing rod. From a machine of this kind, having a fixed disc of 24 inches in diameter, and a rotating disc 23 inches in diameter, sparks of 9 to 10 inches in length may be obtained.

Duplex machines, with two fixed and two rotating plates, have been made with vulcanite discs, by Bleekrode. One of the plates of this machine may be rendered quiescent by removing the neutralizing rod.

A new kind of neutralizing rod was devised by Bleekrode, having gas flames instead of combs for collecting the electricity from the surface of the rotating disc. Gas burners, consisting of pieces of bent glass tubes, were fixed on the end of a transverse wooden rod occupying the same position as the ordinary neutralizing rod in front of the rotating disc. Gas is supplied to the burners by flexible tubes, and the flames are put in conducting communication by a metallic wire, the ends of which dip in the respective gas flames. These flames behave as if they were positively electrified, the flame opposite the negative field plate is attracted, while that opposite the positive field plate is repelled. Such a neutralizing rod furnishes a useful method of visibly showing the direction of the electric current in the neutralizing rod. It is evident that the machine will not work if the wire is removed. If the vulcanite should deteriorate by the action of light or ozone it may be restored by washing with a solution of carbonate of magnesia.

Machines with Multiple Field Plates.—In machines hitherto described there have usually been two field plates. In one of Holtz's earliest machines we have seen that he suggested the use of more than one pair of field plates, when it was desired to get larger quantities of electricity from a machine.

Poggendorff also devised a machine, Fig. 54, in which there were four field plates, four openings in the fixed disc, and four collecting combs standing opposite the field plates in front of the rotating disc. In such a machine, going round the disc the field plates have alternately positive and negative charges, and consequently a pair of field plates lying at opposite ends of a diameter have similar charges of electricity; hence the collecting combs which stand opposite these field plates draw off similar charges from the rotating disc. One pair of diametrically opposite collecting combs are connected to one of the discharging rods, while the other pair are connected to the other discharging rod of the machine.

The quantity of electricity generated by a machine with four field plates is greater than that produced by a machine with two field plates, but the length of spark obtained is less.

Holtz constructed a machine with twenty field plates, having discs about $2\frac{1}{2}$ feet in diameter. It produced

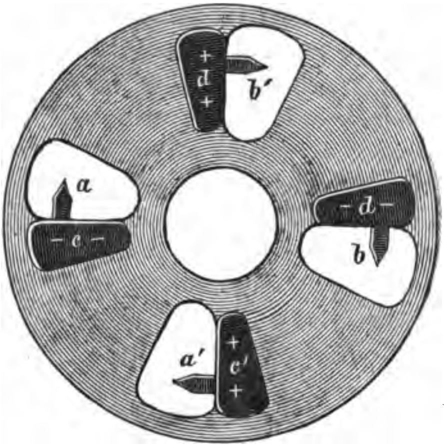


FIG. 54. POGGENDORFF'S MACHINE.

about ten times as much electricity as a machine with two field plates, but it was found to be very liable to reversal of the direction of the discharge.

Duplex Holtz Machines.—The first duplex Holtz machine was constructed in 1869 by Kaiser. It consisted of two rotating discs of glass, between which was one fixed disc of glass. The two movable discs rotated in the same direction. The fixed disc had two openings or windows through which projected the pointed ends of the paper field plates which were pasted on both sides of the disc. For each rotating disc there are two collecting combs, the two negative and the two positive being metallically connected together. Kaiser measured by a galvanometer the quantity of electricity obtained from a single disc of the duplex machine, and from the two combined, and found that the quantity obtained in the latter case was 2·12 times as great as that in the former.

Poggendorff, in 1870, devised a duplex machine in which the movable discs were fixed on the same axis about four inches apart. Outside the movable discs stood the fixed discs, the paper sectors of which are pretty broad, and subtend a considerable angle. The collecting combs were fixed on the ends of horizontal brass rods lying between the rotating discs parallel to their axis and supported on glass pillars. The discharging rods were mounted on the ends of vertical brass rods rising from the centre of the horizontal rods of the collecting combs.

There are no neutralizing rods on Kaiser's machine, but in Poggendorff's machine there is one fitted in front of each movable disc at an angle to the horizon of about 45°.

At a later date Ruhmkorff very much simplified and improved the construction of the duplex machine. His machine is illustrated in Fig. 55. The two fixed discs in this case are between the movable discs. The points of the collecting combs are fixed on the inner sides of the prongs of two forks which embrace the four discs at opposite ends of a horizontal diameter, and are connected at their inner ends to the horizontal rods leading to the discharging rods. On the ends of these horizontal rods

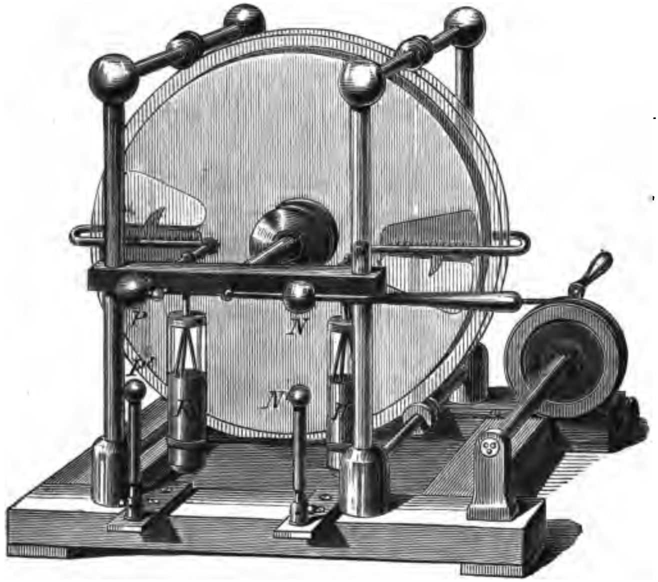


FIG. 55. RUHMKORFF'S DUPLEX MACHINE.

balls *P* and *N* are fixed, and through one of these *N*, one of the discharging rods can be moved backwards or forwards by means of an ebonite handle. Leyden jars *K* and *H* have their inner coatings connected to the electrodes, and their outer coatings to each other by a metallic rod. Two vertical rods surmounted by knobs

P^1 N^1, and connected one to each electrode, are employed for discharging the current through Geissler's tubes or other external bodies. To start the machine the electrodes are placed in contact, and the discs are turned in the proper direction, while an excited plate of vulcanite is placed between the fixed plates in contact with one of the field plates. The duplex machine produces about double the quantity of electricity obtained from a single machine with the same size of plates. This is true, however, only when the striking distance is short. The duplex machine is capable of giving longer sparks than a single disc machine with discs of the same size; for example, a spark of seven inches was obtained from a single-disc machine, while a spark of 8¾ inches was obtained from a duplex machine with discs of the same diameter. With discs 36 inches in diameter sparks of 12 inches in length have been obtained.

It has been found that a duplex machine will retain its charge when at rest much longer than a single machine.

These machines are also less liable to reverse or cease working when the electrodes are separated to a considerable distance. The reversal will not take place at all if the electrodes are connected with Leyden jars, and both discs are fitted with neutralizing rods. If one of the neutralizing rods is removed the current in the disc from which it has been removed will reverse, and thereby cause the other half of the machine to reverse.

To start a duplex machine we shall assume that a positive charge is communicated to one of the four paper sectors. The influence of this charge will cause the two connected collecting combs to deposit a charge of negative electricity on the outer surface of the nearest disc, and a charge of positive electricity on the outer surface of the furthest disc. The charge on the surface of this latter disc induces a charge of positive electricity on the furthest end of the other sector which lies adjacent and parallel to the sector which received the original positive charge. Thus the charges on the parts of these adjacent sectors which lie opposite the ends of the neutralizing rods are both positive, and consequently negative electricity will be induced on the surface of both discs at the ends of the neutralizing rod, and carried round to charge the other pair of adjacent sectors with negative electricity. From the above explanation it is easy to see that the current in both discs will be in the same direction if there is a neutralizing rod on each disc.

The Voss Machine.—This machine which is at the present time in very considerable use in this country was constructed in 1880 by Voss, an instrument maker in Berlin. It may be described in general terms as a combination of the Holtz and Töpler machines. As shown in Fig. 56, it consists of a fixed and a rotating disc as in the Töpler machine, Fig. 41, or the Holtz machine, Fig. 49. It differs from the Töpler machine in having the fixed disc in one piece, and also in having the replenishing brush for each field placed in front of the rotating disc opposite the field plate to which it is connected, instead of being opposite the other field plate as in the Töpler machine. It resembles the Töpler machine in having on the front surface of the rotating disc carriers consisting of circular pieces of tinfoil, on which are fixed hemispherical brass knobs for the brushes to touch. The field plates *C C* are paper sectors resembling those of the Holtz machine; but be-

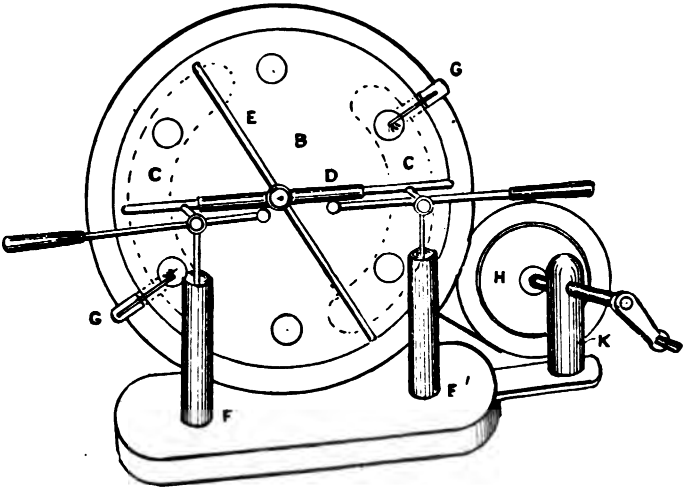


FIG. 56. VOSS MACHINE.

tween the paper sectors and the back surface of the fixed disc on which the paper sectors are glued there are two tinfoil discs connected by a strip of tinfoil, and about the same distance apart as the carriers. The paper sectors prevent the too ready escape of the electricity from the field plates, while the tinfoil discs are said to facilitate the self-excitement of the machine.

The neutralizing rod *E* is fitted as in the Holtz machine, but at the ends small metallic brushes are fixed in such a position as to touch the brass knobs on the carriers as they pass under them. For replenishing the field plates ⊃ shaped brass tubes *G G* are connected at one end to the field plates, and have metallic brushes on the other end which touch the knobs on the carriers as they pass. The collecting combs and electrodes are fixed as in the Holtz machine; they stand in front of the rotating disc between the brushes of the replenishing rods and the brushes of the neutralizing rod, which latter brushes stand opposite the ends of the paper sectors. To obtain sparks, Leyden jars $F F^1$ must be connected to the electrodes.

This machine is self-exciting, and is not so susceptible to damp weather as the Holtz machine. As there are no windows to cut in the fixed glass disc it is easier to make than the Holtz machine. It is however liable to reversal when charging Leyden jars with the discharging rods separated beyond the striking distance.

Duplex and multiple Voss Machines have been constructed and give very good results.

Holtz Machines without fixed Field Plates.—These machines are designed on an entirely different principle from the Holtz machines we have already described, and have been called machines of the "second kind," or machines "with oppositely rotating plates."

Before describing an actual machine of this kind we shall explain the principle of their action by means of the Bertin diagrams, in which the glass discs of the machine are represented by cylinders.

In Fig. [illegible] C and C' represent two discs which rotate in opposite directions as shown by the arrows. Collecting combs A and B in connection with the electrodes P and N are fixed in front of the disc C. Another pair of collecting combs A' and B' are placed at an angular

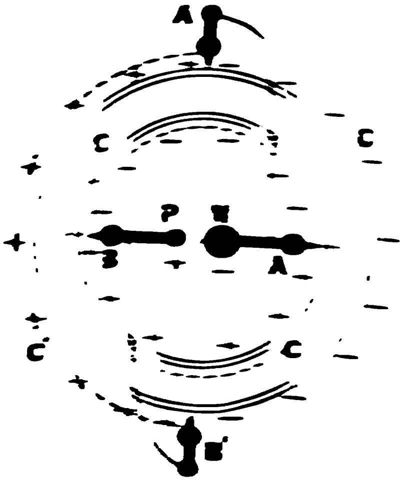


Fig. [illegible] Diagram of [illegible] Machine with [illegible] Rotating Plates.

distance of 90° from the first combs in front of the other disc C'. The combs A' and B' are connected by wires to the electrodes as shown.

To excite the machine hold a negatively charged body opposite the end of the fork A. Positive electricity will be induced on the surface of the disc C and carried round by the motion of the disc in B so that the half of the disc between *A* and *B* in the direction of the motion of the disc will be covered with positive electricity. This layer of positive electricity on *C* will by its influence draw negative electricity from the comb *B*¹ on to the disc *C*¹ which in the course of its rotation will be coated with a negative charge between *B*¹ and *A*¹ as shown in the figure. If the discharging knobs of the electrodes are in contact, negative electricity will be formed on the surface of the disc *C* from the comb *B*, simultaneously with the discharge of positive from *A* on the surface of the disc. The upper half of *C* will thus become coated with negative, and this by its influence will draw positive from *A*¹ on to the disc *C*¹ and thus coat the left side of *C*¹ with positive electricity. Positive and negative electricity having thus been distributed on the disc *C*¹ by the influence of the charges on the disc *C*, these charges on C¹ will react upon *C* and draw increased negative charges from *B* on to *C*, and positive charges from *A* on to *C*. The electricity received by the combs *A*¹ and *B*¹ is conveyed by the connecting wires to the electrodes *N* and *P* respectively, and helps to reinforce their charges. When the machine is fully excited the electrodes may be separated, and sparks will pass between them.

It will be observed that in this machine there are no fixed field plates; in fact, parts of the surface of one rotating disc act as field plates for the other rotating disc. The positive field plate for the disc *C* is the half of the rotating disc *C*¹ which is charged with positive electricity, and the negative field plate is the half of *C*¹

a Holtz condenser tube may be laid between the rod joining $A A^1$ and the rod joining $B B^1$, as shown in the figure.

To start the machine the electrodes are placed in contact, and an electrified body is held opposite one of the collecting combs; for example, below the lower disc and opposite the comb *B*, while the discs are set in rapid rotation. The direction of rotation of the lower disc must be the same as the hands of a watch, and that of the upper disc in the opposite direction. A peculiar crackling noise will indicate when the machine is working. The electrified body may now be withdrawn, and the electrodes separated. It has been observed that these Holtz machines of the "second kind" are liable to die out when the electrodes are separated beyond the striking distance, though according to other authorities a reversal of the current takes place.

It is also stated that if the machine, when supplied with Leyden jars, is stopped just when the electric brushes disappear, it may be started after an interval of several minutes, and will be found active, but in the opposite direction.

The reversal of this machine, if such take place, is no doubt due to the fact that there is no continuous neutralizing rod. The complete reversal of the charges on the disc C^1 at A^1 and B^1, Fig. 57, will not take place unless the collecting combs A^1 B^1 are in metallic connection, or both connected to the earth. In fact when the electrodes *P* and *N* are separated beyond the striking distance there may be no reversal of the charges on the discs at A^1 B^1, or A and B. The result will be that the charges will be carried past the collecting combs till positive takes the place of negative, and negative the place of positive, giving a distribution exactly the reverse of that shown on the diagram. With this new disposition of electricity on the surface of the discs it is easy to see that the current in the electrodes will be reversed. It will be interesting to consider the result of putting A^1 and B^1 in metallic connection, that is to say, applying a neutralizing rod to one of the discs in a direction at right angles to the electrode collecting combs in front of the other disc. This arrangement is shown diagrammatically at Fig. 59. The brushes A^1 and B^1 are connected by a metal wire or rod. If a piece of ebonite excited by friction is brought opposite the comb A, positive electricity will be drawn from the comb on to the surface of the disc, and carried round till the whole of the lower half of the disc from A to B is coated with a positive charge. If the discharging knobs P and N are in contact, the upper half of the disc will be coated with a negative charge. The two halves of the front disc thus charged with opposite electricities act as field plates to the other disc,

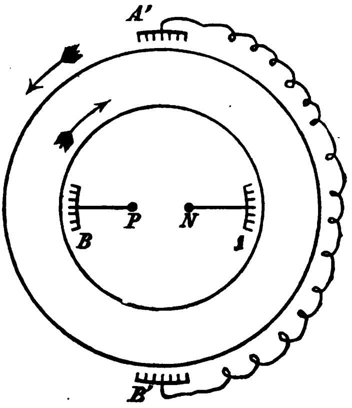


FIG. 59.

and by their influence positive electricity will be drawn from the comb A^1 on to the latter till its left side between A^1 and B^1 is coated with positive electricity, and negative electricity from the comb B^1 till its right side is coated with negative electricity. The right and left sides of the back disc now act as field plates for the front disc, and by their influence negative electricity will be driven into the discharging knob *N*, and positive electricity into the discharging knob *P*, with sufficient force to cause sparks to pass between the knobs when they are separated. A curious point about this machine is that when the direction of rotation of the discs is reversed, the direction of the discharge from the electrodes is not reversed. A moment's consideration of the diagram will show the reason for this. If the excited piece of ebonite be placed opposite the brush *A* as before, and the direction of rotation of both discs be reversed, there will now be a *positive* charge on the upper half of the front disc, and a *negative* charge on the lower half. These charges will draw on to the back disc a negative charge from the brush A^1 and a positive charge from the brush B^1. These charges are of the opposite kind to those which were poured on the surface of the back disc in the first case, but the rotation of this disc is now in the opposite direction, so that the charges are carried to opposite sides from those they were carried to before. The result of these two reversals is that the distribution of electricity on the back plate is the same as before; and hence the direction of the discharge from the electrodes will be the same. The direction of the current in the neutralizing rod, however, will be reversed.

The Holtz machine illustrated diagrammatically in Fig. 57 may have a neutralizing rod applied to the front disc, and we shall now consider the effect of applying this rod in different positions. In the diagram, Fig. 60, we shall suppose that the inner circle or front disc is divided into four quadrants, marked with the numerals I., II., III. and IV. In the first place we shall suppose the neutralizing rod connects the two quadrants I. and III. The machine is supposed to be excited in the same way as in Fig. 57, that is to say, negative electricity on the upper half of the front disc, and positive on the lower; negative on the right side of the back disc, and positive on the left side. The neutralizing rod in this position prevents the reversal of the machine, or loss of the excitement, in case the electrodes are separated to too great a distance, because the positive charge which is carried past the comb *B* is drawn off at I. by the neutralizing rod, and prevented from passing round to the other side of the disc. The other end of the neutralizing rod, of course, deposits the positive

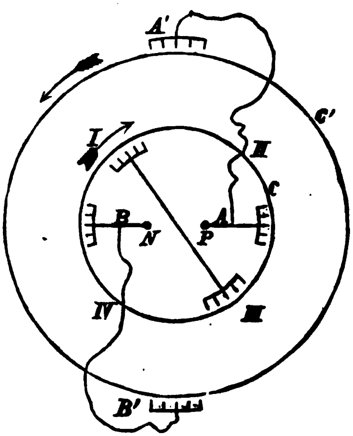


FIG. 60.

electricity on the disc at III., whence it is carried round to the collecting comb *B*.

If the neutralizing rod is placed so as to join the quadrants II. and IV., its ends will now be under the influence of opposite charges on the outer circle C^1, with the result that positive electricity will be drawn upon the quadrant II., and negative upon the quadrant IV. Positive electricity will be imparted to the electrode *A*, and negative to the electrode *B*; this will change the distribution on the outer circle C^1, which in turn will cause a reversal in the discharge. The action of the machine rapidly diminishes and soon altogether ceases. If the neutralizing rod occupies a vertical position, its ends will stand opposite the collecting combs A^1 and B^1, and the action of the machine will not continue, as the influence of the two halves of the disc upon the combs A^1 and B^1 will neutralize each other.

Musaeus Machine.—Musaeus has devised a modified form of the Holtz machine of the "second kind," in which there are four combs on the front disc, and two combs on the back disc, connected to those on the front by metal bows.

CHAPTER IV.

MODERN MACHINES (CONTINUED): WIMSHURST MACHINES.

IN recent years a most important advance has been made in the construction of reliable and powerful Influence machines, by Mr. Wimshurst, one of the consultative staff of the Board of Trade.

Before proceeding to the description of the machine now so widely known as the Wimshurst machine, we shall describe a simplified form of the Holtz machine constructed by Mr. Wimshurst.

Wimshurst-Holtz Machine.—This machine was first described in 1882, though one had been constructed as early as 1878.

The Holtz machine, as we have already explained, contains in its simplest form one fixed plate, and one plate which rotates. In the fixed plate, on its horizontal diameter, are three holes of considerable size (one for the axis, and two for the collecting points of the field plates), which are very difficult and expensive to cut, and very much increase the risk of breaking the plate.

In the multiple plate machine especially, these expensively cut plates are a great drawback, for as they have frequently to be removed for cleansing or repair, they must necessarily undergo a good deal of rough handling.

Another well-known objection to the multiple plate form of the Holtz machine is the aptitude of the alternate

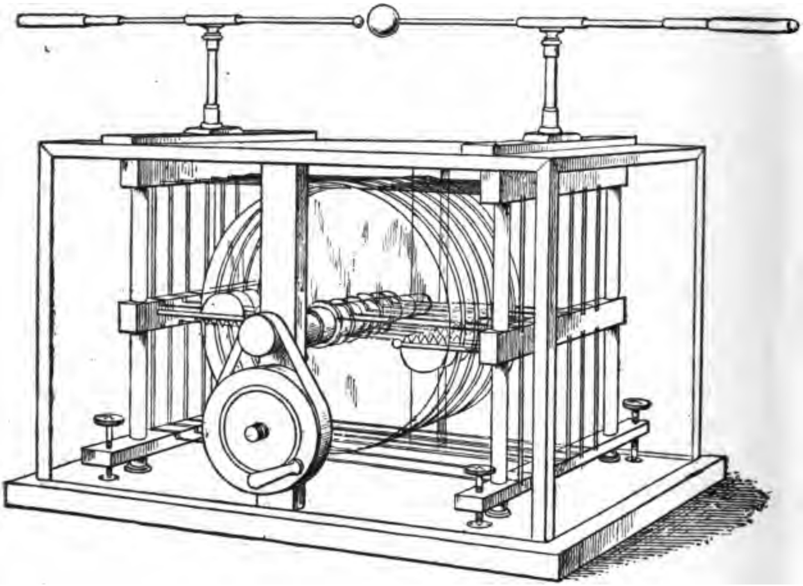


FIG 61. WIMSHURST-HOLTZ MACHINE.

revolving plates to obtain an opposite excitement, and thereby neutralize each other's effect. For the successful working of the apparatus, all the field plates on one side of the spindle should be positively electrified, and all those on the other side of the spindle should be negatively electrified.

It occurred to Mr. Wimshurst that these objections might be overcome, and accordingly he constructed the very large machine illustrated in Fig. 61. This machine consists of twelve circular discs of glass, each 32 inches in diameter, mounted on a spindle, which by a simple multiplying gear of a belt and two pulleys, can be rotated at a high velocity. To get rid of the objectionable perforated fixed plates, for each one of these he substituted two separate rectangular pieces of glass, fixed a little apart from each other, the gap between the two pieces lying opposite a horizontal diameter of the rotating disc. The paper field plates were pasted on the back of the rectangular plates, with their tongues projecting through the gap in the usual way. This arrangement was continued throughout the machine; hence for the twelve discs there are twenty-four rectangular pieces of glass, twelve above and twelve below the spindle. The gaps between the upper and lower sets of plates, are of sufficient width to allow the spindle to pass freely between them. These plates are not fixed in any way, but are simply dropped into grooves, and in a few minutes can all be removed, cleansed and replaced. All the plates are well coated with shellac varnish. The rotating discs run freely between the plates without touching them, so there is no friction in the working of the apparatus, except the friction at the bearings, which is inconsiderable.

To prevent alternate plates obtaining an opposite excitement, Mr. Wimshurst connects together all the paper field plates on the one side of the machine by a metal wire, which also serves as a conductor for giving the machine its initial charge. The machine is inclosed in a glass case to protect it from dust.

The machine gives off dense showers of sparks, through a distance of seven inches between the terminals; when

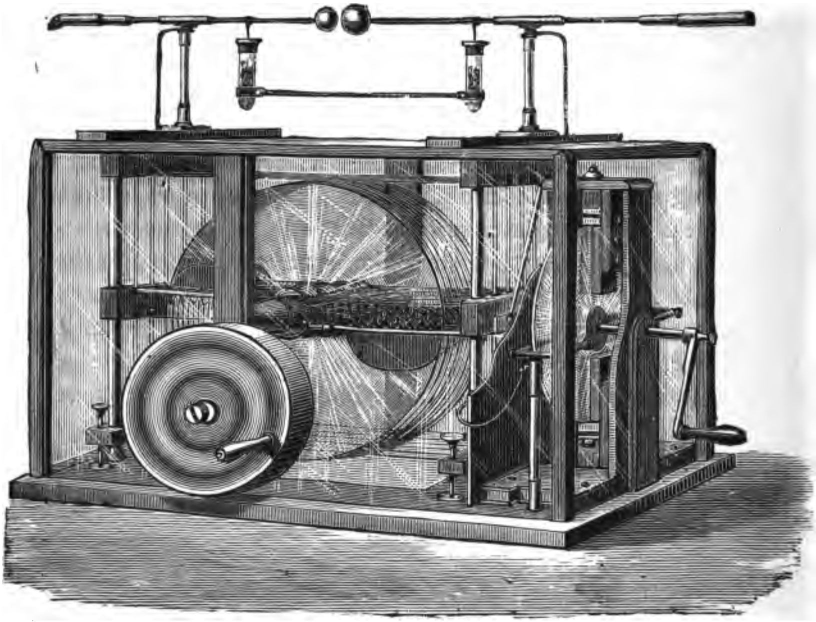


FIG. 62. WIMSHURST-HOLTZ, WITH FRICTIONAL STARTER.

Leyden jars are attached to the terminals, the sparks appear to be continuous, and the discharge is almost deafening.

Mr. Wimshurst has constructed smaller machines of this type, having in combination with them a frictional machine for producing the initial charge, as illustrated in Fig. 62. He has also constructed these with self-exciting influence machines for supplying the initial charge to the field plates.

Machine with oppositely rotating Plates.—We now come to the type of machine which has most recently been introduced by Mr. Wimshurst, and which is more especially associated with his name.

It was first described in January, 1883, and, as may be seen from the illustration, Fig. 64, differs essentially in construction from either of the machines which preceded it. It also differs greatly in its behaviour, for it is self-exciting, and will discharge its torrents of electricity under atmospheric conditions which are fatal to the working of the other forms of electrical machines. Moreover, the direction of the current will not change when the machine is at work; nor will the excitement die away when the terminals are opened beyond the limit of the sparking length.

Following the plan which we have already adopted in dealing with other machines, we shall explain the action of the Wimshurst machine by means of a diagram, Fig. 63, before describing the different forms of it which have been constructed.

In the diagram, the oppositely rotating discs are represented by Bertin's method, as sections of cylinders D and D^1. The inner circle D represents the front disc, the outer circle D^1 the back disc, and each rotates in a direction shown by the adjacent arrow. On each disc there is fixed a series of metallic carriers denoted by the letters *C* and *C*ˡ. A neutralizing rod *E F* is fixed on the disc *D*, so as to connect diametrically opposite carriers as they pass and touch the contact brushes fixed on its extreme ends; and a similar neutralizing rod *G H* is mounted on the face of the disc *D*ˡ, with its contact brushes in a diameter at right angles to *E F*. The

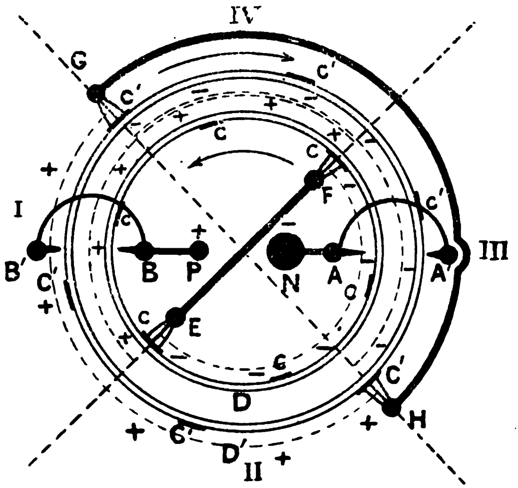


FIG. 63. DIAGRAM OF WIMSHURST MACHINE.

electrodes *B P* and *A N* have discharging knobs *P* and *N* at one end, and collecting combs *B B*ˡ and *A A*ˡ at the other. The collecting combs *B B*ˡ stand facing each other, one in front of each disc, and are metallically connected by a bent rod passing round the edges of the discs; *A* and *A*ˡ are fitted up and connected in a precisely similar manner.

This machine, like all those having metallic carriers, is self-exciting, that is to say it requires no charge of electricity imparted to it from an external source to set it in action. The action of the machine does not depend on the presence of the collecting combs; for the charges on the surfaces of the plates are produced though the collecting combs are removed. In considering the development of electricity in the machine, the collecting combs and the electrode circuit may be left out of account. It is not yet certainly known how the initial charge is produced which leads to the starting of self-exciting machines, but probably it is due to the fact that there are no two places in the atmosphere at exactly the same potential at any given moment. As a consequence of this, we shall suppose that one half GB^1H of the disc D_1 has a small positive charge, and the other half HA^1G has a small negative charge. Under the influence of the positive charge on D^1, each carrier C on D, when in contact with the brush E, will receive a negative charge, which will be carried round by the motion of the disc till every carrier on the half EAF of the disc has a negative charge. In the same way, the influence of the negative charge on D^1 will impart a positive charge to each carrier C as it passes under the brush F, by which operation the half FBE of the disc D will be coated with positive electricity. The two halves into which the disc is divided by its neutralizing rod have thus far acted as field plates, to induce charges on the two halves into which the disc D is divided by its neutralizing rod. The two halves of D now in turn act as field plates to induce charges on the carriers C^1 of the disc D^1, and a little consideration will show that owing to the motion of this latter disc, the charges originally upon it will be increased by this action. The discs will continually react upon each other in the manner just described, and raise the potential of each other's charges according to the compound interest law, till the limit fixed by leakage is reached. The final distribution reached, is shown by the doted lines, and + and − signs on the diagram. If we consider the discs divided into four quadrants I., II., III., IV., by the two neutralizing rods, it will be found that the charges on the two discs in quadrants II. and IV. are opposite, and therefore, attract each other, but on the two quadrants I. and III., they are the same, and therefore repel each other. The collecting combs are placed opposite the middle of the quadrants I. and III. to draw off the self-repelling electricities. This, as shown in the diagram, imparts a positive charge to the discharging knob *P*, and a negative charge to the discharging knob *N*, and if these knobs are not too far apart, sparks will pass between them. As the action of the machine takes place without the collecting combs, it is not necessary that they should be in contact in order to start the machine. It is for the same reason impossible to reverse the action of this machine by separating the discharging knobs beyond the striking distance.

The machine illustrated, Fig. 64, which was one of the first constructed by Mr. Wimshurst, consists of two circular discs of ordinary window glass 14½ inches in diameter, mounted upon a fixed horizontal spindle in such a way as to be rotated in opposite directions at a distance apart of not more than one-eighth of an inch.

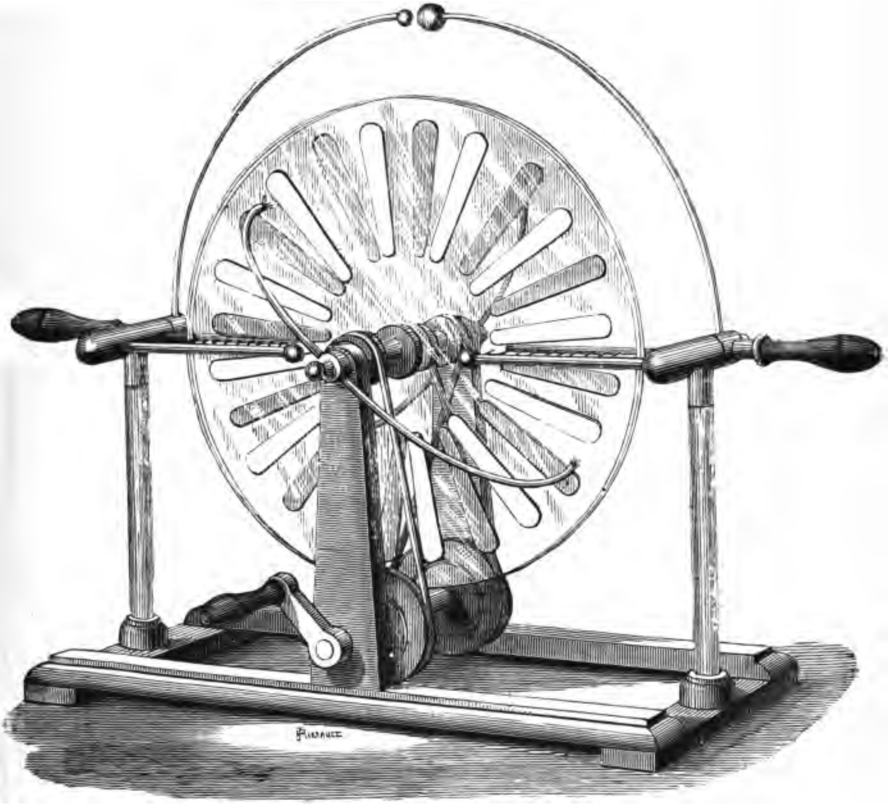


FIG. 64. WIMSHURST'S ORIGINAL MACHINE.

Each disc is attached to the end of a hollow boss of wood, or of ebonite, upon which is turned a small pulley.

This is driven by a cord or belt from a larger pulley, of which there are two attached to a spindle mounted below the machine and rotated by a winch handle, the difference in the direction of the rotation being obtained by the crossing of one of the belts.

Both discs are well varnished, and attached by cement to the outer surface of each are twelve radial sector-shaped plates of thin brass, which are disposed around the discs at equal angular distances apart, and act both as carriers for the disc on which they are fixed and field plates for the other disc. There are two neutralizing rods, one for each disc, having fine wire brushes fixed on their ends to touch a pair of diametrically opposite metallic sectors, and supported at the middle of their length by the projecting ends of the fixed spindle upon which the discs rotate. The position of the two pairs of brushes on the neutralizing rods with respect to the fixed collecting combs and to one another is variable, as each pair is capable of being rotated on the spindle through a certain angular distance, and there is one position of maximum efficiency. This position in the machine we are now describing appears to be when the brushes touch the discs on diameters situated about 45° from the collecting combs and 90° from one another. The fixed conductors consist of two forks furnished with collecting combs, the sharp-pointed teeth of which are directed towards the external faces of the two discs. The arms of the two forks which lie along a horizontal diameter and inclose the two rotating discs, are supported on ebonite pillars, and are of sufficient length to cover the metallic sectors on the faces of the rotating discs. The terminal electrodes are mounted on the transverse part of the collecting forks, so that they can be rotated by the ebonite handles as shown in the illustration, and the distance between the discharging knobs varied to any required extent.

The presence of these collecting combs, as we have already explained, appears to play no part in the action of the apparatus except to convey the electricity to the discharging circuit; for the electrical excitement of the machine is as rapid and as powerful when both the collectors are removed, and nothing is left but the two rotating discs and their respective contact and neutralizing brushes. The whole apparatus bristles with electricity, and if viewed in the dark presents a most beautiful appearance, being literally alive with luminous brush discharges.

The Wimshurst machine does not reverse its polarity, even when worked with a distance between its terminals greater than its sparking distance, and in this respect it has the advantage over most other influence machines, as for example the Holtz and the Voss.

With a machine of the size we have described and shown in the illustration, there is produced under ordinary atmospheric conditions, a powerful spark discharge between the electrodes when they are separated by a distance of $4\frac{1}{4}$ inches, a pint size Leyden jar being in connection with each electrode; these $4\frac{1}{4}$-inch discharges take place in regular succession at every two and a half turns of the handle. The machine is perfectly self-exciting, requiring neither friction nor a spark from any outside electric exciter to start it; and it is one of the remarkable features of the machine that under ordinary conditions it is working at its full power after a few turns.

Seven-foot Wimshurst Machine.—In the end of 1884, Mr. Wimshurst constructed for the Science and Art Department at South Kensington perhaps the largest influence machine in existence at the present time. This machine is illustrated in Fig. 65.

On reference to the illustration it will be seen that the form of the machine is nearly identical with the smaller type which has already been illustrated and described; its points of difference lying in its size and in the construction of the supporting parts, which the greater weights have necessitated. Thus while the diameter of the circular plates of the smaller machine was 14½ in., that of those of the great machine is 84 in.; the former being cut out of ordinary window glass, while the latter are discs of plate glass, ¾ in. in thickness and weighing 280 lbs. each. Each of these discs is pierced at its centre with a hole 6½ in. in diameter, and is firmly attached to a gun-metal boss 15 in. in length, carrying the disc at one end and a pulley at the other. The boss is bored so as to run freely on an iron tube 3 in. in diameter, and supported at each end by strong oak trusses, which rise from a firm base, also made of oak, and fitted with lockers at each end, for holding spare parts and necessary apparatus. The heads of the two trusses or A frames consist of massive castings of gun metal, which are so shaped as to hold the hollow iron tube and the ebonite rod to which the collecting combs and discharging rods are attached. The iron tube projects at each end beyond the trusses, and to the projecting ends are attached the brass neutralizing rods, which terminate in light wire brushes, shown in the illustration.

To the discs, which are well varnished with an alcoholic solution of shellac, are attached at equal angular distances apart, radial sectors of tinfoil, to the number of 16 on each disc. These sectors are 19 in. long and have a mean width of 1·65 in., thus having an area of 31·35 square inches. There is thus on each plate a metallically coated area of 500 square inches, or 1,000 square inches on the two discs together.

The collecting combs are attached to the discharging rods, as shown in the engraving, by interchangeable brass rods, some being straight while others are bent, so that their positions with respect to the horizontal diameters of the discs may be varied within a range of about 16 in., that is to say, between 8 in. above and 8 in. below the horizontal diameter, as it is found that the best effect is got when the combs are thus set obliquely in a direction which depends on the direction of rotation of the discs. The discharging rods or terminals are made of brass tube $1\frac{1}{4}$ in. in diameter, and are fitted with terminal knobs of different diameters, which are made interchangeable, so that they can be arranged to suit the direction in which the positive discharge may happen to take place. The distance of these balls or knobs apart—and therefore the striking distance of the spark discharge—can be varied by glass handles with

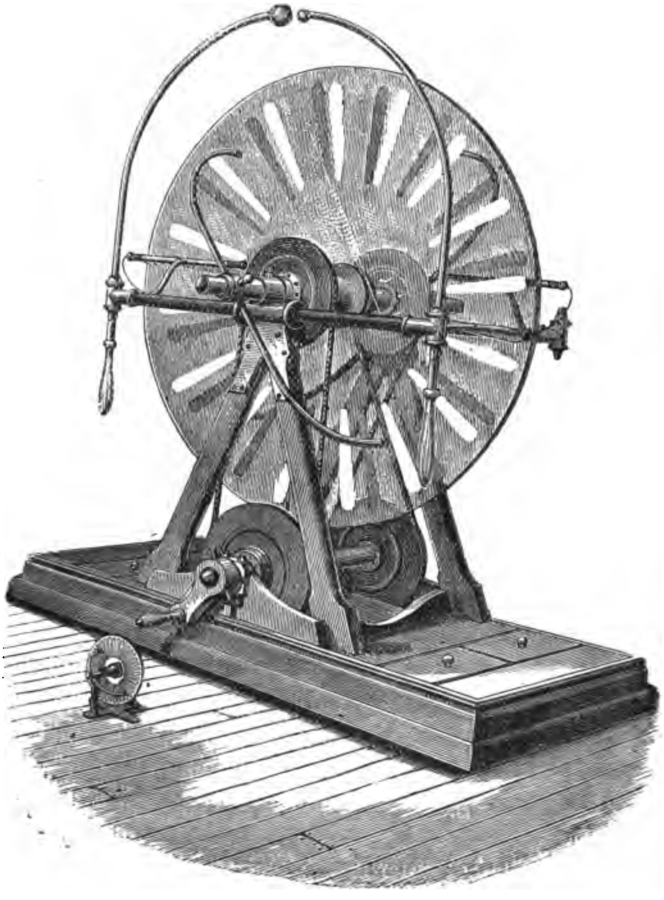


FIG. 65. SEVEN-FOOT WIMSHURST MACHINE.

which the discharging rods are fitted at their lower ends, these handles being attached by a hinged joint, so that they can be used as levers wherewith to turn the terminal rods around a vertical axis, and thus vary the distance between their upper ends. The discs are rotated in opposite directions by the belt-and-pulley driving gear shown in the figure. This consists of a horizontal spindle fitted with a winch handle at each end, and carrying a pair of oak pulleys connected respectively to the two pulleys attached to the discs by an open and a crossed belt, thereby causing the discs to rotate in opposite directions. As the height of the bearings of the lower spindle is adjustable the driving cords can always be maintained perfectly tight.

Owing to the want of a Leyden jar strong enough to hold the charge without rupture, it has not been possible to test the full length of the spark which can be obtained from this great machine. Sparks up to 14 in. in length have been obtained from it in an atmosphere above the average humidity.

The Sparkler.—In the illustration, Fig. 65, has been introduced (partly to serve as a comparison of size) a sketch of what is perhaps the simplest and cheapest electrical influence machine ever constructed. This little apparatus consists simply of two discs of varnished glass 12 in. in diameter, fitted with *a very large number* of tinfoil sectors close together, and mounted on a spindle which can be held in the hands, while the discs are rotated in opposite directions by spinning them with the finger and thumb. When this is done—although

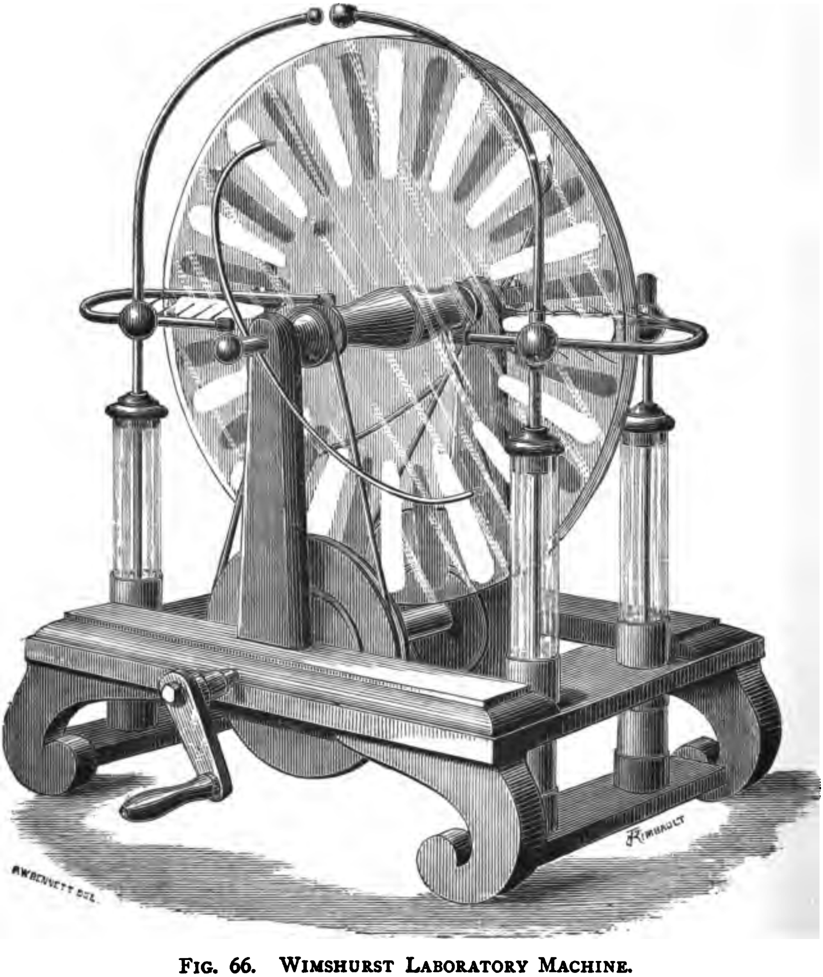


FIG. 66. WIMSHURST LABORATORY MACHINE.

there are no collecting combs or discharge conductors—the most brilliant effects can be produced, the whole apparatus literally bristling with electric discharges immediately after the rotation commences.

Laboratory Machine.—A compact form of the Wimshurst machine, designed by the inventor for use in the laboratory, is illustrated in Fig. 66. It differs very little from the machines already described except in the compactness of its design. The collecting combs are supported by the central rods of four Leyden jars, the outside coatings of which are metallically connected. The distance between the terminals can be varied by turning round the Leyden jars to which the terminal rods are fixed.

Eight-plate Machine.—Mr. Wimshurst has constructed several powerful machines on the principle already applied to the Töpler and other machines, of combining a number of single machines into one large machine. These machines are usually inclosed in a glass case, which protects them from dust and serves as a support for the neutralizing rods. No drying material is necessary inside the case to secure the successful working of the machine in ordinarily dry weather, and in this respect we have a striking advance on the great Töpler machine already described.

The multiple-plate machine illustrated, Fig. 67, has eight glass discs, mounted on the same spindle, and rotated alternately in opposite directions by open and crossed belts. The discs are each 2 ft. 4 in. in diameter, and carry each sixteen tinfoil sectors on one side. The neutralizing brushes are fixed on the ends of brass rods

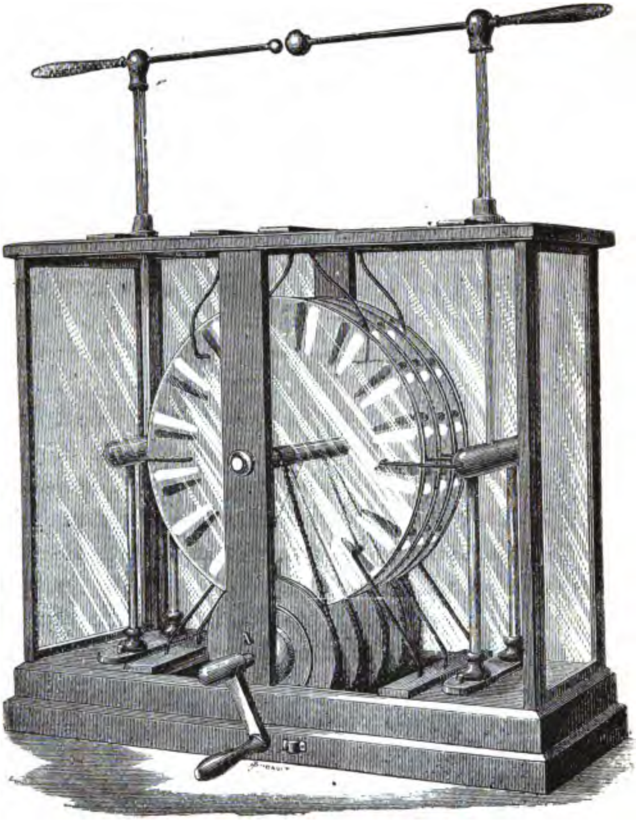


FIG. 67. EIGHT-PLATE WIMSHURST MACHINE.

fixed to the framework of the case of the machine, and connected together by wires, to insure that all the brushes shall be at the same potential. All the conductors and even the rods carrying the metallic brushes are covered with a thick coating of gutta-percha. With the same object the brass rods which lead from the prime conductors to the outside terminals are carried up through glass tubes. By these means the losses due to leakage and discharge to neighbouring bodies are greatly reduced.

Some idea of the electrical power of this machine may be formed from the fact that every turn of the handle gives six sparks each 8 in. in length. Sparks of 10 in. and 12 in. are readily obtained. The condensers used were made of ordinary wine bottles, and the discharge was accompanied by an almost unbearable snapping noise, comparable in loudness to a pistol-shot.

Twelve-plate Machine.—The largest multiple-plate machine constructed up to the present time by Mr. Wimshurst has twelve plates. It is essentially the same in design as the eight-plate machine just described.

The illustration in the frontispiece shows the construction of the machine.

Each of the twelve plates is 2 ft. 6 in. in diameter. The greatest length of spark is $13\frac{5}{8}$ in. To show how readily such machines excite themselves, Mr. Wimshurst stated, in his lecture before the Royal Institution, that, though every care was taken during the construction of the machine to avoid electrical excitement in any of its parts, the machine showed strong electrical excitement at the end of a half-revolution of the driving handle. He also stated that he has never found this machine to fail in its performance, even with the most unfavourable atmospheric conditions.

Cylindrical Wimshurst Machine.—A moment's consideration will show that a Wimshurst machine may be designed in which glass cylinders are used instead of glass discs. In recent years this type has been extensively made and sold as an improved form of the Wimshurst machine. This form, however, was made by Mr. Wimshurst himself as early as 1882, and rejected as being inferior to the disc machines. The illustration, Fig. 67, shows the cylindrical machine as constructed by Mr. Wimshurst. The two glass cylinders on which the tinfoil carriers are glued, are mounted so that they can turn independently about the same vertical axis. They are set in rotation in opposite directions by means of friction gear, consisting of a disc fixed on the end of the winch axis, and gearing on two small indiarubber friction pulleys attached to the outer and inner glass cylinders respectively, as shown in the illustration. Neutralizing rods are fixed at right angles to one another, one inside the cylinders and the other outside. The collecting combs are fixed so as to bisect the angle made by the neutralizing rods. Vulcanite is not recommended as a material to be used in the construction of these machines, as it warps with age, and its surface undergoes chemical change and becomes a conductor.

Mr. Thomas Gray, C.B., has also given considerable attention to the study of these machines. He took considerable interest in Mr. Wimshurst's work while the seven-foot machine was being constructed, and shortly

Fig. 68. Wimshurst Cylindrical Machine.

afterwards fitted up a multiple machine with eight discs, each 30 in. in diameter, which though not protected by a glass case, gave very satisfactory results. He also constructed a machine of considerable theoretical interest, by inserting a fixed plate between the two oppositely rotating discs of a single Wimshurst machine. It was found that the fixed disc did not interfere with the self-excitement of the machine, but caused it when at work to change the direction of flow of the electricity with the greatest regularity at each few revolutions of the handle. This machine, therefore, constitutes an alternating-current influence machine, and the explanation of its action, when discovered, will no doubt throw considerable light on the theory of other influence machines.

CHAPTER V.

MODERN MACHINES (CONTINUED): SIR W. THOMSON'S MACHINES.

A SERIES of influence machines, characterized by great simplicity of construction and theoretical perfection of design, has been invented by the celebrated physicist, Sir W. Thomson. As these machines were constructed, as a rule, for practical application in connection with telegraphic apparatus, electrometers and such like, they have usually been made on a small scale, and not like those of Holtz, Töpler, etc., for giving long sparks. There is apparently, however, no reason why they should not be constructed for this latter purpose.

The earliest influence apparatus constructed by Sir W. Thomson, preceded those of Töpler and Holtz, if not also that of Varley; the water-dropping apparatus having been described in the Proceedings of the Literary and Philosophical Society of Manchester, for October 18th, 1859.

Water-dropping Apparatus.—This apparatus was intended for observing atmospheric electricity. It consisted simply of an insulated can, Fig. 69, of water set on a table or window-sill *inside*, and discharging by of some electrified body in the neighbourhood, in a metallic insulated vessel. If the potential at the place where the drops fall away is higher than that of the can the drops will fall into the insulated vessel with a negative charge, which, if the vessel is deep enough, will be completely transferred to the outside of the vessel.

To make provision for maintaining the charge of the field plates in the water-dropping apparatus, Thomson devised a reciprocal or regenerative arrangement, in which the body charged by the drops of water is connected to the field plate for another stream of drops, the drops from which latter keep up the charge of the field plate of the former.

FIG. 70.

The illustration, Fig. 70, shows the arrangement for a single stream. The spout *a* from which the water falls in drops, is inserted into the tube *b*, which serves as an inductor or field plate, to such a distance that the drops are formed at the centre of the tube. After leaving the tube *b* with their charge of electricity they drop into the collecting tube *c*. Inside this latter tube there is fixed a conical or funnel-shaped tube with an aperture at its apex of sufficient diameter to allow the water to escape from it as fast as it is received. The charge of electricity is completely discharged from the water falling in *c*; the escaping stream being almost entirely without electric charge. If the collector of this first stream is connected to the inductor or field plate of a second stream, part of its charge will be transferred to it; in fact, almost the whole of its charge will be transferred to the inductor of the other stream, as the capacity there is much greater, owing to the presence of the drops of water in its centre, at the potential of the earth.

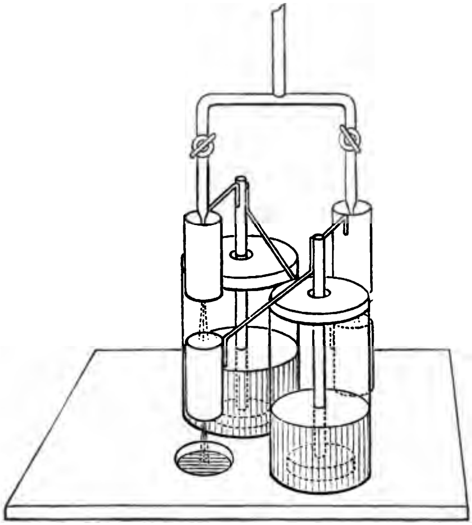


FIG. 71. THOMSON'S WATER-DROPPING MULTIPLIER.

Fig. 71 shows the arrangement of the apparatus with two streams. The two rods connecting the inductor and the collecting tubes are connected to the stems of two Leyden jars, which enables considerable charges to be accumulated. "The practical limit to the charges is when one is so strong as to cause sparks to pass across some of the separating air-spaces, or to throw the drops of water out of their proper course, and cause them to fall outside the receiver through which they should pass. It is curious after commencing with no electricity except a feeble charge in one of the jars, only discoverable by a delicate electrometer, to see in the course of a few minutes a somewhat rapid succession of sparks pass in some part of the apparatus, or to see the drops of water scattered about over the lips of one or both the receivers."

Sir W. Thomson mentions that he was led to the invention of the regenerative principle in the above machine by a consideration of the analogous principle in the self-exciting dynamo which had just previously been invented by Siemens and Wheatstone. He also mentions that the influence machine just described was constructed by him many years before 1867.

Using a single inductor and a single receiver, and putting the inductor in metallic communication with the metal vessel or cistern whence the water flows, the vessel being connected with a delicate electrometer, an electric effect is generally found to accumulate in the receiver and electrometer, when the lining of the cistern and the inner metallic surface of the inductor are of different metals. If the inner surface of the inductor be dry polished zinc, and the vessel of water above be copper, the receiver acquires a continually increasing charge of negative electricity. There is little or no effect if the inductor present a surface of polished copper to the drops where they break away from the continuous water above; but if the copper surface be oxidized by the heat of a lamp, until instead of a bright metallic surface of copper, it presents a slate-coloured surface of oxide of copper to the drops, these become positively electrified, as is proved by the continually increasing positive charge exhibited by the electrometer. When the inner surface of the inductor is of a bright metallic colour, either zinc or copper, there seems to be little difference in the effect whether it be wet with water or quite dry.

Copper filings dropping from a copper funnel, and breaking away from contact in the middle of a zinc inductor to which the copper funnel is soldered, as shown in Fig. 72, produce a rapidly increasing negative charge in a small insulated can placed below to receive them.

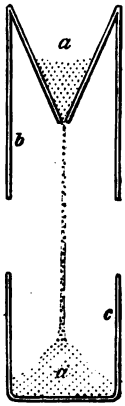


FIG. 72.

The action of the apparatus just described is closely analogous to that of the voltaic cell, but differs in deriving its energy from the falling of the drops of water instead of from chemical action.

In his lecture before the Royal Institution, 1860, Thomson also pointed out that the flame of an insulated lamp acted in the same way as the water-dropping apparatus, *i.e.*, it reduced the lamp and other conducting material in connection with it to the same potential as that of the air in the neighbourhood of the flame.

Separately Excited Influence Machine.—This machine was designed to facilitate the application of an instrument for recording the signals of the Atlantic cable. The machine was driven by the wheelwork of an ordinary Morse instrument. The field plate was excited by another machine, which will be described later.

"A wheel of vulcanite, with a large number of pieces of metal (called carriers for brevity) attached to its rim, is kept rotating rapidly round a fixed axis. The carriers are very lightly touched at opposite ends of a diameter by two fixed tangent springs. One of these springs (the earth spring) is connected with the earth, and the other (the receiving spring) with an insulated piece of metal called the receiver, which is analogous to the "prime conductor" of an ordinary electric machine. The point of contact of the earth spring with the carriers is exposed to the influence of an electrified body (generally an insulated piece of metal) called the inductor. When this is negatively electrified, each carrier comes away from contact with the earth-spring, carrying positive electricity, which it gives up through the receiver spring to the receiver. The receiver and inductor are each hollowed out to a proper shape, and are properly placed to surround, each as nearly as may be, the point of contact of the corresponding spring.

"The inductor, for the good working of the machine, should be kept electrified to a constant potential. This is effected by an adjunct called the replenisher, which may be applied to the main wheel, but which for a large instrument ought to be worked by a much smaller carrier-wheel, attached either to the same or another turning shaft."

The Replenisher.—The replenisher, Fig. 73, consists chiefly of two properly shaped pieces of metal called inductors (field plates) which are fixed in the neighbourhood of a carrier wheel, such as that described above,

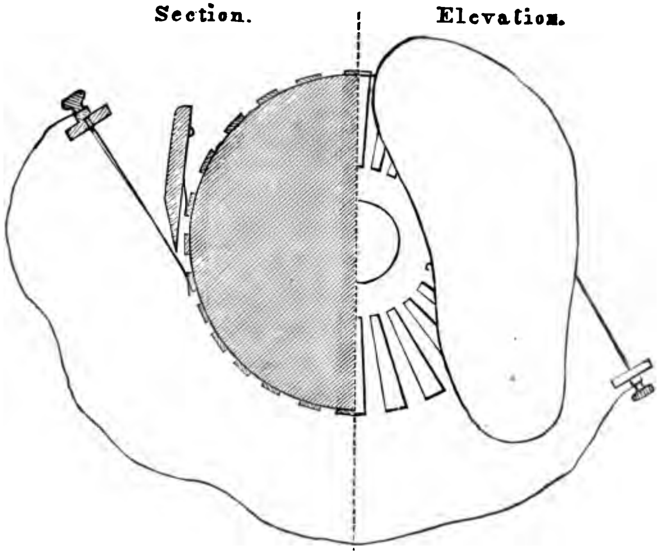


FIG. 73. THOMSON'S REPLENISHER.

and four fixed springs touching the carriers at the ends of two diameters. Two of these springs, called receiver springs, are connected respectively with the inductors, and the other two (called connecting springs) are insulated and connected with one another; one of the inductors is generally connected with the earth, and the other insulated. They are so situated that they are touched by the carriers on emerging from the in-

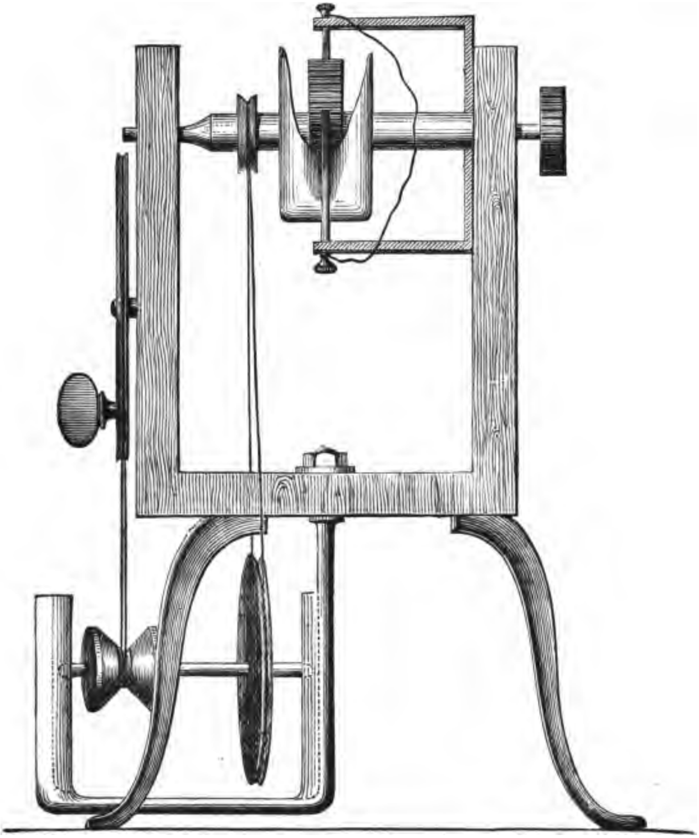


FIG. 74. THOMSON'S REPLENISHER.

ductors, and shortly after the contacts with the receiver springs. If any difference of potential between the inductors is given to begin with, the action of the carriers increases it according to the compound interest law, so long as the insulation is perfect. Practically in a few seconds after the machine is started running, bright flashes and sparks begin to fly about in various parts of the apparatus, even although the inductors and connectors have been kept for days as carefully discharged as possible.

An instrument of this kind, Fig. 74, with a wheel 2 in. diameter, was constructed for Atlantic Telegraph application; its action was so startlingly successful, that in Sir W. Thomson's opinion good effects might be expected from larger machines on the same plan.

When this instrument is used to replenish the charge of the inductor in the constant electric machine described above, one of its own inductors is connected with the earth, and the other with the inductor to be replenished. When accurate constancy is desired, a gauge electroscope is applied to break and make contact between the connector springs of the replenisher, when the potential to be maintained rises above or falls below a certain limit.

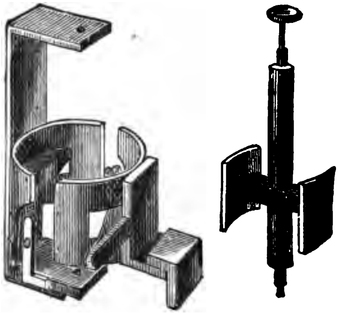


FIG. 75. THOMSON'S REPLENISHER.

Another form of the replenisher, Fig. 75, was used in the quadrant electrometer, to replenish the Leyden jar.

The inductors or field plates F_1 F_2, Fig. 76, are cylindrical pieces of metal subtending an angle of 120° each. The carriers C_1 C_2 are also cylindrically shaped pieces of metal which are carried on a crossbar of vulcanite *B*, mounted on a vertical axis *A* of vulcanite. The field plates are not quite concentric with the axis, but are shaped so that the carriers approach closer to them just before emerging. The object of this will be explained afterwards.

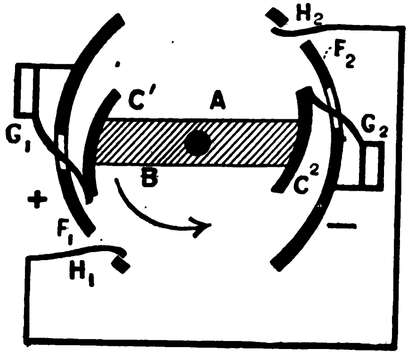


FIG. 76. DIAGRAM OF REPLENISHER.

Openings are cut in four places in the inductors, through which springs are passed to touch the carriers as they pass. Two of these springs, G_1 G_2, called the receiving springs, are connected to the inductors. The other two, H_1 H_2 are metallically connected with one another, and neutralize the carriers, or reduce them to the same potential, when in contact with them. The carriers are not arranged concentrically with the axis, but so that the front edge only comes in contact with the springs. All the springs must be placed so that the carriers are completely covered by the inductors when they are in contact with the springs. The action of the machine is as follows: The potential of the two inductors is usually slightly different, however completely the apparatus may have been discharged. We will assume that this difference takes the form of a positive charge on one of the inductors F_1, the other inductor F_2 being at a less potential. When the carriers are in the position shown in the diagram, Fig. 76, they are in contact with the receiving springs, and a very large proportion of any charge which they may have will be communicated to the inductors. By continuing the rotation of the carriers they come in contact with the springs H_1 H_2 of the neutralizing circuit. In this latter position they are still almost completely inclosed by the inductors, and are at the same potential. The result of this will be that C_1 will receive a negative charge, and C_2 a positive charge, these charges being in amount almost as large as the charges on the inductors. As the rotation proceeds, C_1 with its negative charge comes in contact with the receiving spring G_2, and communicates a large proportion of its negative charge to the inductor F_2, thereby increasing the negative charge it already carries. The charge which each carrier carries away from the receiving spring must be less than the charge which it acquires when in contact with the connecting spring, for otherwise charges in the inductors will not increase, but diminish. To insure this the inductors are bent so as to be closer to the carriers when they are in contact with the connecting springs, than when they are in contact with the receiving springs. By turning the replenisher in the opposite direction the charges on the inductors will be diminished.

The replenisher can be spun rapidly round by a milled head on the end of a steel pivot fixed to the top of the vulcanite shaft, and passing through the cover.

The Potential Equalizer.—Sir W. Thomson has constructed an instrument for equalizing the potential of a spring (which might be connected with an electrometer) with the potential of the air in contact with it at

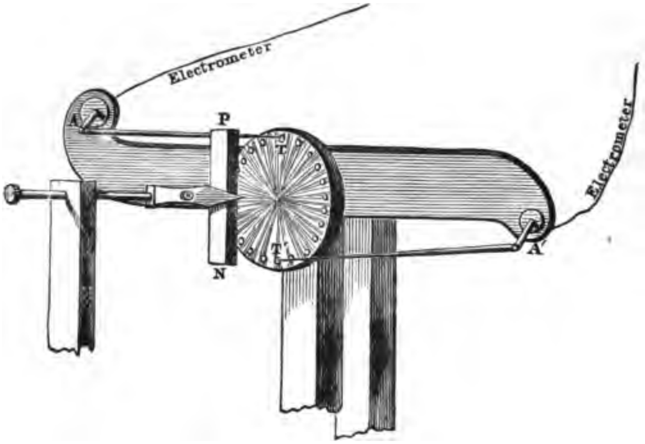


FIG. 77. THOMSON'S POTENTIAL EQUALIZER.

any given point. This instrument was used for investigating the electricity of crystals, the theory of the galvanic cell, and similar researches. One form of the instrument suited for testing the electricity of crystals when heated is shown in Fig. 77.

The springs $A\ T$ and $A^1\ T^1$ are insulated and connected to the two electrodes of a quadrant electrometer —or one of them may be connected with the insulated part of the electrometer and the other with the metal inclosing the case, when there is only one insulated electrode. A circle of small brass pegs on the face of a vulcanite disc are fixed so as to touch the points of the two springs, $A\ T$ and $A^1\ T^1$, as the disc rotates. A crystal of tourmaline $P\ N$ is held in a clip at the end of a metallic arm, parallel to the disc, and with its ends over the ends $T\ T^1$ of the springs, where they make contact with the brass carriers on the disc. The crystal is now heated, preferably by a hot plate placed behind

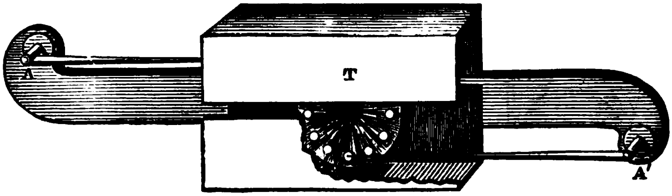


FIG. 78. THOMSON'S POTENTIAL EQUALIZER.

it, and, as is well known, one end of the crystal will become positive and the other negative. The potential of the air surrounding the points T and T^1 will in one case be higher than that of the spring, and in the other lower. Thus an accumulation of positive electricity will take place at one point, and an accumulation of negative at the other. These accumulations will be carried off by the brass carriers as long as any difference of potential exists between the springs and the surrounding air. The principle is the same as in the water-dropping apparatus already described.

Another form of this apparatus suited for investigating experimentally the difference of potential produced by the contact of different metals is illustrated in Fig. 78.

Two inductors are placed over the ends of the springs, as shown; the inner surface of each being of smooth brass. To experiment on the contact difference of potentials between zinc and copper, one of the inductors is wholly lined with sheet zinc or with sheet copper, and the two inductors are metallically connected together. The springs are each in metallic communication with the electrodes of the quadrant mirror electrometer. The disc is now kept turning, and soon a permanent reading will be obtained with the electrometer. The difference of the readings obtained with zinc and copper is proportional to the difference of potentials produced by the contact of the metals. Any number of different metals may be tested in this way.

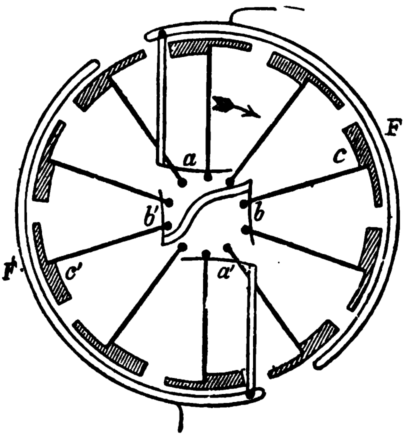


FIG. 79. THOMSON'S MOUSE MILL.

This instrument may also be applied for testing the insulation of insulated conductors of small capacity.

The Mouse Mill.—A cylindrical form of the machine last described may obviously be constructed, and this form has been called by Sir W. Thomson the *mouse mill*, on account of its resemblance to the wheel of a mouse mill. The ends of the wheel are made of discs of vulcanite, and the carriers are metallic plates or bars connecting the two discs, and parallel to the axis of the wheel. The field plates or inductors may be tangent planes or curved into cylindrical shape.

The *mouse mill* used for electrifying the ink vessel of the syphon recorder in cable signalling, is a combination of an influence machine and an electromotor. The Froment type of electromotor, the armature of which resembles the wheel of the mouse mill, is used. The parallel iron bars of the motor, which are insulated, serve as the carriers of the influence machine. On opposite sides of the armature are two cylindrically shaped field plates, $F F^1$, Fig. 79. A pin is attached to each carrier-bar, which projects so as to come in contact with the receiving springs $a a^1$, connected to the field plates. They also touch at intermediate points the springs $b b^1$ of a neutralizing circuit. Rotation of the motor, and hence of the influence machine, is produced by a battery.

Endless Band Influence Machines.—Thomson suggests that "when great intensity is desired the best pattern will probably be had by substituting for the carrier-wheel an endless rope ladder, as it were, with cross bars of metal and longitudinal cords of silk or other flexible insulating material. This, by an action analogous to that of the chain pump, will be made to move with great rapidity, carrying electricity from a properly placed inductor to a properly shaped and properly placed receiver, at a distance from the inductor, which may be as much as several feet."

It may be well to describe here some other machines that have been made on the principle of Sir W. Thomson's endless band machine.

In 1872 Righi designed a machine for multiplying small electric charges. An endless indiarubber tube is mounted like an ordinary lathe band, on two pulleys. At intervals on the tube are wound rings of copper wire. These rings act as the carriers of the machine. One of the pulleys is connected to the earth and the other is turned by a handle. Opposite the belt, where it leaves the earth-connected pulley, is held the body with the small charge which is to be multiplied. Each copper wire carrier, as it passes under this electrified body, being in contact with the pulley and thus with the earth, receives a charge of the opposite kind of electricity. Each carrier with its charge proceeds towards the other pulley, and about half-way it enters a metallic sphere, through a perforation in which the band passes. While inside the sphere the carrier is discharged by means of a contact spring. If the sphere is connected to a Leyden jar, a very large charge may thus be communicated to the jar, though the original charge in the influencing body may be very small. This evidently belongs to the class of addition machines.

An influence machine of the endless band type, and arranged to multiply the charges on the field plates, has been designed by the author. The machine is illustrated in Fig. 80. An endless band *A*, of india-rubber cord is stretched over two grooved pulleys, *B* and *C*. Both these pulleys are mounted on insulating supports, and one of them is turned by a handle, which should also be insulated. Short pieces of brass tube are slipped on the cord, at equal intervals, to act as carriers.

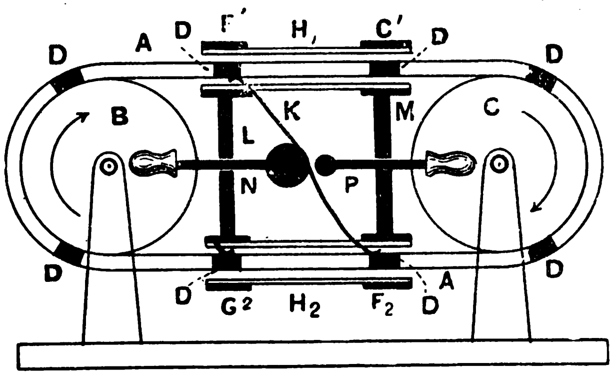


FIG. 80. ENDLESS BAND INFLUENCE MACHINE.

The field plates or inductors are in this case ferrules, or short pieces of brass tube, F^1 and F_2, surrounding the ends of the glass tubes H^1 H^2 through which the endless band *A* passes. The two carriers inside the inductors F^1 F^2, are connected for the moment by a neutralizing rod *K*. They thus receive an opposite charge to the inductors. Each carrier with its charge next passes inside the collecting ferrules, G^1 G^2, on the other ends of the glass tube, to which they give up their charges by contact with a spring or brush fixed on the ferrule. The ferrules F^1 and G^2 are connected by a transverse brass rod *L*, and the ferrules G^1 F^2 by a transverse brass rod *M*. Sliding electrode rods *N* and *P*, furnished with discharging knobs, may be fitted to *L* and *M*. If the pulleys *B* and *C* are removed to a sufficient distance from the electrodes of the machine to prevent sparks passing to earth, it will be unnecessary to insulate them. Machines of this kind may be constructed with flat gutta-percha or indiarubber belts, and glass plates above and below, instead of the glass tubes, as in the forms first described. A silk ribbon belt with tinfoil carriers forms a very good arrangement.

CHAPTER VI.

MODERN MACHINES (CONTINUED): ADDITION MACHINES, MAXWELL'S MACHINE AND EXPERIMENTAL NOTES.

THE modern influence machines hitherto described have belonged, with one or two exceptions, to the class of multiplying machines, that is machines in which the initial charge increases according to the law of compound interest, or geometrical progression, till the limit fixed by leakage is reached. There is another class of machines which may be called *addition machines*, in which the original charge on the field plates is not replenished by the machine, and which therefore do not follow the compound interest law, but the law of arithmetical progression, that is to say, they deliver a fixed quantity of electricity at each revolution of the machine. We shall describe one or two of the best-known forms of these latter machines.

Bertsch's Machine.—This machine, Fig. 81, consists of an ebonite disc P, collecting combs A and A^1, and a fixed ebonite sector S, which acts as a field plate.

To start the machine, the field plate S must be excited by rubbing it with a piece of fur, and the disc P then turned on its axis. If the knobs C C^1 are not too far apart a discharge will take place between them. A front view of the disc is shown on the right side of Fig. 81. By the influence of the negative charge excited in the field plate S, negative electricity will be driven through the comb A to the discharging knob C, and a positive charge left on the surface of the disc. If the direction of rotation of the disc is that shown by the arrows, positive electricity will be carried round from A to A^1, whence it will be conveyed by the collecting comb to the discharging knob C^1. At every revolution of the disc a certain quantity of negative electricity will be added to the knob C, and of positive to the knob C^1 till the difference of potential is sufficient to produce a discharge.

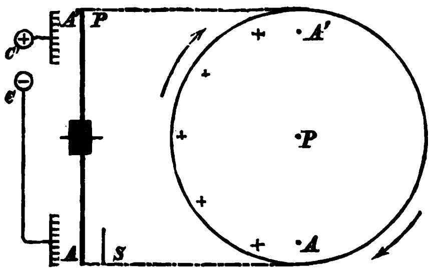


FIG. 81. BERTSCH'S MACHINE.

A machine made on this principle by Bertsch, having a disc 20 inches in diameter, gave sparks of 5 to 7 inches in length.

The action of the Bertsch machine is liable to stop, owing to the disappearance of the charge on the field plate through leakage. In the next machine to described a contrivance is introduced to overcome t difficulty.

Carré's Machine.—This machine is essentially of t same construction as that of Bertsch, but instead of ebonite plate, the disc of a frictional electric machine is used as a field plate. This has the advantage of being always in an excited condition.

Two discs, *A* and *B*, Fig. 82, are mounted on parallel axes, and geared together by a belt-and-pulley arrangement, so that by turning the handle *M* both discs are caused to rotate; the disc *B* rotating at a much higher speed than the disc *A*. The disc *A*, which is made of glass, is electrically excited by the friction of the amalgamated pads *D*, and overlaps, at the opposite side from the pads, the disc *B*, without however touching it. The disc *B* is of ebonite, and runs free, that is without being in rubbing contact with anything. On the opposite side from the frictional disc is fixed a collecting comb *E*, which is connected to a discharging rod *T*. Another collecting comb *F* stands in front of the disc B at the opposite side from *E*, and is connected to a large conductor *C*.

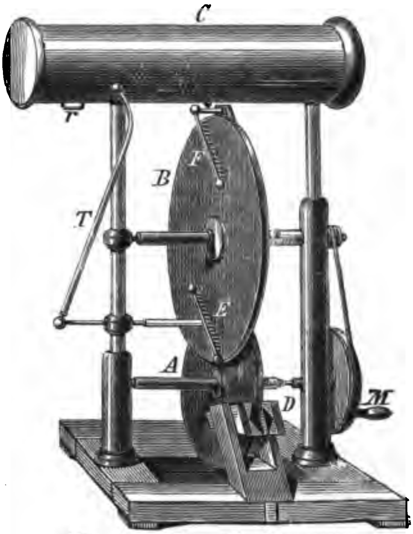


FIG. 82. CARRÉ'S MACHINE.

The action of this machine is similar to that of the Bertsch machine. The surface of the disc *A* where it overlaps *B*, acts in this case as the field plate. If this is positively electrified, negative electricity will be drawn from the collecting comb *E* on to the surface of the disc *B*, while a positive charge will be communicated to the discharging rod *T*. The negative charge on the surface of the disc *B* is carried round and imparted to the collecting comb *F*, and thence to the conductor. After a sufficient number of revolutions, sparks will pass between the discharging rod *T* and the conductor *C*. Sparks of about $7\frac{1}{2}$ inches have been obtained from a Carré machine, having discs *A* and *B* of 15 in. and 20 in. respectively in diameter. The energy of the sparks is considerably increased by connecting the two electrodes to the inner and outer coatings of a Leyden jar. The Leyden jar may be suspended from the ring *r* by a hook, its other coating being connected to the other electrode by a chain.

Wimshurst has greatly increased the efficiency of the Carré machine by fixing a glass plate in front of that half of the disc *B*, which is conveying the electric charge from the comb *E* to the comb *F*. This plate probably fulfils the same purpose as the fixed disc in the Holtz machine, viz., prevents the dissipation of the charge on the disc *B* into the atmosphere.

Up to the present time the influence machine has proved of very little practical use. Professor Lodge has suggested that it might be used for collecting dust, smoke, or fog by electrifying the particles, and thus causing them to adhere; and as a consequence of this suggestion an attempt has been made to condense the fumes produced in the manufacture of lead. The attempt, however, has not as yet proved a practical success.

Another application, which has been more successful, is to the lighting of gas jets. Clarke has invented an instrument for gas-lighting, in which short electric sparks are produced by an influence machine inclosed in the

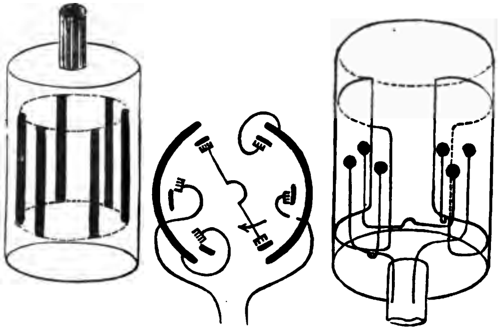


FIG. 83. CLARKE'S GAS LIGHTER MACHINE.

handle of the apparatus. The type of influence machine which he usually employs is a combination of the Thomson's replenisher and Voss machine. There are, Fig. 83, two field plates of tinfoil shaped as in the ordinary Thomson replenisher. Between the field plates is a rotating ebonite cylinder, having eight pieces of metal foil fixed on it to serve as carriers. A pair of neutralizing brushes are fixed to a cross conductor; a pair of replenishing brushes are connected to the field plates; and, lastly, a pair of collecting brushes are connected to the wires, which lead up through the stem of the instrument to the sparking points.

Clerk Maxwell's Machine.—We shall conclude our account of modern influence machines by a description of a machine of very great theoretical interest, invented by the late Clerk Maxwell.

Maxwell pointed out that a great loss of efficiency, even though loss by leakage were to be entirely eliminated, would result from the passage of sparks whenever a carrier comes in contact with a conductor. The reason of this is that part of the energy employed in turning the machine is spent in producing the heat and noise of electric sparks instead of being converted into electrification in an available form.

To obviate this loss he proposed to employ a contrivance called in heat engines a regenerator.

"In Fig. 84 let A, B, C, A^1, B^1, C^1 represent hollow fixed conductors so arranged that the carrier P passes in succession within each of them. Of these A, A^1 and B, B^1 nearly surround the carrier when it is at the middle point of its passage, but C, C^1 do not cover it so much.

We shall suppose A, B, C to be connected with a Leyden jar of great capacity at potential V, and A^1, B^1, C^1 to be connected with another jar at potential $-V^1$.

P is one of the carriers moving in a circle from A to C^1, etc., and touching in its course certain springs, of which a and a^1 are connected with A and A^1 respectively, and e and e^1 are connected with the earth.

Let us suppose that when the carrier P is in the middle of A the coefficient of induction between P and A is $-A$. The capacity of P in this position is greater than A, since it is not completely surrounded by the receiver A. Let it be $A+a$.

Then if the potential of P is U, and that of A, V, the the charge on P will be $(A+a)\ U-A\ V$.

Now let P be in contact with the spring a when in the middle of the receiver A, then the potential of P is V, the same as that of A, and its charge is therefore $a\ V$.

If P now leaves the spring a it carries with it the charge $a\ V$. As P leaves A its potential diminishes, and it diminishes still more when it comes within the influence of C^1, which is negatively electrified.

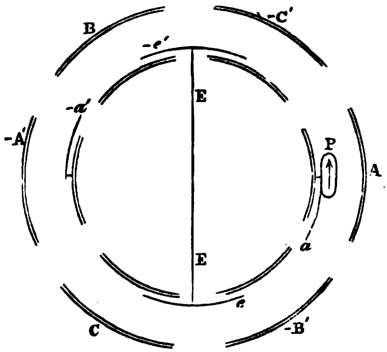


FIG. 84. CLERK MAXWELL'S MACHINE.

If when P comes within C^1 its coefficient of induction on C^1 is $-C^1$ and its capacity is C^1+c^1, then if U is the potential of P, the charge on P is

$$(C^1+c^1)\ U+C^1\ V^1=a\ V.$$

$$\text{If} \qquad C^1\ V^1=a\ V,$$

then at this point U the potential of P will be reduced to zero.

Let P at this point come in contact with the spring e^1, which is connected with the earth. Since the potential of P is equal to that of the spring, there will be no spark at contact.

This conductor C^1, by which the carrier is enabled to be connected to earth without a spark, answers to the contrivance called a regenerator in heat engines. We shall therefore call it a regenerator.

Now let P move on, still in contact with the earth spring e^1, till it comes into the middle of the inductor B, the potential of which is V. If $-B$ is the coefficient of induction between P and B at this point, then, since $U = O$ the charge on P will be $-B\ V$.

When P moves away from the earth spring it carries this charge with it. As it moves out of the positive inductor B towards the negative receiver A^1 its potential will be increasingly negative. At the middle of A^1, if it retained its charge, its potential would be

$$-\frac{A^1\ V^1 + B\ V}{A^1 + a^1},$$

and if $B\ V$ is greater than $a^1\ V^1$ its numerical value will be greater than that of V^1. Hence there is some point before P reaches the middle of A^1, where its potential is $-V^1$. At this point let it come in contact with the negative receiver spring a^1. There will be no spark, since the two bodies are at the same potential. Let P move on to the middle of A^1, still in contact with the spring, and therefore at the same potential with A^1. During this motion it communicates a negative charge to A^1. At the middle of A^1 it leaves the spring and carries away a charge, $-a^1\ V^1$ towards the positive regenerator C, where its potential is reduced to zero, and it touches the earth spring *e*. It then slides along the earth spring into the negative inductor B^1, during which motion it acquires a positive charge, $B^1 V^1$, which it finally communicates to the positive receiver A, and the cycle of operations is repeated.

During this cycle the positive receiver has lost a charge, $a V$, and gained a charge, $B^1 V^1$. Hence the total gain of positive electricity is

$$B^1 V^1 - a V.$$

Similarly the total gain of negative electricity is $B V - a^1 V^1$.

By making the inductors so as to be as close to the surface of the carriers as is consistent with insulation, B and B^1 may be made large, and by making the receivers so as nearly to surround the carriers when it is within them, a and a^1 may be made very small, and then the charges of both the Leyden jars will be increased in every revolution.

The conditions to be fulfilled by the regenerators are

$$C^1 V^1 = a V, \text{ and } C V = a^1 V^1.$$

Since a and a^1 are small, the regenerators do not require to be either large or very close to the carriers."

It may assist us to understand the use of the regenerator in Maxwell's machine, if, in accordance with the hypothesis explained in Part I., Chap. II., we assume that the carrier P is an elastic bag filled with the electric fluid. The object aimed at in this machine is to bring the elastic bag into such a field of pressure that when it comes in contact with a discharging spring, the pressure inside the bag will be the same as that of the spring. As a consequence of this there will be no transference of fluid when the contact is made; the transference takes place as the bag moves into a field of higher or lower pressure, while still in contact with the spring.

Experimental Researches on Influence Machines.

Rossetti, Mascart, and other experimenters have made a series of measurements on influence machines to ascertain the relations between the electro-motive force, current, and work spent in driving.

The electro-motive force, or difference of potential required to produce a spark, may be calculated approximately from experiments made by Sir W. Thomson on the electro-motive force required to produce sparks of known length. These experiments were made with sparks not exceeding 1·5 centimetre in length, and it was calculated that to produce a spark between two slightly convex metallic surfaces at $\frac{1}{8}$ of a centimetre asunder, in ordinary atmospheric air, requires an electromotive force of 5,510 Daniell cells. From this we may deduce an approximate rule, that to produce a spark 1 inch in length, an electro-motive force of 100,000 volts is required.

Sir W. Thomson's experiments seemed to point to the conclusion that for sparks above 1 cm. in length the *E. M. F.* would be proportional to the length of spark; but other experiments have not confirmed this conclusion. Macfarlane, who experimented with sparks of 0·1 to

1 cm. in length, found the results could be represented by the formula

$$V = 66{\cdot}940 \sqrt{x^2 + 0{\cdot}205\, x}$$

in which V is the potential difference and n the spark length, in other words, by a hyperbola; if the sparks strike between a ball and a plate, or two plates, the curve approaches a parabola. Mascart, experimenting with spark lengths of 0·1 to 15 cm., between two balls 22 cm. diameter, found

Distance.	Potential Difference.
·1 cm.	5,490 v.
1 ,,	48,600
2 ,,	64,800
5 ,,	94,800
10 ,,	119,100
12 ,,	124,200
15 ,,	127,800

According to Warren de la Rue and H. Muller the spark length between a point and a plate increases approximately as the potential difference for distances up to 1 cm. If the length exceeds 2 cm. the potential difference increases very slowly, so that it does not go beyond a certain limit which falls about 120,000 v. This applies to a point and a plate as electrodes. It appears from the researches of Mascart that for two balls the limit lies rather higher.

Rossetti employed an ordinary Holtz machine with a neutralizing rod in his experiments. The machine was turned by the descent of a weight, the number of revolutions being taken by an electro-magnetic counter. The current was measured by a galvanometer, and resistances consisting of glass tubes filled with water were used for varying the amount of current by putting more or less resistance in the external circuit. The effective work employed in producing the electricity was ascertained by measuring the amount of work required to drive the machine when not excited, and deducting it from the total work required to drive the machine when producing electricity. It is this effective work that is understood to be meant in what follows. Rossetti's results were as follows :—

The current is nearly proportional to speed ; or to state it more exactly—the current increases a little more rapidly than in proportion to the speed.

The effective work is exactly proportional to the current.

In dry days there was more electricity for a given quantity of work, and less for an equal speed.

With increased distances between the discs, the current and the amount of work required diminished.

With increased resistances in the external circuit, when the driving weight was the same throughout, the speed decreased, and therefore also the work and the current.

Riecke showed that for machines of the "second kind," that is, Holtz machines with oppositely rotating plates, the current is proportional to the speed.

Mascart measured the relative output of several influence machines and frictional machines, by determining the number of sparks per second from jars of known capacity. The output was taken to mean the quantity of electricity produced per second per unit of useful surface. The following table gives the results of his experiments:—

Frictional Machines.	Output.
Ramsden	0·42
Van Marum	0·80
Nairne	1·2
Influence Machines.	
Holtz, single	12·8
Holtz, duplex	12·3
Holtz (second kind)	9·7
Carré	7·2

A Holtz machine is reversible in the same sense as a dynamo-electric machine, that is to say, it will act as a motor if electricity is supplied to it from another influence machine. To perform this experiment the rotating disc of the Holtz machine must be mounted so as to run with very little friction. The electrodes of the machine must be separated beyond striking distance, and wires from another Holtz machine (by preference a more powerful machine), connected to the two collecting combs. If a slight impulse is given to the rotating disc in one direction or the other, it will rotate equally well in either direction. This appears to show that the action of the electricity in the combs upon that on the surface of the disc is greater than that on the field plate.

A Wimshurst machine can also be made to act as a motor, if electricity is supplied to its combs from another machine as described above.

PART III.

PRACTICAL CONSTRUCTION OF INFLUENCE MACHINES.

CHAPTER I.

WIMSHURST MACHINES.

THE simplest form of Wimshurst machine is that with two oppositely rotating plates. This may be made to give an average length of spark, and excite itself readily even in unfavourable atmospheric conditions; or it may be constructed to give the maximum possible length of spark for a given diameter of disc. The former design, which has been called by Mr. Wimshurst the laboratory machine, Fig. 66, will be described in detail first, and then the latter, which may be called the long-spark machine, will be illustrated, and its differences from the ordinary type indicated. Finally a twelve-plate machine will be described.

The Laboratory Machine.—In Fig. 85 the completed machine is illustrated; the reference letters appended to each detail correspond with those marked on the separate details in Plate II.

The Stand.—The stand is made of mahogany. For this is required—two side pieces *A*, each 16 in. by $2\frac{1}{2}$ in., to be planed and moulded round three sides as shown, and mortised at the centre to receive the tenons of the uprights or stanchions *F*; two transverse end pieces *C*, each $12\frac{1}{2}$ in. by $3\frac{1}{2}$ in., having two round holes bored out

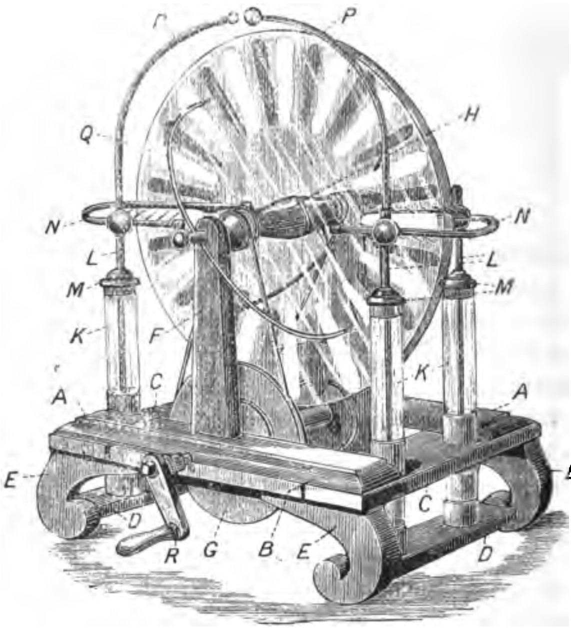


FIG. 85. LABORATORY MACHINE.

in each to receive the Leyden jars *K*; two pieces *B* to support the bearings of the driving spindle, each $9\frac{5}{8}$ in by $1\frac{3}{4}$ in.; two transverse pieces *D*, recessed to support the bottoms of the Leyden jars, each $10\frac{1}{4}$ in. by $2\frac{1}{2}$ in.; four scroll pieces *E*, for feet as shown; two tapering pieces *F*, for uprights or stanchions to support the spindle of the glass discs, $10\frac{3}{4}$ in. long by $2\frac{1}{2}$ in. to $1\frac{1}{4}$ in. in breadth, tenons being cut at the wide ends to fit into the mortises in the side pieces *A*. The stanchions should be fairly rounded upon their edges and tops. The scroll feet should be cut out with a turning saw to a pretty shape, and care should be taken that they quite cover the ends of the tables *D* which support the Leyden jars, since it looks ugly if the ends of the tables are shown. These parts may all be glued together, and as they are chiefly surfaces glued to surfaces, screws should be used as well as glue, care being taken that the points of the screws do not show themselves through the stand. The tables, which support the jars, have circular pins cut upon their ends, which fit into holes bored in the scroll feet, and they must be glued into place in their proper order.

Driving Spindle and Wheels.—The driving spindle of the pulleys *G* is made from iron rod, 13 inches long and $\frac{1}{2}$ inch in diameter. Good centres having been drilled in its ends, it is placed in a lathe; one end is then turned up for a length of $1\frac{1}{8}$ inch and screwed; a thick iron ring is then tapped and screwed on the end of the spindle to form a collar to act as a stop for the driving handle when it is screwed on to the end of the spindle afterwards. A piece of mahogany is next bored out, and driven tight on to the spindle. The spindle is now put back in the lathe, and the mahogany sheath turned down to a cylindrical shape, its ends being reduced to a somewhat smaller size and driven into discs, which are large enough to be turned up to form driving wheels 7¾ inches in diameter, with grooves to receive a round band. The spindle may now be trued up and its ends finished; the discs for the driving wheels are glued on to the mahogany sheath, and turned up and finished in the lathe after the glue is dry. The grooves should be of good size, as the bands run better in large than in small grooves. If the mahogany sheath is not tight enough upon the metal spindle, it will be desirable to bore a hole through wood and iron, and drive in a metal pin. Care should be taken that the driving wheels are about ½ inch free from the bench on which the machine stands.

Clamps to hold Spindle.—These (denoted by the letter *B*) should be made sufficiently long to fit against the ends of the frame. The corner pieces which fit between the scroll feet and the side bars *A* are neatly cut out and glued in their places, so that the remaining portion of the clamp may be the more easily removed when necessary. The clamps are fixed to the side bars *A* by two screws in each.

Holes for Leyden Jars.—The position of these holes should be accurately marked at equal distances from the ends of the transverse bars *C* and tables *D*, and bored out 1¾ inch in diameter. A good centre-bit will do this. The holes must be quite vertical and extend through the transverse bars, and about half-way through the tables.

Spindle for Glass Discs and Tubes for Brushes.—The former must be of straight, polished steel wire, which can be purchased ready for use at Smith's tube warehouse, St. John's Square, Clerkenwell, or other similar shops. The wire for one spindle should be 10 inches long and $\frac{3}{8}$ inch in diameter, and when selecting it, enough should be taken for two spindles, as a second spindle will be found useful in many ways.

The latter consist of pieces of drawn brass tube, which can be obtained at a tube warehouse, of the exact size to turn nicely on the steel spindle. It is advisable in this case also to select three or four times the length required, as it is useful for experimental bosses.

Bosses for the Glass Discs.—For these (denoted by the letter *H*) well-seasoned wood must be selected. They are 4 inches in length and $2\frac{1}{2}$ inches in diameter at the large end. A hole is first bored through the piece of wood from end to end, of such a size that the brass tube must be pushed tightly into it. It is now placed in the lathe and turned up, first for proper length, and afterwards to form, taking care that its *V* groove is over the *V* groove of the driving wheel.

Driving Bands.—The round leather for sewing machines answers very well for this size of machine. The joint is best made by cutting each end to a scarf, causing the scarf to overlap about $1\frac{1}{2}$ inch, and stitching together with a needle and stout thread; or a steel wire hook may be used.

Connections for outer Coatings of Leyden Jars.—These connections are made by a small wire extending from the two Leyden jars to one end of the machine, and carried thence up to a terminal; the wire, should, as far as practicable, be placed on the underside of the several parts. It may be attached by means of small staples or by small tacks, the wire being twisted round the tack just before it is driven close up. The other end of the machine is then similarly completed, and the circuit is then closed by means of a removable piece of brass wire placed between the terminals.

Brasswork Rods for the Leyden Jars.—The four rods *L* for the Leyden jars are made of brass tube, each being 12 inches long by $\frac{1}{4}$ inch internal diameter. At $1\frac{1}{2}$ inch from one end a nicely shaped brass ring is soldered on, to form the shoulder upon which the ball of the comb *N* rests. The whole is then polished up and lacquered.

Combs.—These (denoted by letter *N*) are made by first cutting a $12\frac{1}{2}$ inch length of $\frac{1}{4}$-inch brass wire, of which the ends are to be rounded. It may then be bent up to U shape as in the drawing. Then get four cast balls with holes bored through them, of such size as to freely pass over the rods of the Leyden jars. With a small round file a groove is cut on the one side of each ball of such a size as to fit upon the bent brass wire. Having done this, drill the holes in the bent brass wire, and fit in the collecting points, five of which on each side will be found sufficient. After this, solder the brass wire, the points, and the balls together as shown in the sketch *N* (Plate II.), and then polish up and lacquer.

Discharging Terminals or Electrodes.—These (denoted by *P*) are made of brass wire, the size to fit into the tubes or rods *L* for the Leyden jars, and $16\frac{1}{2}$ inches in length. One end is filed slightly taper, a brass ball is soldered upon it, the wire is then bent to the proper form, and the whole cleaned up and lacquered.

Neutralizing Rods.—These (denoted by *Q*) are made up of an axis of consisting of 1¾ inch of brass tube, of the same size as is used to bush the bosses; and a piece of brass wire 18½ inches long, which is passed through a $\frac{5}{32}$ inch hole bored transversely through the axis at a distance of ¼ inch from one end. The ends of the wire are drilled up (say ⅜ inch) to receive the brushes; the wire is soldered to the axis; a brass ball is soldered on the outer end of the axial tube to make a finish; the whole is then polished up, the wire is bent to the proper form, and a coating of lacquer applied.

Brushes.—For the brushes on the ends of the neutralizing rods, it is necessary to get some fine wire, such as is made by the gilt-lace makers, of the gauge which they call No. 22. A quarter of an ounce (costing 3*d.*) will be enough for several hundred brushes. About ten turns of the fine wire is wound upon a piece of metal plate, say 1¼ inch broad; the turns of wire are then cut through by a knife, at one side of the metal plate. The turns are now slid off the metal plate, the uncut ends are twisted up tightly by the finger nails, the wires are slightly pulled and bent till they are straight, and the sharply hooked ends are clipped off by a pair of scissors. The brush is then complete, and may be fixed in the end of the neutralizing rod by a small wooden wedge.

Driving Handle.—It is best to make a pattern for this (denoted by *R*) and have it cast in brass. It then only requires to be surfaced. The hole for the driving spindle should be screwed, and a wooden case fitted over the driving pins.

Leyden Jars.—These (denoted by *K*) are 10½ inches by 1⅝. The tinfoil coating is about 4 inches in height upon the inside of the jar, and about 3 inches in height upon the outside. Besides which, on the outside of the jar, there is a band of leather, which takes the chafing of the hole in the end of the stand, through which the jar passes.

Tops of Jars.—These (denoted by *M*) are turned up from short lengths of wood. To put them, the tubes, and the jars together the following order is perhaps the best :—First cement the top to the tube, leaving the shoulder of the tube at a proper height to carry the comb ; then at the foot of the tube cement on a ring of wood just large enough to enter the jar ; coat this ring with tinfoil, so that it shall make the metal contact with the inner coating of the Leyden jar, then cement the top on the jar, and lastly drop down each of these tubes small sticks of wood, of just sufficient length to touch the bottom of the jar with their lower ends, while their top ends are of sufficient height to carry the lower ends of the discharging terminals. The balls on the discharging terminals must be kept high enough to pass over the tops of the glass discs, to avoid breakage through the balls striking the glass.

The Glass Discs.—These are made of selected window glass; care being taken that they are flat and of uniform thickness. The dark green coloured glass, or at least some of it, appears to conduct away high tension electricity; therefore select the whiter qualities. They should be cut on a revolving table illustrated in Fig. 86.

This table consists of a disc covered with chamois leather, which is mounted so as to turn freely on a vertical axis. The sheet of glass to be cut into circular shape is placed on this disc or table. A glass-cutter's diamond is mounted on the end of a springy arm, so that it can be pressed in contact with the surface of the sheet of glass, while the latter is turned round by pressing the fingers of one hand on its surface. A perfectly circular cut will be made by the diamond on the surface of the glass,

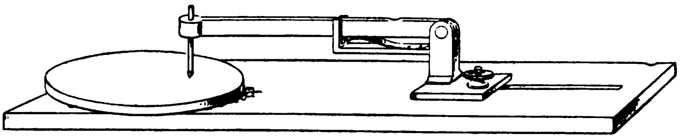


FIG. 86. REVOLVING GLASS CUTTING TABLE.

which will in a short time, with judicious tapping, penetrate through the glass, when the outside pieces can easily be taken off by the fingers. The hole in the centre of the disc can be cut in the same manner by moving the arm supporting the diamond nearer to the centre of the disc; the arm being mounted so that it can slide radially and be clamped at any point on the baseboard of the apparatus. After the diamond cut has penetrated through the glass, the centre piece must be carefully broken out in fragments by crushing it with a small hammer over the end of a steel punch fixed in a vice. The centre hole may also be bored out with emery, but this takes a much longer time. The glass discs may be bought, cut out to circular shape, with the hole in them, from many of the large glass cutters. For the machine we are describing they should be 17 inches in diameter, with a hole in the centre $1\frac{1}{4}$ inch diameter. They must be coated with shellac varnish on both sides; this should be done in a warm room, and the plates should be dried by heat.

For Mounting the Sectors.—For mounting the sectors, draw a circle of the same diameter as the discs, on a sheet of paper, and divide it into sixteen or eighteen equal parts. Draw radial lines from each point in the circumference to the centre, and set off outlines of the sectors with these lines as centre lines. The outer ends of the sectors should be $\frac{3}{8}$ inch from the circumference of the glass discs; the sectors should be $3\frac{1}{2}$ inches in length, $1\frac{1}{8}$ inch broad at the wide end, and $\frac{1}{4}$ inch broad at the narrow end, and rounded off at each end, as shown in Fig. 85. The glass disc upon which sectors are to be fixed is placed on the paper on which the drawing has been made, so that the circumference of the disc coincides with the circle drawn on the paper. The tinfoil sectors having been cut out to the proper shape, are varnished on one side with shellac varnish, and stuck on to the glass plate so as to coincide with their outlines drawn on the paper beneath the disc. Now place the glass disc again on the revolving table of the glass-cutting apparatus, and with a small brush held in contact with the fixed arm, make two rings of shellac varnish—one at the outer ends of the sectors and the other at the inner ends of the sectors. These rings help to attach the ends of the sectors and slightly insulate the extremities.

Shellac Varnish.—The best way to prepare and to keep this extremely useful varnish is as follows:—Get a wide-mouthed bottle and fit in it a soft wooden bung, in which a hole is bored to receive the handle of a large brush, which when not in use will remain inside the bottle. Fill the bottle half full with shellac, and pour in methylated spirits of wine till the shellac is covered. With occasional shaking the shellac will in time be dissolved. The varnish will be ready for use in about twelve hours.

Cement.—The best cement to use for fixing wood or brass to glass is bicycle-tyre cement.

LONG-SPARK MACHINE.—Fig. 87 is an illustration of a machine to give the longest possible spark from a given size of plate. The principal points to be attended to are to make the collecting combs shorter, and the sectors fewer in number. The discs in the machine shown are about 17 inches in diameter. The sectors are made from one-sixth to one-fifth the diameter of the discs, and about 1 inch in breadth at the broadest part, the sides of adjacent sectors being parallel to one another. The number of sectors on one disc is ten to fourteen. The radial rods of the collecting combs should be of sufficient length to cover the sectors and no more, the ends of the rods being covered with knobs. The stand of this machine is somewhat different in construction from that of the laboratory machine, but it can be easily understood from the illustration. The point to be aimed at is to obtain the greatest distances for insulation between the several points.

TWELVE-PLATE MACHINE.—This machine has already been described; it is shown complete in the frontispiece

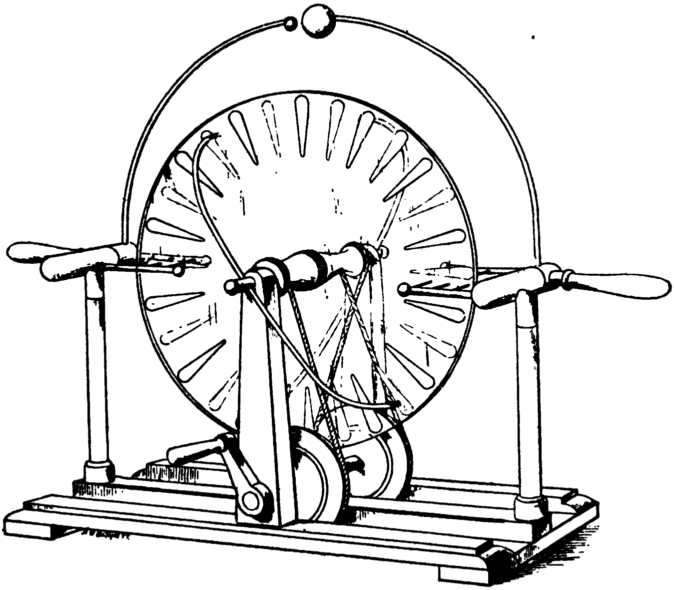


FIG. 87. LONG-SPARK WIMSHURST MACHINE.

and in detail in Fig. 88 and Plate III. The dimensions of each piece is marked on the parts in Plate III.; very little description therefore will be necessary. Fig. 88 is the case of the machine, consisting of a mahogany frame with panes of glass fitted in grooves in the sides and ends. Both end frames with their panes of glass are removable to enable the discs to be got at for dusting and cleaning. The central uprights have each two holes bored in them for the driving

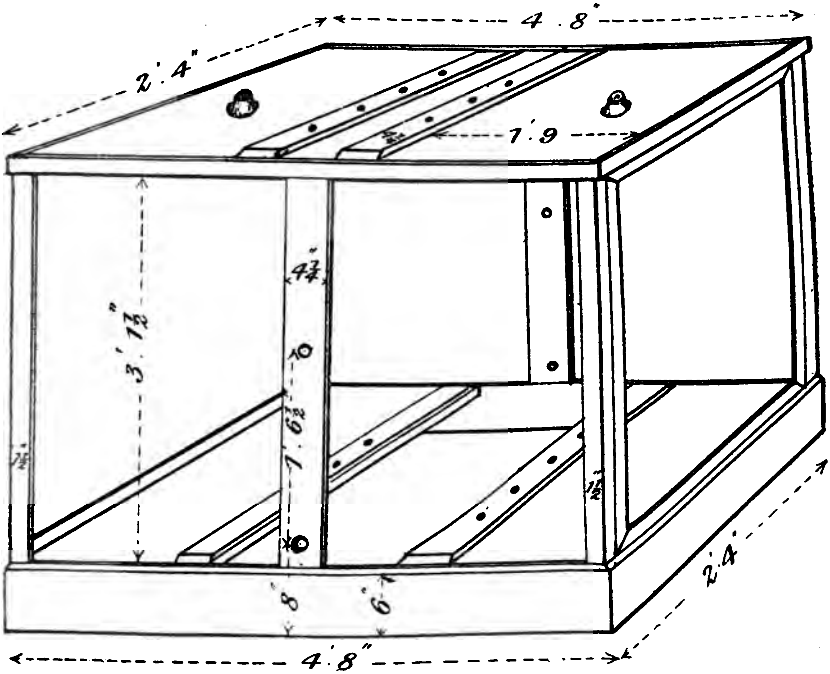


Fig. 88. Case of 12-Plate Wimshurst Machine.

spindle, and for the spindle of the discs. Removable boards with bevelled edges, and holes for fixing the rods which carry the neutralizing brushes, are fixed in pairs across the top and bottom of the frame.

The driving spindle, with its pulleys and the driving handle, are shown at Fig. 1, Plate III. It consists of an iron spindle with bearings turned on it and one end screwed for the handle which is screwed tight up against a collar, as shown. A hole is bored through a square piece of mahogany so as to fit (an easy fit) on to the iron spindle. The discs to form the driving pulleys are made with square holes in their centres, and are driven tight on to the mahogany sheath at suitable distances. The sheath may be fixed to the iron spindle by four transverse iron pins at right angles to one another, two at each end of the spindle. Wooden distance pieces are glued on the flat sides of the wooden sheath between the pulleys, and the whole is placed in a turning lathe, where the sheath is turned up, true, and the pulleys are turned to the proper size, with V grooves for the belts. The crank handle may be cast of brass and fitted with a wooden handle.

The spindle and bosses for the glass discs are shown at Fig. 2. The bosses are turned out of well-seasoned wood, with V grooves for the belts, as shown. Each boss is bushed with a piece of brass tube, which turns freely on the polished steel spindle, which is supported at each end by the uprights, somewhat loosely, so that it can be easily drawn out. Wooden caps are screwed over the ends of the spindle to prevent it coming out, and bifurcated distance pieces, Fig. 3, are fastened inside the uprights to prevent the bosses from separating too far from each other. These distance pieces are so fixed that they can be easily removed by lifting them up, and then the bosses and their attached glass discs can be separated to a convenient distance for dusting and cleaning. The way in which a glass disc is fixed on a boss is shown on a larger scale at Fig. 4. A projection on the end of the boss fits into the hole in the glass disc. A disc of vulcanized fibre cemented to the glass is fixed by wood screws on this projection, and clamps the disc firmly between it and the end of the boss. The brass tube forming the bush of the boss, projects slightly beyond the disc of vulcanized fibre, so as to bear against the end of the bush tube of the next adjacent boss, and prevent the fibre discs rubbing on each other.

Fig. 5 is a side view of the conductor to which the collecting combs are fixed. It consists of a brass tube, into which a wooden core is tightly driven. The ends are rounded wooden knobs. The radial rods forming the backbones of the collecting combs are driven through holes in the brass tube of the conductor and tight into the wooden core, as shown in the sectional plan, Fig. 6. These holes are bored alternately above and below the horizontal centre line of the conductor, as shown in Fig. 5. It has been found advantageous not to have the collecting combs for one pair of discs in the same horizontal plane, but to displace them, or give them a slight advance in the direction of rotation of the disc in front of which they stand; hence the zig-zag arrangement of the holes in which the collecting combs are fixed. The conductors are supported on two glass pillars fixed with collars on a wooden board, which is screwed on to the base of the case of the machine by wood screws, whose heads are covered with wooden knobs.

The rods carrying the neutralizing brushes are fixed in the removable boards already mentioned. They are shaped as shown in general view in the frontispiece. The brushes should touch the discs at points separated from each other by an angular distance of about 60°. All these neutralizing rods should be carefully connected together by copper wires recessed into the stand of the machine; good metallic connection being made at all the joints, as it is essential that the resistance should be as small as possible in the neutralizing circuits. Fig. 7 shows a segment of one of the glass discs, with two tin-foil sectors on it.

GENERAL NOTES ON THE CONSTRUCTION OF WIMSHURST MACHINES.—To obtain the longest possible sparks from a Wimshurst machine a small number of sectors must be used. When the number is reduced below a certain limit (say eight), the machine will not excite itself, but will work if a charge is imparted to it from an external source. The larger the number of sectors the more readily the machine will excite itself: for example, with sixteen or eighteen on each disc it will be freely self-exciting under almost every condition of atmosphere; while if, say, forty sectors are placed on each disc, it is only with difficulty, and under the very worst conditions of atmosphere, that self-excitement can be prevented.

A machine may be self-exciting in a cold room, but will cease to work when brought into a warm room

PLATE III.

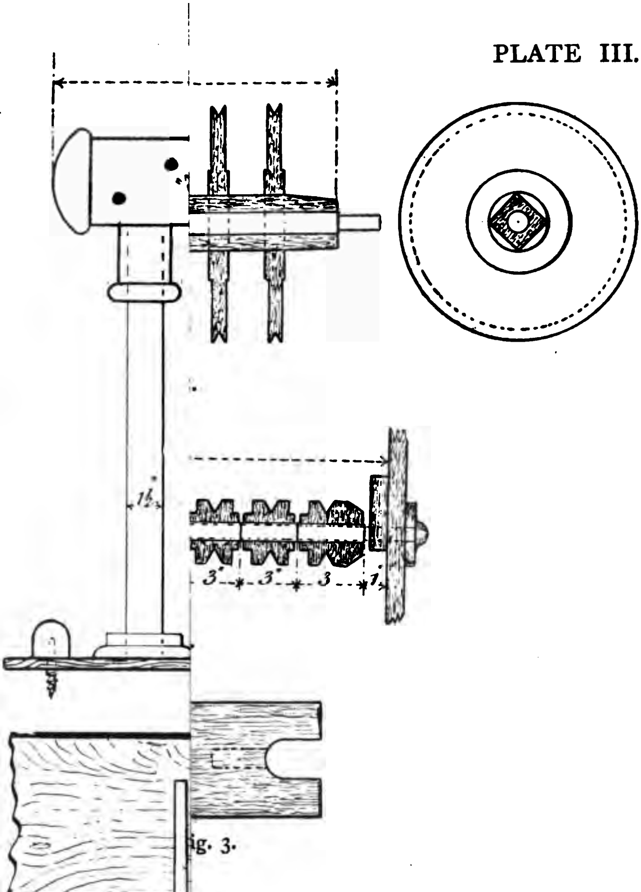
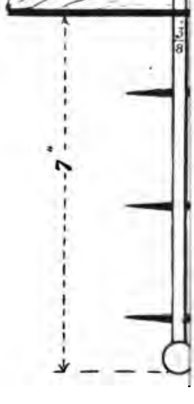


Fig. 3.



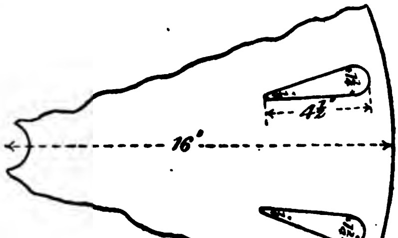


Fig. 7.

To face p. 222.

where a number of people are present. After a few minutes, however, when the handle is turned, the machine will excite itself. The explanation is that while the machine was colder than the atmosphere it condensed moisture on its surface, but after it had acquired the temperature of the room the condensed moisture evaporated and enabled the discs to retain their charges.

It is important that the metal brush should be in absolute metallic contact with the neutralizing rod. The brushes on the opposite ends of the neutralizing rods must touch the sectors on opposite sides of the centre of each plate at the same time. If the rods are not of the proper shape to cause the brushes to touch the sectors in this way, they should be bent into the proper shape.

In the two-plate machine the neutralizing rods should be made to turn on their axis, so that they can be set to different angles. The best position for these rods can be found by experiment. The rule given by Mr. Wimshurst is as follows:—Take your watch, hold it by the chain, and let its back come to the spindle on which the discs revolve: the neutralizing rod for the front disc should then be parallel with the line joining XI and V, and the rod at the back of the machine, seen through the glasses, must be on the line joining I and VII—that is, the two rods will make an angle with one another of 60 degrees. The above is about the best position, though, if the machine does not seem to pick up its charge readily, the rods may be turned into a more horizontal position, say to an angle of 90 degrees. This rule also applies to multiple plate machines.

The brushes must be kept in good condition and clean. If they are worn out or are corroded, replace them with new ones.

The balls on the discharging rods should be unequal in size to give the best results. To obtain the maximum length of spark with, say, 17 inch discs, one ball should be about $\frac{3}{8}$ inch and the other about $1\frac{1}{4}$ inch diameter. They should be very nicely polished. Leyden jars must be used to get good sparks. When the balls are of different sizes, attention must be given to make sure that the positive or negative electricity is on the side of the machine to give the best results. This is readily discovered by slightly darkening the room, and observing on which collecting comb the electric brush is, and on which the luminous point. Having discovered this, see that the larger ball is in connection with that comb which has the electrical brushes on its points.

To reverse the direction of the current in the machine, where this is necessary, the best course is to charge a Leyden jar from, say, the right hand comb; then close the discharging balls, and with them closed, turn the discs a few revolutions in the opposite direction; then separate the discharging balls, and touch the left hand comb with the charged Leyden jar. The current will then be reversed.

To produce the greatest length of spark, the Leyden jar connections have to be carefully attended to. The inside coating of each of the jars should be connected to one of the collecting combs, and the outside coatings of the two jars should be connected, say by allowing them to stand on a strip of tinfoil. For connecting the inner coatings of the jars to the combs, good stout gutta-percha-covered wire is best, great care being taken to see that there are no points exposed. To show the injurious effect of points, tie a pin on to the connecting wire of either of the Leyden jars, so that it points away from the wire and from the machine. It will then be found that scarcely any spark can be obtained.

It is very important that the machine should be kept free from dust. Each particle forms to a certain extent a point; besides, a layer of dust acts in some degree as a conductor.

It will sometimes be found that though all the foregoing points have been attended to, the charge will not remain in the Leyden jars. It will then probably be found either that the glass of the jar is cracked, or that its quality is bad.

If vulcanite supports are used anywhere in the machine, their insulating quality should be tested by trying whether a spark from a Leyden jar will pass through them to the earth. If they are found to be conductors, their surfaces should be washed with a solution of carbonate of magnesium, or placed in a lathe and turned up.

The bearings of the machine should be carefully oiled with a little sperm oil.

If on turning the machine it is found that there is abundance of electricity, but that it is all at the top and bottom of the discs, and none at the combs, the inference is that the machine is being turned in the wrong direction. This may be remedied by interchanging the open and crossed belts.

CHAPTER II.

HOLTZ AND VOSS MACHINES.

Holtz Two-plate Machine.—The type of machine designed by Holtz, that has been already described, is by no means easily constructed, owing to the difficulty of cutting the openings in the fixed plate. Such machines are also quite unworkable in ordinary atmospheric conditions in this country, unless inclosed in a case with drying substances. We would therefore recommend the amateur to construct the modified form of the Holtz machine designed by Mr. Wimshurst.

Fig. 89 is an illustration of a machine of this type, with two rotating discs and two fixed plates. Each fixed plate is in two pieces, one edge of each piece being inclined so that when fixed in the frame a parallel space is left between the two edges, slightly inclined to the horizontal diameter of the discs. This space corresponds to the windows or apertures cut in the plate of the ordinary Holtz machine, as the tongues or serrated edges of the paper armatures project through it. The parallel space between the plates also allows the axis of the rotating discs to pass through without touching. The fixed plates are supported in grooves in transverse wooden bars, which are supported by four glass pillars at the corners.

The spindle of the rotating discs consists of a round steel bar ⅝ inch in diameter, which passes through from

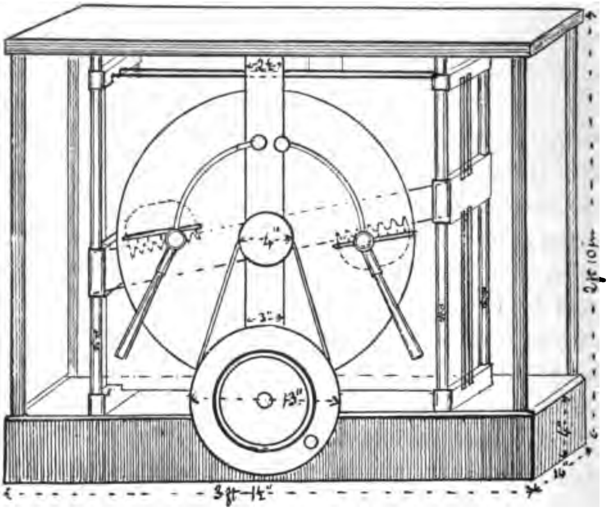


FIG. 89. WIMSHURST-HOLTZ MACHINE.

upright to upright. A cylindrical wooden boss is turned on the spindle and cut into three separate lengths. The length next the driving pulley is fixed to the spindle by a transverse pin. The other two pieces of the boss being removed the first rotating disc is slipped on, then the second length of the boss is slipped on the spindle, then the second disc, and finally the third length of the boss. The two discs are thus gripped between the three sections of the boss. To hold them firmly together an iron cotter or wedge may be driven into a slit cut through the steel spindle.

The paper field plates shown in the illustration are not so long, that is do not subtend so great an angle at the centre of the disc, as those in the ordinary Holtz machine. It has been found that if the collecting combs are fixed an inch or more back from the points, the machine will work quite well; hence a great length of field plate is unnecessary.

The fixed plates are placed close together, so that their paper field plates are in contact. A strip of paper or tinfoil connected to one pair of the field plates in contact may be brought to the outside, for the purpose of imparting a charge to start the machine.

The collecting combs are carried by horizontal brass rods, parallel to the spindle of the discs, which pass through and are fastened to the front glass plate of the case. On the outer ends of these horizontal rods, the discharging terminals are mounted, so that they can be swivelled on the rods. The discharging knobs of the terminals can thus be adjusted at any required distance from each other.

A large driving pulley is mounted on a spindle fixed to the front upright, as shown, and this is connected by a round or flat belt to the smaller pulley on the disc spindle. A suitable handle is fixed in the side of the large driving pulley. Insulating handles of glass or ebonite are fixed on the ends of the discharging terminals.

The following are the principal dimensions of the above machine:—Height of case, 2 ft. 10 in.; height of moulding at base, 4 in.; length of case, 3 ft. $1\frac{1}{2}$ in.; width of case, 14 in.; diameter of discs, 2 ft.; diameter of wooden bosses on disc spindle, 3 in.; glass pillars, 2 ft. 4 in. long and $\frac{7}{8}$ in. in diameter; distance between a fixed and a revolving plate, 1 in.; diameter of large driving pulley, 13 in., and of small pulley 4 in.; uprights $2\frac{1}{2}$ in. broad at top and 3 in. broad at bottom.

Twelve-plate Holtz Machine.—Fig. 61 is an illustration of a twelve-plate Holtz machine of the Wimshurst type. The construction is very similar to that of the machine just described. This machine has already been described in general terms on p. 151.

The parallel space between the two halves of one of the fixed plates is not inclined as in the previous machine, but horizontal. The transverse wooden bars slide upon the glass pillars, and can be raised or lowered by means of four levelling screws; by this means the height of the fixed plates can be adjusted. The collecting combs are fixed to the middle transverse bars, and are all connected by copper wires to upright rods, leading to the discharging terminals, which are fixed on the top of the case. The revolving discs are fixed to the spindle by wooden bosses, as in the two-plate machine. An important point about this machine is to connect together all the paper field plates on each side of the machine by copper wires. This connection consists of a brass rod lying across the tops of the fixed plates and connected to the paper field plates by thin wires, which descend from it between the fixed plates. There is of course one brass rod with descending wires at each end of the fixed plates, that is, one for the positive and one for the negative set of field plates. Care must be taken that the collecting combs, or their connecting wires, do not at any point come too close to the wooden framework of the glass case in which the machine is inclosed, as the charge would in that case leak through the woodwork to the earth. The shortest distance should be greater than half the greatest sparking distance of the machine.

For charging the machine a wire connected to one set of field plates is brought out through a hole in one of the end plates of glass. The frame of the other end plate of glass may be made separate and detachable from the rest of the case to give access to the interior of the machine, for dusting, cleaning, etc. If the air inside the case is not sufficiently dry, a shallow dish containing concentrated sulphuric acid may be placed inside the case.

To start the machine the discharging knobs are brought together, and the knob of a charged Leyden jar is brought in contact with the charging wire while the machine is turned. The discharging knobs are separated as soon as it is seen that the machine is excited.

The following are the principal dimensions of this machine:—Width of case, 2 ft. 6 in.; length of case, 3 ft. 10 in.; height of case, 3 ft. 8 in.; diameter of large driving pulley, 13 in.; diameter of small driving pulley, 6 in.; distance between the centres of the pulleys, 13 in.;

diameter of glass discs, 2 ft. 8 in.; paper field plates, 8 in. long by 4 in. wide; diameter of the steel spindle of the glass discs, 1 in.; diameter of the wooden bosses, $3\frac{1}{2}$ in.; width of the horizontal space between the two halves of a fixed plate, $2\frac{1}{2}$ in.; distance between the rotating discs, $1\frac{3}{8}$ in.; the ends of the collecting combs are at a distance from the centres of the rotating discs equal to half the radius of a rotating disc.

Voss Machine.—The Voss machine is a useful machine for many purposes, on account of its ready self-excitement, and the considerable quantity of electricity which it furnishes. The great objection to it is its liability to reversal when the limit of its sparking distance is reached. The principle of its action has been already explained (see p. 138).

The machine illustrated in Fig. 56 has one fixed and one revolving disc. The fixed disc is attached at its centre by a boss to the top of a wooden pillar fixed in the base-board, but not seen in the illustration. The revolving disc *B* is mounted on the end of a steel spindle, which turns in a bearing passing through the centre of the wooden boss to which the fixed disc is attached. The paper field plates *C C*, shown in dotted lines, are pasted on the back of the fixed disc. Previously, however, to pasting the paper field plates on the glass disc, two small discs are pasted on the surface that comes in contact with the glass disc. These tinfoil discs are of the same diameter as the tinfoil carriers on the revolving discs, and are fixed at the same distance from each other; they are connected together by a strip of tinfoil, also pasted on the inner surface of the paper sector.

On the revolving plate there are six carriers, placed at equal distances apart, and consisting of small discs of tinfoil, on which may be placed hemispherical brass projections of about half the diameter, for the brushes to touch.

The collecting combs are fixed to the ends of a rod of vulcanite *D*, to the centre of which the axis of the neutralizing rod *E* is also fixed. The two collecting combs thus joined together are connected to the central rods of two Leyden jars, *F* and F^1, by horizontal rods parallel to the axis of the revolving disc. The Leyden jars must be firmly fixed in the base-board, and the central rods must be firmly fixed in the jars by means of discs of wood or metal. The discharging rods slide in holes bored through the tops of the central rods of the jars.

The neutralizing rod is mounted so that it can be turned on its axis to different angles till the best position is found. Besides having brushes near its ends to touch the carriers, points are often fixed on each side of the brushes, as in the collecting combs. The collecting combs are also sometimes furnished with a brush to touch the carriers, as well as with points.

To replenish the field plates, metallic brushes are fixed on the ends of bent pieces of brass wire, which are soldered to brass clamps *G G*, which are clamped to the edge of the fixed disc. Radial strips of tinfoil connect these clamps to the paper field plates.

The large driving pulley *H* is fixed on one end of a steel spindle, on the other end of which the driving handle is fixed. A bearing for the spindle, consisting of a brass tube, is fixed near the top of the wooden pillar by driving it tight into a hole bored through the pillar. A smaller driving pulley is fixed on the end of the spindle of the revolving glass disc. Both pulleys have V grooves turned in their peripheries, and are geared together by a round leather belt.

The principal dimensions of this machine are as follows :—Diameter of fixed disc, 1 ft. 6 in.; diameter of revolving disc, 1 ft. 3 in.; field plates subtend an angle of 60° at the centre of the disc, and are 2 in. in breadth; diameter of large driving pulley, 7 in.; diameter of small driving pulley, 2 in.

Of course, modifications may be made in the design of this machine, or of any of the machines, if the maker thinks he can in any way improve, or get a form more convenient to construct with the materials and tools at his command. The designs described are those of machines that have actually been constructed, but if the amateur should happen to be out of reach of the large dealers in metal from whom he can procure brass tubes, brass balls, polished steel spindles, &c., in a condition almost ready for use, he must employ his lathe and other means available, to get the best possible substitutes, and make the necessary modifications in the types of construction that have been described above.

END.

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