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ELECTRICITY & MAGNETISM

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ELECTRICITY AND MAGNETISM,

A POPULAR INTRODUCTION

BY

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PREFACE.

THE object of the following pages is to present an easy and attractive introduction to the sciences of Electricity and Magnetism. The work is not intended as a text-book; hence no recondite calculations, and no mere enumeration of all the existing electro-magnetic appliances are introduced. Care has been taken to impart exact knowledge, that will not have to be unlearnt, in a readable form. The two old theories are sufficiently dwelt upon to enable the reader to form an intelligent conception of them, while very special stress has been laid upon the modern, and more satisfactory, "molecular" theory. Many instruments are described and figured; very many more are left entirely unnoticed, such as the accumulator, etc., since these can be perfectly understood from a perusal of this work, after reference to more technical works written by the Author. Enough, however, has been done, without increasing the dimensions of the work beyond the limits prescribed, to awaken the desire for further information.

S. BOTTONE.

1893.

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ELECTRICITY AND MAGNETISM.

CHAPTER I.

INTRODUCTORY.

BECAUSE we know so little of the real nature of the agencies which we designate by the above names, it is perhaps advisable not to attempt any profound theorization in studying their phenomena, but rather to proceed in the same way that a child learns its mother tongue, by synthesis only : that is, by an examination of the facts as they present themselves to our notice, leaving all theory aside until we have collected a sufficient number of facts on which to theorize, and always remembering that a theory, until it has stood the test of rigid proof in all directions, is but a theory, and only useful in so far as it enables us to group together and explain in an intelligent manner the phenomena which are passing before our eyes.

§ 2. Since the phenomena which we designate MAGNETISM are somewhat more easy of examination by the tyro than the kindred ones of electricity, and the experiments may be performed with greater certainty in the former than in the latter case, magnetism will form our first subject for consideration.

§ 3. In certain parts of Asia Minor, such as Magnesia, also in China, Arabia, Norway, and more rarely in England, masses of a ferruginous mineral[1] or iron ore known in English as the *lodestone* (from the A. S. *leden = to lead*) are found. One of the peculiarities of this lodestone is its power of attracting pieces of soft iron or steel. If a piece of lodestone be suspended by means of a silken fibre so as to be free to move it will be found to take up after a few oscillations a certain set position, to which it will return even if disturbed. This position will be found to be in a line with what we usually term the *north* and the *south*.

§ 4. If we approach a piece of this lodestone to a small piece of iron, we shall find that there are two points in the lodestone (usually at two opposite extremities) at which the attractive force is greatest ; and one (near the centre of the mass) at which there is little or no attractive force : between this neutral point and the two extremities the attractive force gradually increases until it reaches its maximum at or very near the extreme points. It is usual in speaking of these different portions of the lodestone or natural *magnet* (from Magnesia, the place where the mineral was originally found) to designate the extremities by name of *poles* and the central portion by that of neutral part. In order farther to distinguish these active portions or poles from one another the name of *north seeking* or for short *north* pole is applied to the one which, when the lodestone is freely suspended, points to the north, while the name *south seeking* or for brevity's sake *south* pole, is applied to that end which points to the south.

§ 5. On suspending, as before, a piece of lodestone so

[1] Having a chemical composition represented by the formula $Fe_3\ O_4$; that is, three atoms of *iron* united to four of *oxygen*.

as to be free to move, and presenting to it several substances for trial, it will be found that it will be attracted by, or attracts (which amounts to the same thing), a very limited number of bodies only—these being those which consist of iron, steel, or which contain much iron in their composition; a few other bodies such as cobalt, nickel, chromium, etc., being also gifted with the power of attracting and being attracted by the lodestone, though not in so marked a degree as soft iron. Bodies which are thus capable of being attracted by the magnet are termed *magnetic* bodies.[1]

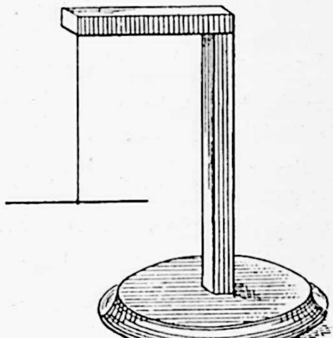


FIG. 1.

§ 6. It is particularly recommended, in order to arrive at an intelligent conception of the phenomena under consideration, that the reader should perform the experiments himself, and to this end the experiments described, while of a nature to exemplify fully the facts which it is desired to elucidate, are chosen with a view to facility in execution. Having procured a few ordinary sewing needles, the reader will suspend these by means of a single fibre of silk tied round the centre so that they shall hang horizontally, and the silk can be slung for convenience of suspension to an L-shaped wooden standard, as shown at Fig. 1. In like manner he will suspend a few pieces of soft iron wire (the wire which is used for binding flowers by nurserymen will do very well for this purpose;

[1] Or in scientific parlance, *paramagnetic*.

it is absolutely necessary that it should be very soft), and will proceed to notice the difference of behaviour which exists between the iron and the steel with respect to the magnet. In the first place he will notice that on approaching the magnet to the needles, and the iron wire respectively, the latter will be much more powerfully attracted; and in no case will the iron wires evince a tendency to be repelled by the lodestone whichever extremity or pole be presented to the iron wire. In the second place, on approaching the lodestone to the steel needle, the attraction will not, *at first*, be so marked as in the case of the iron wire: and if one end of the needle be allowed to remain in contact with one of the poles of the magnet, say for the sake of example, the north pole, for some little time, it will be found to have acquired the power of attracting other needles, and also the soft iron wire, precisely in the same manner, though in a less degree, as the original lodestone. On examining the soft iron wire even after prolonged contact with the magnet we do not find that it has acquired any such property of attracting; hence we are led to the conclusion that the magnet has the power of imparting permanent magnetism to steel, but not to soft iron: or in other words, that soft iron is incapable of being *permanently* magnetised, or has no "magnetic memory," while steel is capable of permanent magnetisation.

§ 7. On continuing our examination of the steel needle which has been for some time in contact with the lodestone, we shall find that it is gifted with some peculiar properties. If we notice and mark which end of the needle is attracted by the north pole of the magnet we shall find that this same end will be likewise attracted by the north pole of any other magnet or of any other magnetised needle; but it will be *repelled* and not attracted by the south pole either of the original magnet, or of any other magnetised body. Farther, if we allow this magnetised needle to come to rest, it will be found that the end which was attracted by the north pole of the original magnet, will point to the south, or, in other words, be a south seeking or south pole, the other extremity being north. An observation of these facts leads us to the conclusion that *poles of like name repel each other*, while *poles of unlike name attract*. In other words, a north pole presented to a north pole will repel it, and be repelled by it; a south pole in like manner will repel and be repelled by a south pole, whereas a north will attract a south and be attracted by it, as also will a south attract a north pole.

§ 8. Since it is possible, as we have seen in the last section, to magnetise artificially masses of steel, and since it is difficult to procure large or powerful natural lodestones, the reader will do well to provide himself with a few artificial steel magnets [1] both of the bar and horseshoe form, in the prosecution of the experiments about to be described. Taking a powerful bar-magnet in one hand let him approach it to within an inch or two of a rod of soft iron, say about half-an-inch in diameter and a foot in length, close to the opposite extremity of which he has placed one of the suspended steel needles previously described; and which should have been also magnetised. He will notice, that if the north seeking pole of the suspended needle be placed near the extremity of the iron bar and the north pole of the bar-magnet be ap-

[1] These can be procured at almost any cutler's shop.

proached (without touching) the needle will be repelled from the opposite extremity of the iron bar and the south pole will swing round until it approaches it. In a similar way, if the south pole of the bar-magnet be approached to one extremity of the iron bar, the south end of the suspended needle will be repelled by the farther extremity of the iron bar, while the north end will swing over towards it. From this we gather that a magnet influences bodies in its vicinity, without being in actual contact with them, and in the case of magnetic bodies it is capable of imparting, by this influence, magnetism to them, even though not in actual contact. This influence or effect at a distance is known by the name of *induction*. It will be found that on removing the bar-magnet from the neighbourhood of the iron bar, the said bar will lose its acquired magnetic properties and fall back again into its original condition of possessing no magnetism. If the same experiment, however, be performed with the substitution of a steel rod for the soft iron one originally employed, the induction effect will not be so marked at first, and will take a longer time to evince itself, but when once set up it will be found to be permanent. The student is particularly requested to note carefully this induction effect and to master its peculiarities, as it will conduce very much to his comprehension of the kindred phenomenon of electrical induction.

§ 9. If the same experiments as last described be performed, with this difference, namely, that the bar-magnet be placed in *actual contact* with the iron or steel rod experimented on instead of being placed at a distance, we shall find that exactly the same phenomena will present themselves, only in a more marked degree ; and we shall also notice that although the bar-magnet has imparted magnetism to the steel bar, yet it has lost none of its magnetism itself. In other words, there has been no transfer of magnetism from the original steel magnet to the newly magnetised steel rod.

§ 10. If several pieces of soft iron of different thicknesses, from $\frac{1}{8}$ to $\frac{3}{4}$ of an inch in section be filed up to fit squarely over the poles of a horseshoe-magnet,[1] and be placed across the poles, it will be found that they will be attracted with different degrees of force ; which increases, up to a certain point, with the increase of section of the iron piece. In other words, a given magnet will support a greater weight if it be attached to an iron keeper $\frac{3}{4}$ in. in section, than it will if the weight be attached to a keeper of only $\frac{1}{8}$ in. in section. A little consideration will render the cause of this peculiar behaviour quite clear. Since a magnet, if placed near a mass of iron, influences it by induction, and produces in it a *south* pole in the portion which is nearer to its own *north*, and a *north* pole in that portion nearer to its own *south*, and since unlike poles *attract*, it follows that the *keepers* in the above experiments are also acting like magnets, and attracting the horseshoe-magnet with a force proportionate (up to a certain point) to their own bulk ; consequently the larger armatures, by acting like larger magnets, enable the horseshoe to sustain a greater weight. This experiment also shows that *induction must always precede* attraction ; so that in fact, the first effect of placing a magnet near a piece of soft iron, is to induce magnetic poles in it, and then these poles, being of oppo-

[1] Such pieces are called "*keepers*" or "*armatures*."

site name to those of the inducing magnet, attracting and being attracted, cause the iron to fly to the magnet. This induction effect is illustrated in Figs. 2 and 3, in which A represents the inducing magnets (a bar in Fig. 2, a horseshoe in Fig. 3), while B represents the armature

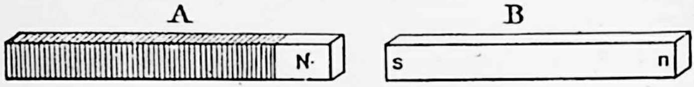


FIG. 2.

or keeper; the letters N, S, represent the polarity of the inducing magnets, while *n*, *s*, shows the polarity induced in the armatures or keepers.

§ 11. From this it will be evident that since the earth is capable of causing a suspended magnetised needle to take up a position north and south, it must be acting like a huge magnet, and, in point of fact, we find that it is

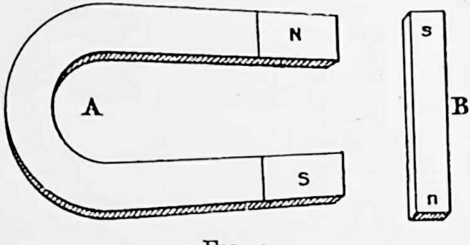


FIG. 3.

gifted with all the powers of a magnet. For instance, if we suspend here in England a steel bar, say a kitchen poker, vertically, so that its lower end is pointing towards the north, and leave it for some time in this position, and more especially if we tap the upper end by striking it with a light hammer (the vibration set up appears to facilitate induction) we shall find that the steel bar will have acquired, under the influence of the earth's magnetism, all the properties of a magnet. So general is this result, that it is very rare to find the fire-irons of a

Fig. 4.

house which have not become magnetised by the earth's induction ; and in these cases the extremities which are usually downwards are found to be north seeking, while the upper ones are south seeking.

§ 12. There are several means by which magnetism can be imparted to pieces of steel or similar bodies. The following are perhaps among the best:

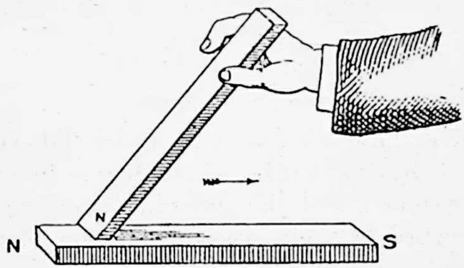


Fig. 5.

1st, *By simple juxtaposition*, that is to say, by placing the body to be magnetised between the dissimilar poles of two bar-magnets, as shown at Fig. 4.

2nd, *By single touch.* In this case the body to be magnetised is laid upon some flat surface, and one pole of a bar-magnet drawn from one extremity to the other . then raised at some distance from the body and brought back again to its original position on the body to be magnetised, and repeating the operation several times, always starting the stroke at the same end, and ending at the opposite, and turning the body over so that all surfaces shall have been subjected to the same treatment, as shown at Fig. 5.

3rd, *By divided touch.*—In this method the bar or other body to be magnetised, having been laid on a flat surface, has the two dissimilar poles of two bar-magnets laid upon

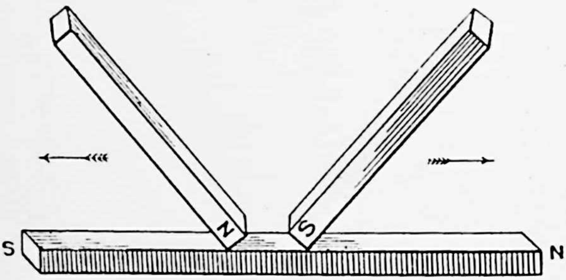


Fig. 6.

its centre, and these are drawn apart by sliding along the surface until the extremities of the bar to be magnetised have been reached, and the inducing magnets are lifted up and returned in their original position to the centre of the bar; by repeating this operation over the four surfaces of the bar, care being taken that the motion of the two bar-magnets, with reference to the bar subjected to their influence, is always the same, it is possible to magnetise very strongly small bar-magnets, Fig. 6.

4th, *By double touch.*—In this process the body to be magnetised is acted on either by a horseshoe-magnet or, what amounts to the same thing, by a pair of bar-magnets, with their dissimilar poles in contact above, while their lower dissimilar poles are separated from each other by a space of about half-an-inch (which can be easily effected by tying a small piece of cork between the lower poles); this horseshoe-magnet or double bar-magnet is then placed on the centre of the bar to be magnetised, and slid backwards and forwards from end to end, care being taken never to reverse the position of the poles with regard to the bar, and repeating the stroking over the four surfaces of the bar for a sufficient number of times until

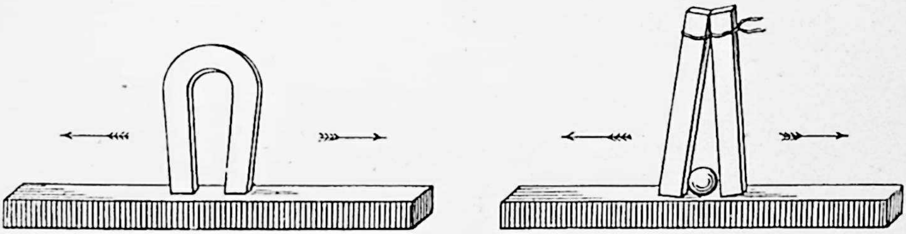


Fig. 7.

the body to be magnetised has received sufficient magnetisation, when the inducing magnet or magnets are brought to the centre of the bar and then removed, as shown at Fig. 7. We shall notice, in studying the effects of current electricity on iron and steel, that there is another method by which magnetism can be imparted more readily and more powerfully than by those above described; but we leave the consideration of this until we have acquired an insight into the laws by which it is governed.

§ 13. If we attempt to magnetise by any of the above means bodies of a circular, ovate, ring, or disc shape, we shall find it very difficult, if not altogether impossible, to make them take up any definite polarity ; in fact it may be said that a ring and a sphere cannot be made to show magnetism, while the nearer the bodies approach in shape to a long parallelopipedon or a long cylinder, the more distinct will be the polarity of the magnetised body. A star wheel of steel may be made to evince polarity by placing, say, the north pole of the inducing magnet at its centre, when the resulting magnetism will be south at the centre and north at the points of the star. It will also be noticed that if, by any inadvertence in magnetising a long steel bar we touch the surface at different separate points, we shall be able to produce a series of weak north and south poles along the surface of the bar. A bar thus

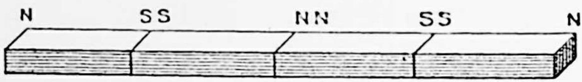


FIG. 8.

magnetised is said to have *consecutive poles*, but it will generally be found that these are not lasting, and that the final condition of the bar after some little time is that of an ordinary magnet having a north and a south pole at opposite extremities. Fig. 8 represents a bar-magnet having consecutive poles. The student will do well to notice the possibility of producing *consecutive poles*, as these are made use of in certain electrical apparatus hereinafter described.

§ 14. Having by any of the processes above described magnetised a stout knitting-needle with true north and south poles, the reader is advised to test the polarity acquired by means of a suspended needle, and mark the north and south poles of the knitting-needle in some distinctive manner. If now he make a mark with a file at the centre of the knitting-needle, so as to be able to break the needle into two halves, he will find after division that he will not have been able to separate, as would have seemed probable, the north pole from the south, but that he will possess two perfect magnets, each gifted with a north and a south pole, and that the two ends which form the line of fracture, and which while the needle was entire were neutral, and constituted the neutral point evincing no polarity, will now be as strongly magnetised as the unbroken ends, but in an opposite sense. If the broken ends be brought into contact, they will again evince no polarity. If we repeat this operation, breaking the separate pieces of the needle into smaller fragments, no matter how far we carry the division, we shall find that each individual fragment of the original magnetised needle will be a perfect magnet in itself, and that it will be impossible to separate a north pole from a south. From this it would appear that these two polarities, namely, north and south, are not two distinct forces, but simply different manifestations of the same force, according as to whether they are viewed from the one side or the other of its sphere of activity.

§ 15. The influence of a magnet, as we have already seen at § 8, extends to a considerable distance in its vicinity, and the portion of space thus influenced is usually spoken of as the *field* of a magnet, or the *magnetic field.* A very good idea of the magnetic fields of bar and horse-shoe magnets may be obtained by placing either of these under a sheet of waxed paper, and sifting lightly some fine iron filings over the paper. The filings will be seen to arrange themselves in certain lines as shown at Fig. 9, in which A represents the distribution of the iron filings in the case of a bar-magnet, and B that in the case of a horseshoe. If while the filings are in this position the paper be cautiously lifted from the vicinity of the magnet so as not to disturb the filings, and the paper gently warmed over the flame of a spirit

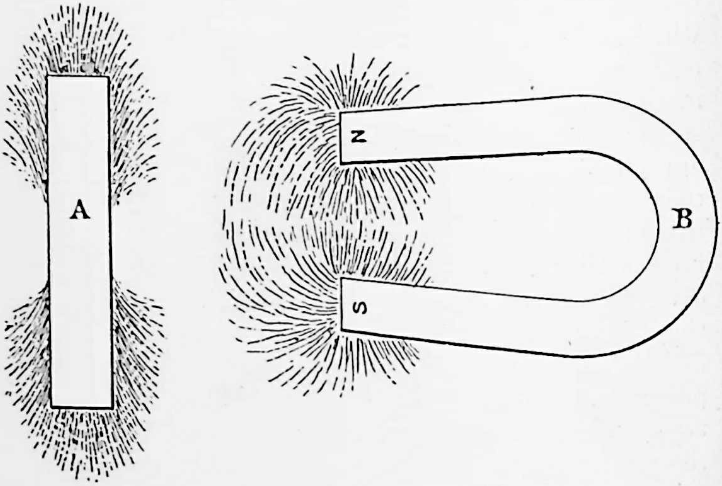


FIG. 9.

lamp so as to fuse the wax, the iron filings will adhere to the paper in the position they took up while under the influence of the magnets, and the resulting picture will give a very good idea of the magnetic field, and of what are generally called the *lines of force*. It will be noticed that the iron filings arrange themselves in curved lines radiating from the poles of the magnet, that these lines are closer and more marked in the vicinity of the poles, growing more diffused and less conspicuous as the distance increases. The term *lines of force* is entirely conventional when applied to the field of a magnet, but it is extremely convenient as giving a clear idea of the intensity and direction of a magnet's action, as we approach nearer and nearer to its poles.

§ 16. An attentive consideration of these lines of force,

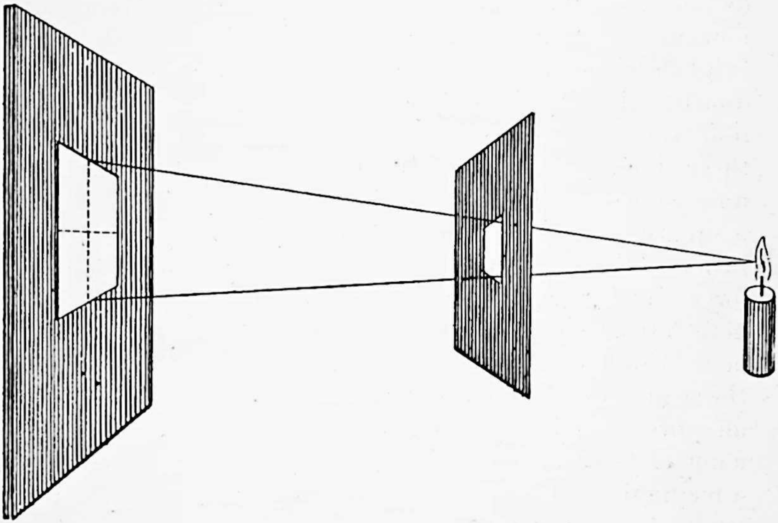


FIG. 10.

as thus depicted by the iron filings, will lead us to the conclusion that the influence of a magnet, like that of all radiating forces, must, from the very nature of things, decrease *inversely as the square of the distance.* This fact can, perhaps, be well illustrated by means of a square aperture cut in a stout piece of cardboard, and held at a few inches distance from a candle or lamp, behind the hole there being a movable white screen to receive the rays of light which pass through the hole in the card-board. This arrangement will be seen at Fig. 10. If we place the screen at such a distance from the hole that the image of the hole is exactly one square inch, and measure the distance at which the screen stands from the hole in this case, and then move the screen back to double that distance, we shall find that the image on the screen will now measure four square inches, but that the light or brightness of the image will be four times less, or one quarter what it originally was, since it is now spread over four times the surface. So if we move the screen to three times the original distance, the image will appear nine times as large, in other words it will measure 9 square inches, the brightness being diminished in like ratio. This fact holds good in all cases of radiating forces, and it can be proved experimentally that magnetic attractions and repulsions obey this same general law. Coulomb devised an instrument by means of which these attractive and repulsive forces can be accurately measured. This instrument, which is known by the name of Coulomb's torsion balance, consists essentially in a magnetic needle suspended over a graduated circle, the whole being inclosed in a glass case (Fig. 11). The needle is suspended by a very fine silver wire depending from a movable milled head on the top of the case; this milled head carries a pointer, which also travels round a smaller graduated circle at the top of the case. The case is perforated at a point opposite the zero of the lower circle, to enable a small test magnet to be inserted. It is a known fact that when a wire is twisted, the angle of torsion is proportionate to the force imparted. To use the instrument the suspended needle is allowed to come to rest at the zero point, the upper pointer also being brought to the zero of its scale. A magnet with similar

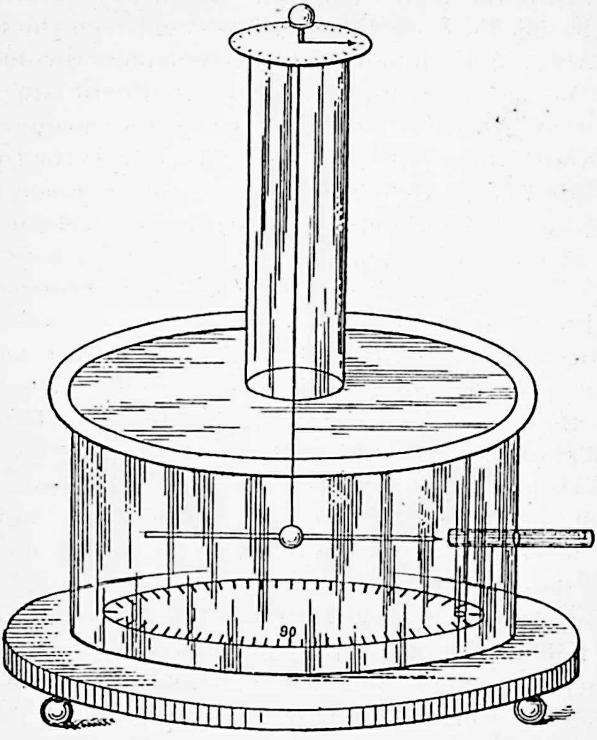


FIG. 11.

pole pointing to the nearer pole of the suspended needle is now inserted in the aperture, and as a consequence the like pole of the suspended needle is repelled through a certain number of degrees of the lower scale. By means of the milled head, torsion is imparted to the silver wire in such a direction as to force the needle towards the repelling magnet. Let us suppose that it had been necessary to turn the milled head one complete revolution to force the needle back through five degrees on the lower scale, it would be found that four complete revolutions would be necessary to cause the needle to approach another five degrees towards the repelling magnet: in other words, the repulsive force is inversely as the square of the distance. Before performing this experiment, it is necessary to determine the earth's action on the needle, so as to know how much to allow for this disturbing effect. In order to effect this, the amount of torsion imparted to the milled head in order to cause the needle to turn through one, two, or three degrees of arc must be carefully noted, and a corresponding allowance made when the above experiment is instituted. There is another method by which the relative strength of a magnetic pole placed at varying distances from a suspended magnetic needle can be ascertained, and this depends on the fact that an oscillating magnetic needle obeys the same laws as a swinging pendulum. This method is therefore called "The method of oscillations." The following is the mode of proceeding. A poised magnetic needle is set swinging, and the number of oscillations it makes per minute carefully noted. These oscillations represent the earth's magnetic influence only. If now a bar-magnet, with its south pole facing the north pole of the suspended needle, be placed at a distance say of a foot from this latter, and the needle be again set oscillating, it will be found that the needle will perform a greater number of oscillations per minute; and if the bar-magnet be now approached to half the distance at which it originally stood, the number of oscillations (having regard to the disturbing influence of the earth's magnetism) will have increased four-fold ; in other words, at half the distance the attractive power is four times as great, or as we have already stated, the attractive and repulsive effects of magnets are inversely as the square of their distance. In Coulomb's original experiment the following were the results obtained: A magnetic needle was used, giving fifteen oscillations in a minute, under the influence of the earth's magnetism alone. A bar-magnet, about 2 feet long, was then placed vertically, so that its north pole was downwards and its south pole pointing to the north pole of the oscillating needle, he found that at a distance of four inches the needle made forty-one oscillations per minute, and at a distance of 8 inches twenty-four oscillations. Now from the laws of the pendulum, we know that the intensity of the forces is inversely as the squares of the times of the oscillations, therefore we have in the first case 15 squared and 41 squared, and in the second case 15 squared and 24 squared. Now subtracting the square of 15 from each of these, in order to eliminate the effect of the earth's magnetism, we get 1,456 in the first case and 351 in the second, which is very nearly as four to one. It will be noticed that these numbers are not exactly as four to one; this discrepancy is due to the fact that the other pole of the magnet is also influencing the needle in an opposite sense.

§ 17. Either of the above-mentioned methods may be employed to test the relative powers of magnets, or in cases where the polar extremities are of suitable form, the direct pull of the magnet in lifting a weight may be measured by means of affixing a hook to a suitable armature or keeper, and thereby ascertaining its actual portative power. It must, however, be borne in mind, as we have already seen at § 10, that the employment of a keeper (although most convenient for retaining the strength of a horseshoe or other magnet), is not to be depended upon in the measurement of relative magnetic strength of different magnets, since the size of the armature itself, as compared to the size of the magnet, has a considerable influence upon its portative power. This source of error, however, is insignificant if the sizes of the armatures and the magnets to be tested do not greatly vary. As the result of many experiments, it has been found that detaching suddenly the keeper from a magnet diminishes its power, that loading a keeper while attached to the magnet with a weight just insufficient to pull it off, will enable the magnet to sustain (up to a certain point), gradually increasing weight far exceeding that which the magnet was originally capable of supporting. But it is also found that when at last the weight is increased to such a point, that the keeper is at last pulled off, the remaining magnetism is very nearly the same as it was before the commencement of the experiment. It is rather difficult to give a simple rule for calculating the maximum portative force which it is impossible to impart to a horseshoe-magnet, since much depends upon the quality and the hardness of the steel. The following algebraical formula will, however, give an approximate idea of the portative power of any steel horseshoe-magnet, made from good magnet steel, when magnetized to saturation :

$$P = 20 \sqrt[\frac{3}{2}]{W}$$

in which P represents the portative power, and W the weight of the steel of which the magnet is composed. From this it is evident that a small magnet will support proportionately a greater weight than a large one. It is to be noticed that the pull or portative power of a bar magnet will be only one third to one quarter that of a horseshoe of similar weight, owing to the fact that the magnetic field produced by the two poles is not concentrated into such a small space as in the case of the horseshoe.

§ 18. We have already seen that the earth may be considered as a huge magnet having one pole near the north polar axis and the other in the southern hemisphere. It is not surprising that such should be the case, because our earth is so largely constituted of ferruginous matter in the state of oxide and compounds of the oxide of iron; nickel, cobalt, and chromium are also found in abundance therein. It is not, however, quite so clear how the earth has obtained its magnetism; but as we shall learn farther on, since a current of electricity travelling around a body equatorially tends to produce magnetic poles axially, and since also the influence of the sun is to set up such currents, it would appear very probable that the magnetism of the earth is due, like its light and heat, to that great luminary. What renders this yet more probable, is the fact that the magnetic poles of the earth are not absolutely constant in position, but vary through long periods of time with the variation of the ecliptic; that disturbances in the sun's activity are translated into corresponding variations in the earth's magnetic intensity; and to so great an extent is this true, that the appearance of any activity on the surface of the sun, as denoted by the occurrence of sun spots, is invariably accompanied by great magnetic perturbations on our earth (generally known as magnetic storms), and by auroræ borealis, which appear to be magnetic manifestations.

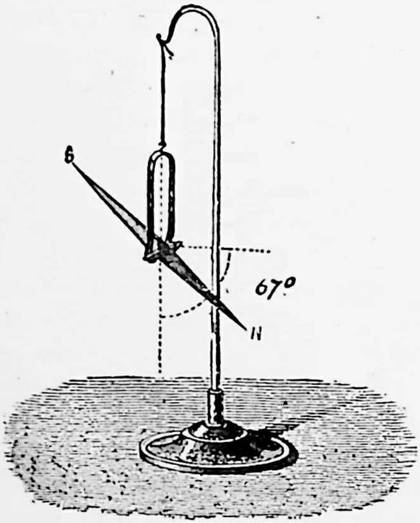


Fig. 11*a*.

§ 19. In studying the earth's magnetic condition we shall do well to notice first that which is fairly constant and then proceed to that which is variable. In the first place, if we travel from the equator towards the poles with a magnetic needle so poised as to be able to swing vertically as well as horizontally (as shown in Fig. 11*a*), we shall find that at the equator the needle will hang parallel to the surface of the earth, but as we proceed from the equator to either pole one end of the needle will begin to *dip*, or point downwards, the amount of "dip," or "inclination," increasing as we approach the northern or southern magnetic poles of the earth,[1] at which points the needle will hang perpendicularly instead of horizontally. It will be found that these two points are not coincident with the earth's axes of rotation, but that the north magnetic pole of the earth is situate about 70° 5′ north, and 96° 45′ west. The south magnetic pole has not yet been reached. Sir James Ross gives it as 154° east longitude, and 75½° south latitude. The position of these poles may be said to be fairly constant; though we know that a small variation—due to, probably, the variations in the earth's inclination to the ecliptic—takes place in periods extending over several centuries. Besides the above facts it is known that the strength of the earth's magnetism, or "*intensity*," varies from time to time, and is now slightly increasing; and, furthermore, that in addition to these secular variations there are daily variations, annual variations, and eleven year periods of variation.

§ 19*a*. But even at any given place, the difference between the direction taken up by a poised magnetised needle pointing to the magnetic north and south (known as the magnetic meridian of that place) and the geographical meridian, is not constant. This difference between the magnetic meridian and the geographical meridian is known as the "declination," or "angle of declination." This angle of declination varies in London from about

[1] The "dip" of the needle in London is now about 67° from the vertical.

24° west of true north to about 24° east of true north, and it takes between 200 and 300 years to perform a full "excursion," or reach the maximum, on either side of the true north. The needle pointed true north at London in the year 1663; that is to say there was then *no declination*: it rose to its maximum *west* declination (24°·41′) in 1818; since that time it has steadily diminished, and is now (1892) about 17° west; that is to say, the true north is about 17° to the east of the north seeking pole of a poised compass needle.

§ 20. The oldest practical service which the magnet has rendered us is that of steering ships; and the instrument made use of for this purpose is known as the mariner's compass. It would appear that the Chinese have been acquainted from time immemorial with this instrument, which consists essentially in a lozenge-shaped magnetised needle, supported at its centre by an agate cap resting on a smooth sharp point, inclosed in a box with glass or talc cover to protect it from air currents. In modern practice it is usual to mount this box on two sets of trunnions, or gimbals, at right angles to each other, so that the motion of the ship may not have any disturbing influence on the poised needle itself. A sketch illustrative of this mode of suspension is given at Fig. 12. Either poised along with the needle, or else underneath it, is a graduated card divided into thirty-two equal parts, called rhombs, or points, of which four are the cardinals, viz., North, South, East, and West, and the remainder the intermediary points. Useful as this instrument is in enabling the traveller to direct his course, it is subject to causes of error, when used on board ships which are either themselves constructed of iron, or in which large masses of iron are employed. As we have already seen, all iron is subject to become magnetic under the influence of the earth's magnetism, and as the iron employed in ship-building is by no means of the softest description, and is, therefore, capable of retaining a very considerable portion of the magnetism imparted to it during the process of manufacture under the combined influence of the earth's magnetism and the vibration set up during hammering,

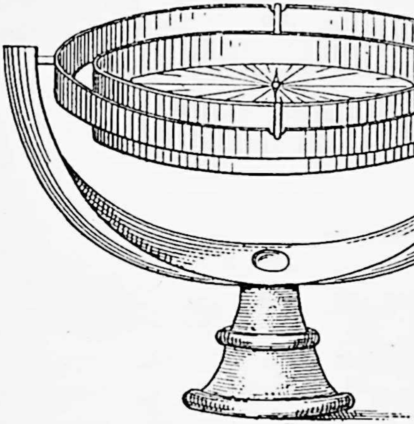


Fig. 12.

rivetting, etc., it follows that a ship so constructed will actually act as a magnet upon the compass on board, and will seriously affect the indications or readings of the ship's compass by pulling its needle out of the true north and south. For this reason it is necessary to test the action of the ship in every possible position with reference to the compass, and to make a table of the variations at every point during this operation ; and besides this it is customary to place a compass at the masthead at such a distance from the hull as not to be seriously influenced by the ship's magnetism, which serves as a check on the readings of the compass in the ship's binnacle.

§ 21. It is possible to arrange two magnetic needles of about the same magnetic strength in such a position with regard to each other that while retaining their individual magnetic properties they shall be virtually unaffected by the earth's magnetism; that is to say, shall remain at rest in whatever position they may be placed. This is

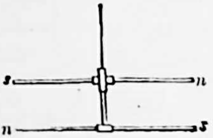


FIG. 13.

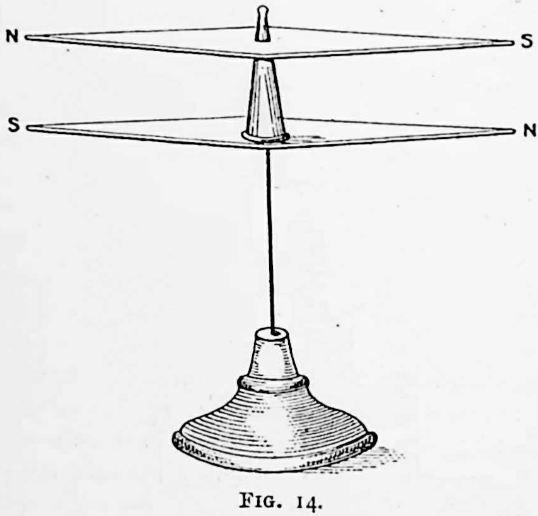


FIG. 14.

effected, as shown at Fig. 13, by placing the needles parallel to one another at a distance, say, of about three-quarters of an inch, with their unlike poles facing and supported at their centre by a straw or a twisted wire, which is in its turn suspended by a fine silken fibre. Or the same end may be arrived at, as shown at Fig. 14, by pivotting the needles on a rather long glass pivot, and poising the combination on a fine steel point. It will be evident that in either of these cases, since the poles which are contiguous are of opposite names and of equal force, the earth's attraction for the one will be exactly counterbalanced by its repulsion for the other: consequently the combination will not tend to take up any set position with regard to the earth's magnetic poles. Such a combination is known as an "astatic needle," and is frequently made use of in delicate electro-magnetic experiments.

§ 22. There are certain circumstances which influence very much the retentive power of magnetic bodies for magnetism. In the first place, and referring more specially to iron and steel, the harder the metal the more retentive it is of the magnetism imparted to it. Perfectly pure soft iron is incapable of permanent magnetisation ; it has no magnetic memory, or in the language of the scientist, it has no *coercive force*. But anything which conduces to the hardening of the iron favours also to its power of retentivity ; hammering, twisting, rolling, or almost any mechanical strain, will tend to impart a power of retaining a certain amount of residual magnetism. Crystallization also, and the presence of minute quantities of impurity, and especially of carbon, greatly enhance the power of retaining magnetism ; and for this reason cast iron retains more magnetism than wrought iron, steel more than cast iron, and hard-tempered steel more than all. Temperature has also a great influence on the power of retaining magnetism ; at a red heat iron and steel lose their magnetism altogether, cobalt and nickel seem to retain it somewhat better. It is possible to demagnetise completely the strongest steel magnet by exposing it to a bright red heat, and allowing it to cool gradually. And in the case of soft iron which, from having been hammered or exposed to other mechanical strain, has acquired some coercive force, and which it is desired to render as far as possible non-retentive, the best means at our disposal to effect this end is to bring the mass to a bright red heat, and allow it to cool down very gradually. By so doing, it would appear that under the influence of the heat the constituent molecules of the iron arrange themselves in positions of no strain, and are consequently

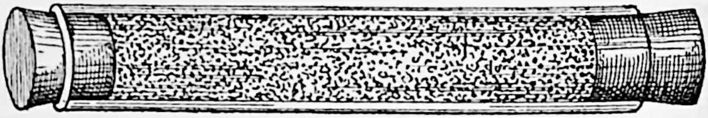


Fig. 15.

incapable of having permanent magnetism imparted to them.

§ 23. As the explanation of the phenomena which have passed under our notice in the preceding sections will be deferred until we have made an acquaintance with the facts and theory of electricity, we shall do no more here but advert to two experiments which tend to prove that the position of the molecules in a mass of iron or steel is closely connected with its magnetic properties. If we take, as shown at Fig. 15, a glass tube about half an inch in diameter, and four inches long, and fit it with a cork at each end, and having removed one of the corks, fill it with fine iron filings, on replacing the cork and presenting the tube to a suspended magnetic needle, we shall find that it is not a magnet, *i.e.*, has no magnetic poles, but acts like any other piece of soft iron, attracting indifferently either pole of the suspended needle. If now we lay the tube flat on a table and draw along it lengthwise one of the poles of a powerful bar magnet (as in the operation of magnetising by single touch) it will be noticed that the iron filings will dispose themselves in certain definite longitudinal arrangements, following the stroke of the inducing magnet, and if after having stroked the tube as above described, we cautiously raise it in a horizontal position (so as not to disturb the arrangement of the filings) and present it to the poised magnetic needle, we shall find that it now behaves as a magnet, having a true north and south pole. But if we shake the tube so as to disarrange the position which the filings had taken up ("orientation," as the French say), and again present the tube to the magnetised needle, we shall find that all traces of magnetism have disappeared. Again, if we suddenly and powerfully magnetise a rod of iron, at the instant of magnetisation the rod will emit a musical note, proving that some internal vibratory motion has taken place in the molecules composing the mass of the rod.

CHAPTER II.

ELECTRICITY.

§ 24.

IF we rub a piece of amber, a stick of sealing-wax, or a rod of glass briskly, with a piece of dry silk or flannel, we shall find that these substances will have acquired the property of attracting light bodies, such as small pieces of paper, bits of cotton, straw, etc. And on presenting the knuckle to a glass rod thus rubbed, in a darkened room, at a distance of about half an inch from the rod, a faint bluish spark accompanied by a crackling sound will make itself evident. These phenomena were first noticed by Thales, a Grecian philosopher, who flourished some 600 years before Christ; and as the body in which he noticed these properties was amber (in Greek *elektron*), the name *electricity* was applied to the agent which gave rise to these effects.

§ 25. If for the convenience of studying the phenomena we suspend a small pith ball by means of a single fibre of silk (a cork ball may be substituted where pith is not obtainable) from a bent arm rising from a stand, as shown at Fig. 16, we shall find that this property of acquiring attractive and sparking powers is not limited to amber, sealing-wax, and glass, but is enjoyed by many other bodies. For instance, all resins, gutta-percha, indiarubber, dry paper, sulphur, fur, many vitreous substances, etc., are gifted with these properties. On the other hand, it will be found impossible in the ordinary way to cause metallic bodies to evince similar powers, or, to use the technical expression, to become *excited.* For this reason the older electricians divided all the bodies with which they were acquainted into two great classes, *electrics* and *non-electrics ;* of which the former included all those bodies which by friction were capable of becoming electrically excited, while the latter contained those which, by the ordinary means employed, were incapable of excitation. It will be shown farther on that this division was erroneous, and consequently we do not give a table here of electrics and non-electrics.

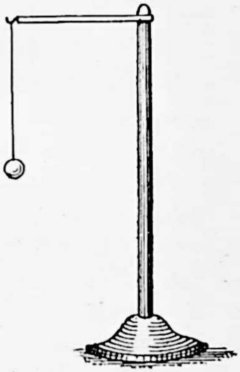


FIG. 16.

Having provided ourselves with a suspended pith ball, as above described, we can prosecute our experiments ; and we shall notice that if we present the electrified sealing-wax rod to the suspended pith ball, this latter will at first be powerfully attracted, and fly towards the excited rod, but after having touched it and remained in contact with it for a few seconds, will be as powerfully repelled. On repeating this same experiment with any other body capable of excitation (the ball having been previously allowed to touch the hand in order to remove any electricity that it has gathered from its contact with the sealing-wax), it will be found that a similar cycle of phenomena will present itself; that is to say, that the ball will be first attracted, and after touching the excited body, will be repelled. Continuing our researches in this direction we shall farther find that if after having produced repulsion by means of the excited sealing-wax we present to the ball a rod of excited sulphur, ebonite, gutta-percha, or amber, the ball will not be attracted, but still repelled; while on the other hand, if we present

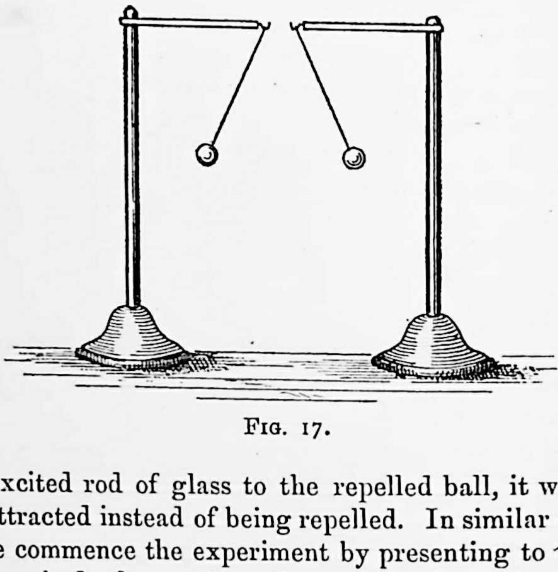


FIG. 17.

an excited rod of glass to the repelled ball, it will now be attracted instead of being repelled. In similar manner if we commence the experiment by presenting to the ball the excited glass rod until repulsion is produced, and then approach an excited vitreous body, such as diamond, or another rod of excited glass, repulsion and not attraction will be the result; and in this experiment, as in the former, the presentation to the repelled ball of any excited body of the opposite class, viz., resinous, will be followed by attraction instead of repulsion. This peculiarity, by which it would appear that a different kind of electricity can be elicited from bodies of a resinous nature to those of a vitreous, can be illustrated even more clearly and in a more striking manner by the employment of two similarly suspended pith balls, which can be brought near one another after being charged with excited bodies of different nature. Fig. 17 repre-

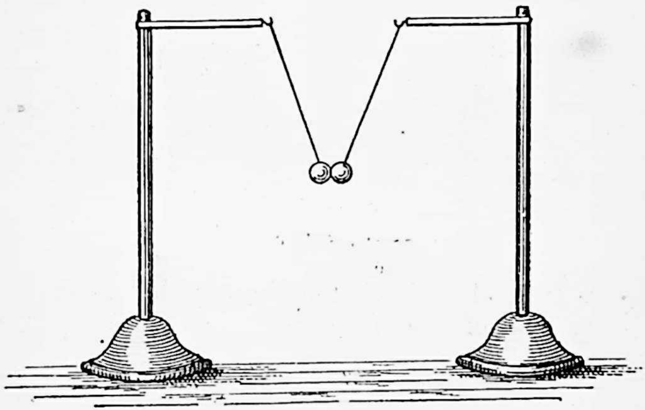


FIG. 18.

sents the result of approaching two such pith balls, both charged by contact with either a resinous or a vitreous body, while Fig. 18 represents the result obtained on approaching the two balls, one of which has received its charge from a vitreous, and the other from a resinous body.

§ 26. From this it would appear that bodies receiving their charge from resinous bodies *repel* one another, as also do those which receive their charge from excited vitreous bodies, but that bodies which have received their charge from vitreous substances attract those which have received their charge from resinous bodies and *vice versa.* Based on the observation of the above facts the older electricians formulated the following law, namely : — Bodies charged with vitreous electricity repel one another ; bodies charged with resinous electricity repel one another ; bodies charged with vitreous electricity attract those charged with resinous electricity, and *vice versa.*

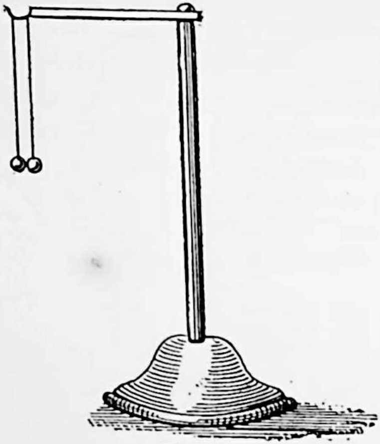


Fig. 19.

§ 27. Instead of having a single pith ball depending from the arm of our little stand, two similar pith balls

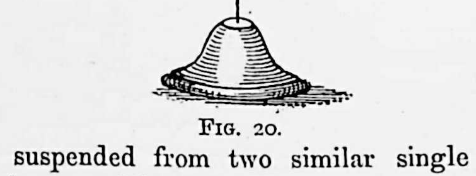


Fig. 20.

may be suspended from two similar single fibres of silk, as shown at Fig. 19. These instruments, whether constructed with one pith ball or two, or whether balanced on a pivot, as shown at Fig. 20, are known as *electroscopes;* from *elektro* and *skopeo,* I see. With the double pith ball electroscope the phenomena of apparent repulsion may be shown in a manner even more marked than in the case of the single ball instrument. It is sufficient to allow the two balls to touch for an instant an excited glass or an excited sealing-wax rod for them to exhibit this apparent mutual repulsion, which is evidenced by their standing aloof from one another, as shown at Fig. 21, when the rod is removed. But something besides this apparent repulsion can also be learned from the experiments with the pith balls, and that is, that this apparent repulsion may be regarded as an actual attraction of the charged pith ball for the neighbouring bodies. That this is really the case may be proved by approaching the hand on the opposite side of the pith ball to that at which the excited rod is held, when it will be found that the pith ball will be attracted by the hand, will seek to touch it, and having done so will fall back into its old position to be again attracted by the excited rod if presented to it.

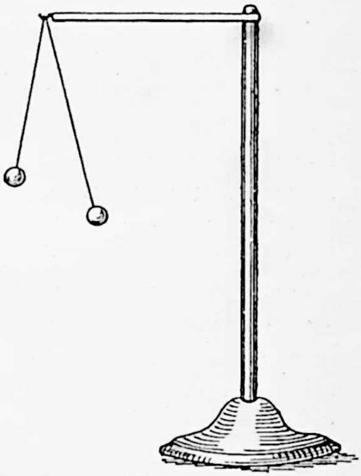


FIG. 21.

§ 28. We have already noticed that the more ancient electricians were not able to get manifestations of electricity from metallic and similar bodies, and therefore classed these as non-electrics. By the following experiment it can be shown that any metal, or, indeed, to speak generally, any substance can be excited. If a brass rod about eight inches long be mounted in an ebonite handle so that it can be grasped by the hand without touching the metal at any point, and if this rod be rubbed with a piece of silk lying upon a sheet of indiarubber, it will be found that the metal rod becomes excited as freely as if it were glass. Here it is evident that the glass and the resin must have some power of retaining the excitation set up which the metal has not; and in point of fact we find that if we touch the metal rod either with the hand, with another piece of metal, or, indeed, with any of the bodies which are incapable of being excited by friction in the ordinary way, it at once loses its electrical properties, which is not the case when glass or any other electric is excited. From this it would appear that metals, etc., have the property of *conducting* or allowing to flow away the excitation produced by friction, while resinous, vitreous, and similar bodies belonging to the so-called electric class do not conduct or allow the passage of the agency, whatever it be, that produces these phenomena; consequently scientists now divide all known bodies into two great classes, namely, *conductors* and *non-conductors;* and as it is found that no substance is a perfect conductor, that is to say, that there is no body which presents no resistance to the passage of the electric force, and on the other hand, that no known body can absolutely stay its passage; so the division of these two classes is only comparative, and is not abrupt, since there are bodies which, compared to others, present such a great resistance to the passage of the energy as to be considered as non-conductors or "insulators,"[1] which, compared to others presenting greater resistance, might be looked upon as tolerable conductors. The following table gives a fairly good idea of the relative conductivity or resistance of the more common bodies.

§ 29. *Table of Conductors and Insulators.*

Quality.	Name of Substance.	Relative Resistance.
Good conductors	Silver, annealed	1·
	Copper, annealed	1·063
	Silver, hard drawn	1·086
	Copper, hard drawn	1·086
	Gold, annealed	1·369
	Gold, hard drawn	1·393
	Aluminium, annealed	1·935
	Zinc, pressed	3·741
	Brass (variable)	5·000
	Platinum, annealed	6·022
	Iron	6·450
	Steel, soft	6·500
	Gold and silver alloy, 2 to 1	7·228
	Nickel, annealed	8·285
	Tin, pressed	8·784
	Lead, pressed	13·050
	German silver (variable)	13·920
	Platinum silver alloy, 1 to 2	16·210
	Steel, hard	25·000
	Antimony, pressed	23·600
	Mercury	62·730
	Bismuth	87·230
	Graphite	145·000
Imperfect conductors	Nitric acid	976000·000
	Hydrochloric acid	[2]
	Sulphuric acid	1032020·000
	Solutions of metallic salts	Varies with strength
	Metallic sulphides	[2]
	Distilled water	[2] 6754208·000

[1] From insula, an island, as cutting off from all other bodies.

[2] These have not been accurately measured.

Quality	Name of Substance.	Relative Resistance.
Inferior conductors	Metallic salts, solid . . .	*
	Linen, Cotton, Hemp, Paper — and other forms of cellulose	*
	Alcohol	*
	Ether	*
	Dry Wood	*
	Dry Ice	*
	Metallic Oxides	*
Non-conductors or insulators	Ice, at 25c.	*
	Fats and oils	*
	Caoutchouc	1000000000000·
	Gutta-percha	1000000000000·
	Dry air, gases and vapours .	*
	Wool	*
	Ebonite	1300000000000·
	Diamond	*
	Silk	*
	Glass	*
	Wax	*
	Sulphur	*
	Resin	*
	Amber	*
	Shellac	*
	Paraffin	1500000000000·

* These have not been accurately measured.

The figures given as indicating the relative resistance of the above bodies to the passage of electricity must be taken as approximate only, since the conductivity of all these bodies varies very largely with their purity, and with the temperature. Metals become worse conductors when heated ; liquids and non-metals, on the contrary, become better conductors. It must be borne in mind that dry air is one of the *best insulators*, or *worst conductors*, with which we are acquainted, while damp air, on the contrary, owing to the facility with which it deposits *water* on the surface of bodies, is highly conducive to the escape of electricity.

§ 30. Several instruments by means of which the presence of electricity may be detected, are constructed, having for basis the property of attraction and subsequent repulsion of electrified bodies. Perhaps the most delicate is "Bennet's gold leaf electroscope," which is illustrated at Fig. 22, in which A represents a glass jar similar to an inverted lamp shade, standing on a base, and furnished with two strips of tinfoil, T T, pasted inside at opposite points of the circumference. This is fitted with a cover of any insulating[1] material at C through which passes a metallic rod reaching about one-third down the jar, which rod carries at its lower extremity a pair of gold leaves hanging parallel to each other, and facing the tinfoil strips. At the upper end of the brass rod is a metal plate or ball. If any electrified body be made to touch the upper plate, the gold leaves in the jar immediately diverge, being apparently repelled by each other, but being

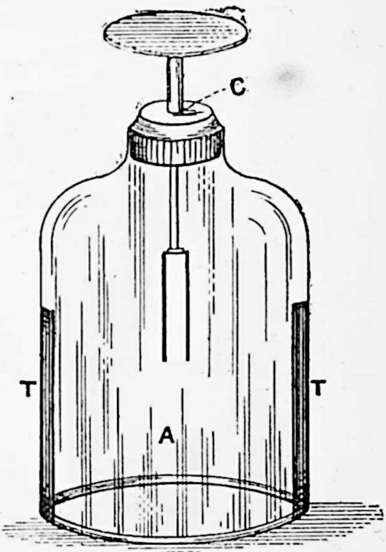


Fig. 22.

[1] Non-conducting.

in reality attracted by the strips. Owing to the great mobility of the gold leaves, this instrument affords a very delicate test for the presence of any electrical charge.

§ 31. Another instrument, based on this apparent repulsion of similarly electrified bodies, is "Henley's Quadrant Electroscope;" this consists in a metallic rod, at one end of which is a small semicircle of ivory inscribed with degrees up to 90, and fitted with a pith ball hanging from the centre of the circle by means of a fine wire passing out on each side of the disc, as shown at Fig. 23. As usually constructed, a single straw or a single wire passes from the centre of the disc to the pith ball, but it is far preferable to allow the wire to be bent so as to embrace the disc on both sides, as then the repulsion between the pith ball and the rod is exerted in a direction which enables the readings to be taken off the graduated disc with ease, while in the former case the pith ball is apt to fly out laterally instead of rising up parallel to the disc. When this instrument is placed upon any charged body, the pith ball rises from its position against the rod and indicates by the degree of divergence from the vertical, in a rough and approximate manner, the charge of the body, *provided all other circumstances be equal.* It must be borne in mind that this instrument cannot, with

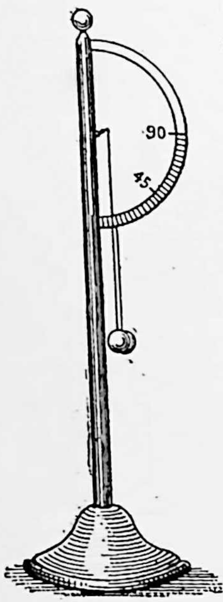


FIG. 23.

any degree of propriety, be considered as a *measure* of the amount of charge, since the slightest variation in the size of the charged body with which it is placed in contact, or the nearness or distance of uncharged bodies in its vicinity will entirely alter its indications.

§ 32. We now come to an instrument which enables us to measure accurately the charge and the repulsive force exerted by charged bodies; this is known as Coulomb's torsion balance, and is simply a modification of the instrument described under the same name at § 16. Here we have the square or circular glass vessel, around which is a graduated circle furnished with an upright central glass tube at the top of which is a second graduated circle, perforated to admit a short rod carrying the milled head and pointer. From this rod depends a fine silver wire; at the lower extremity of this wire is affixed a fine glass or shellac rod, to one end of which is fastened a gilt pith ball. There is a perforation in the lower portion of the glass case to admit of the insertion of a little metallic ball attached to a rod. This instrument is shown at Fig. 24, where A represents the larger glass case, B the glass tube, C the upper graded circle, D the pointer, and E the milled head; F is the silver wire, and G the glass rod with its accompanying pith ball, H. I shows the perforation in the lower glass case through which the glass rod, J, and the metallic ball, K, can be inserted. L shows the lower graduated circle. To use this instrument, the top milled head, E, is turned until the two balls, H and K, just touch one another. The glass rod, I, is then removed, and the ball, K, placed into contact with the body whose charge it is desired to measure and compare, the rod, I, is then replaced, and on the ball H touching the ball K, the

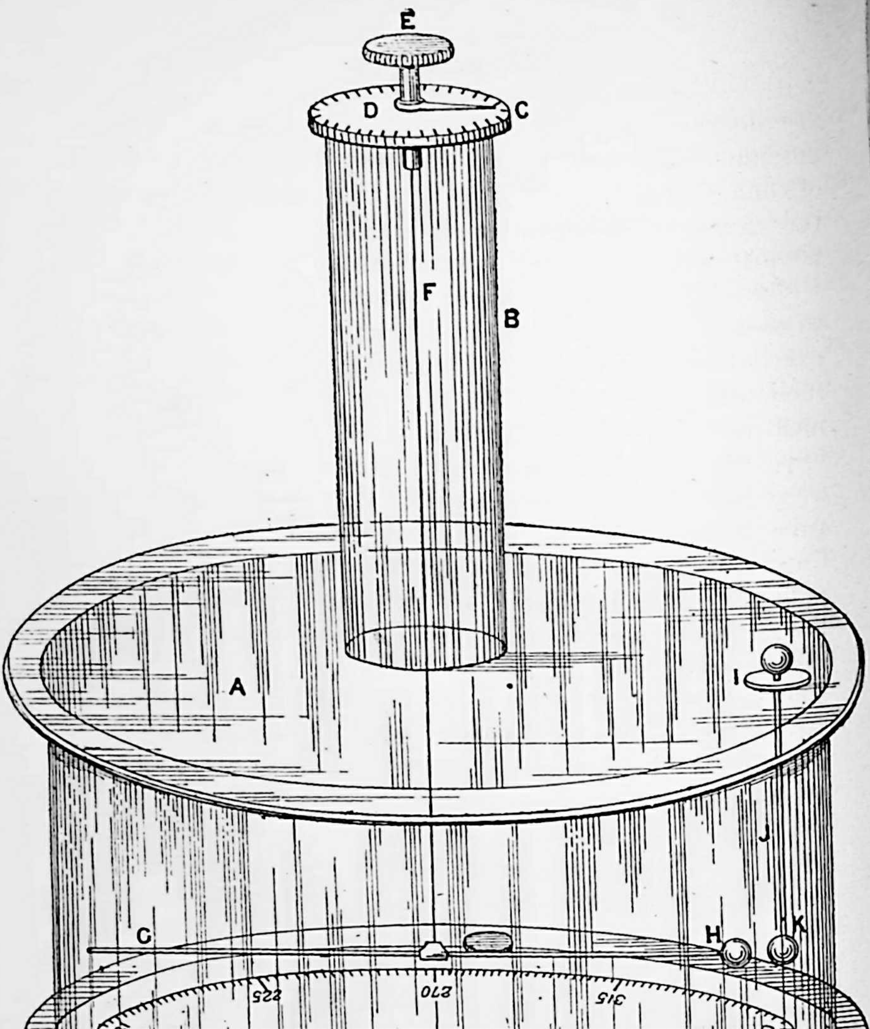


FIG. 24.

former will be found to be repelled through a given number of degrees of arc on the lower circle, and as the force of torsion in the wire is always equal to the twisting force, the readings are strictly comparable. It must be borne in mind, however, that the ball is not repelled in a straight line, but along a circle, and although when the angular distance travelled through is small, the difference between the chord and the arc is so trifling, as to be practically negligible; yet the comparisons would not hold good if the repulsion carried the ball through a very large arc of the circle. By means of this instrument it can be easily shown that the attractive and repulsive forces of electrified bodies vary *inversely as the squares of their distances*, so that it requires a force four times as great to repel a body through 20 degrees of arc, as that required to repel it through 10 degrees of arc. The mode by which this can be proved is a follows:

Having by means of any charged body produced a repulsion, say, equal to 30 degrees, the upper milled head, E, is now turned until the lower pith ball is brought within, say, 15 degrees of the ball K, and the amount of twist required to do this noted by the upper circle, C, and pointer, D. Again, the knob, E, is turned until the lower pith ball, H, is brought to half the distance from the fixed ball, K, namely, $7\frac{1}{2}$ degrees, when it will be found that four times the torsion or twist has been employed to carry the ball from 15 to $7\frac{1}{2}$ as was required to carry it from 30 to 15, in other words, "*the repulsive force varies inversely as the square of the distance.*"

§ 33. This instrument enables us to gauge pretty accurately the electrical condition of any body, and by its aid we find that electrified bodies may have apparently

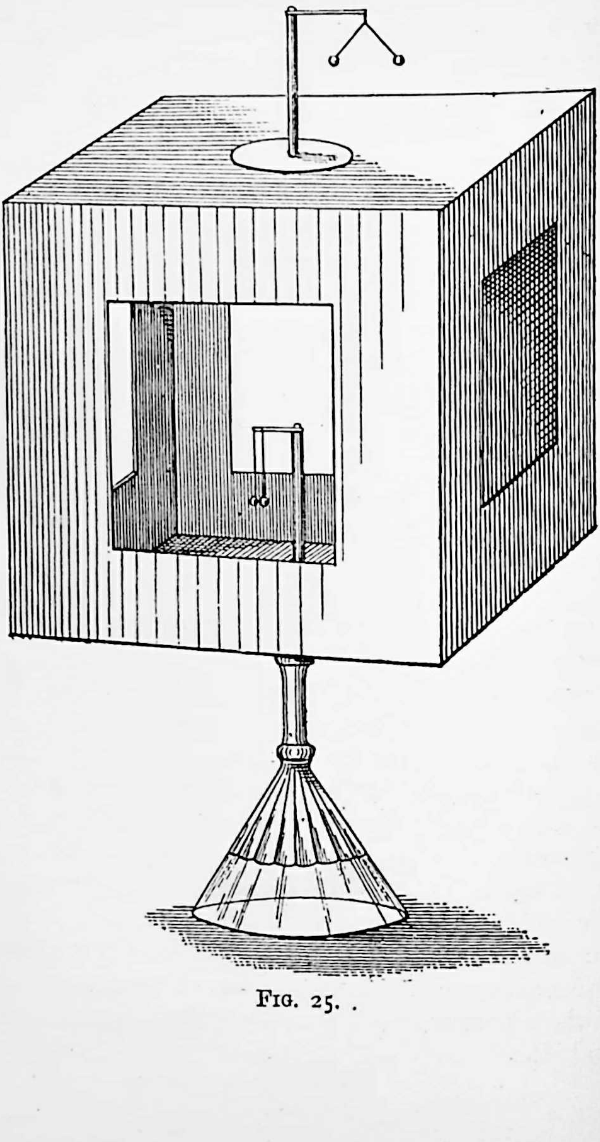


FIG. 25.

different charges at different portions, according to their shapes and their proximity to other bodies. This fact can also be proved experimentally in a variety of ways ; for instance, if we prepare a square tin box, having four small windows, by means of which we can see what is going on inside, fitted with a cover ; and place this on an inverted wine glass or any other insulator, it can be charged in any of the ordinary modes, preferably by contact with a charged body, until it shall give strong indications of its electrification. For example, a little double pith ball electroscope (similar to Fig. 19) may have been previously placed on the top of the box as shown at Fig. 25, when it will be found that the pith balls will stand out from each other, as might be expected. But if previous to charging the box, a similar electroscope be placed *inside*, it will be found that no matter how strongly the box may be electrified, the pith balls within will not diverge. This is generally given as a proof *that electricity resides on the surfaces only of bodies.* If we make a little disc of tinned iron, about 1 inch in diameter, and mount it on an ebonite handle about 6 inches long, and $\frac{1}{4}$ inch in diameter, we shall be able to pick up the charge from the surface of any electrified body in proportion to the intensity of charge existing at that particular spot. This

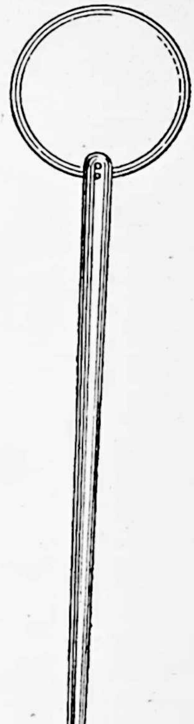


FIG. 26.

little device is termed a "proof plane," and is illustrated at Fig. 26. Having charged an insulated metal body of irregular shape, say an ovate body terminating in a point, on testing the electrical condition of such a body by means of the proof plane, followed by contact with Coulomb's torsion balance, it will be found that the greater charge will reside at the more pointed portions, or to speak more

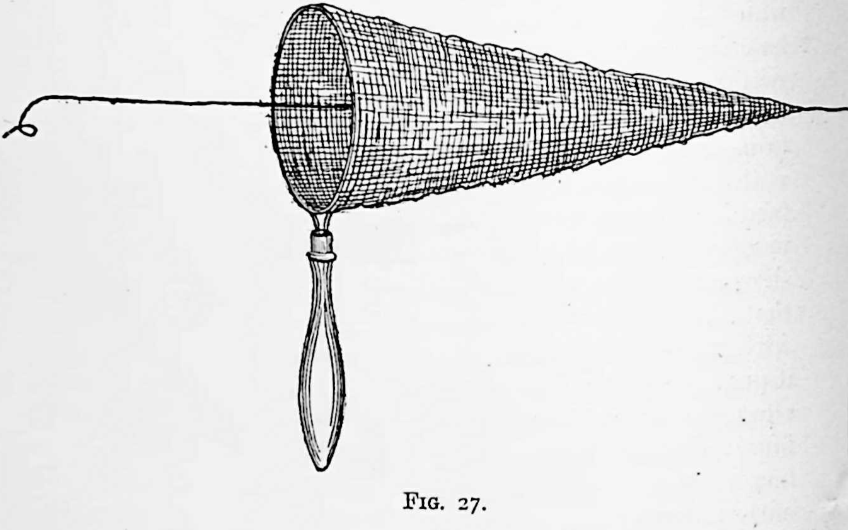


FIG. 27.

exactly at those which are at the greatest distance from the centre of the mass of the body. Hence in a sphere which naturally has all its surfaces at equal distances from its centre, the charge will be equal at all points of its circumference; and in bodies in which the irregularities of surface are great, those portions which extend above the general level of the surface will be found to be charged more intensely and in proportion to their protuberance beyond the general level, while, *per contra*, the depressions or valleys will be less charged in like proportion. On testing the inside of a hollow sphere, provided with a hole through which the proof plane can be passed, no perceptible charge will be taken up by the proof plane. Again, a butterfly net, as shown at Fig. 27, furnished with two long pieces of silk twist at its pointed extremity by means of which it can be turned inside out without coming into contact with any conducting body, if held by an insulating handle and charged, will be found to exhibit the usual electrical properties at its exterior surface, while none will be evident in its interior. If it now be turned inside out, by the aid of the silken twist, the charge will be found on that portion which was originally the inside, but now the out, while the late outside surface (now the inside) will have apparently lost its electrical charge.

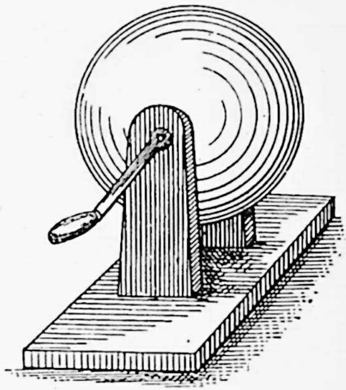


FIG. 28.

§ 34. In order to be able to prosecute our experiments with greater certainty, it will be necessary to provide ourselves with some contrivance by means of which we can call forth electrical manifestations on a larger scale than that which is possible by simply rubbing glass or resinous rods. For this purpose we may fall back on the most ancient form of electrical machine, which consisted in a cast globe of sulphur mounted on trunnions furnished with a handle, against which globe the hand was rubbed while the globe was rotated; this device is shown at Fig. 28. This arrangement is known as Otto Guericke's electrical machine.

§ 35. Or coming to a more modern form, we may em-

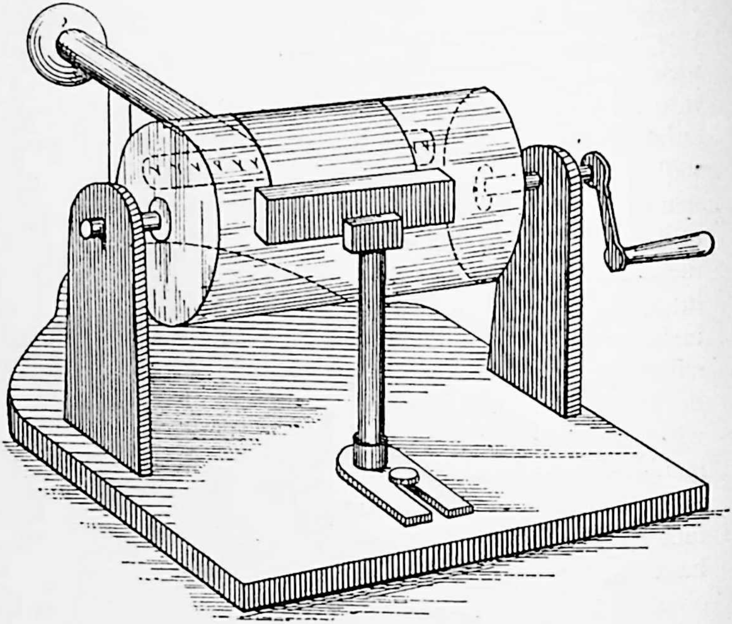


FIG. 29.

ploy the cylinder electrical machine, shown at Fig. 29, in which a cylinder of glass mounted on trunnions takes the place of the sulphur globe, and a rubber covered with leather, and provided with a silk flap, which embraces nearly half the circumference of the cylinder, takes the place of the hand in the Otto Guericke arrangement. In order to collect the electricity set up by the friction of the rubber against the glass, there is placed at the opposite diameter of the cylinder a row of metal points, supported on a rod attached to a metal cylinder with rounded ends, sustained by a glass or other insulating stand. On rotating the handle, the friction of the rubber against the glass cylinder sets up an electrical disturbance on the

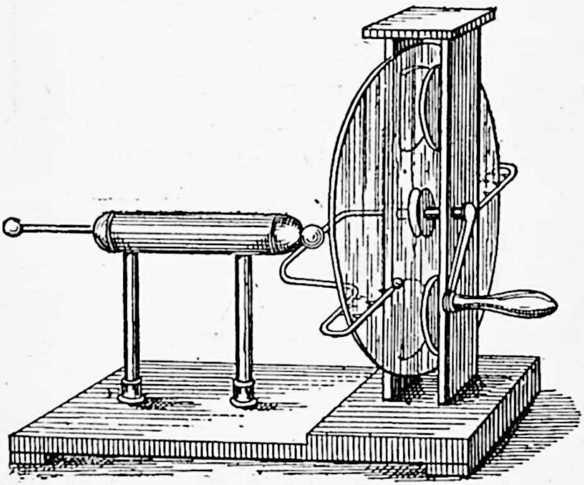


FIG. 30.

surface thereof, which is communicated to the metal cylinder (technically termed the prime conductor) by the agency of the points, and from this prime conductor sparks and other manifestations of electricity can be obtained.

§ 36. Another and more compact form of electrical machine is that known as the plate machine, portrayed at Fig. 30, and which consists of a disc of glass mounted so as to rotate on a central axis, furnished with rubbers affixed to the standards, and provided with a prime conductor fitted with brass rods and points which embrace the plate, which serve the purpose of the portions of like name in the cylinder machine.

§ 37. Being provided with the means of producing ample displays of electrical energy, the student will do well to direct his attention to a phenomenon the knowledge of which has become of the highest importance in the practical application of electricity. If we mount a long metal cylinder with rounded ends on an insulating stand, as shown at Fig. 31, and present to

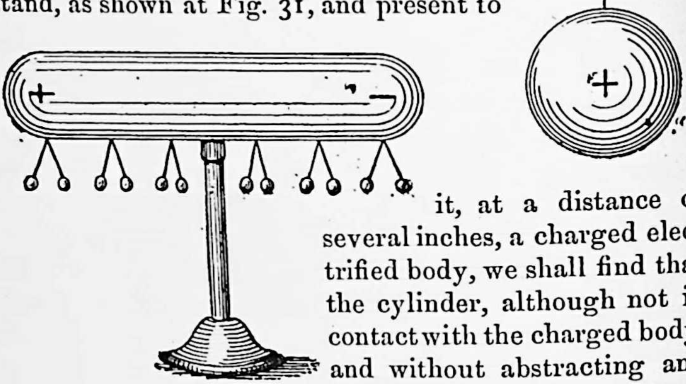


Fig. 31.

it, at a distance of several inches, a charged electrified body, we shall find that the cylinder, although not in contact with the charged body, and without abstracting any electricity from it, will itself evince electrical properties. And if along the cylinder be suspended several pairs of pith balls (as shown in sketch), it will be found that the cylinder is not equally electrified, but that the divergence of the pith balls, and consequently the electrical charge, will be greater at its extremities and less towards the middle, at which point the cylinder will evince no electrical properties. Besides, it will be found that the electrical condition of the two ends is different. If the charged electrified body, which is thus influencing the cylinder, have received its charge from *glass,* then the nearer end of the cylinder will be found charged as if *it* had received its electricity from a *resinous body,* while the farther extremity of the cylinder will be found charged similarly to the influencing body, namely, as if it had received its charge from *glass.* Representing the glass-charged body by + and the resinously charged body by —, the illustration shows fairly well the relative conditions of the influencing body and the influenced cylinder. If now the charged sphere be removed from the proximity of the cylinder, all signs of electricity disappear, the pith balls fall back into their old perpendicular position, and all apparent charge is lost. The experiment succeeds equally well if the charged body receive its electricity from a resinous source, but in this latter case the disturbance set up in the cylinder is of opposite kind to that which took place in the former instance ; in other words, the nearer end of the cylinder will become + while the farther will become —. And, as a general rule, when a charged body is approached to another body, the nearer surface becomes charged with electricity of opposite sign to that of the charged body, while its farther extremity becomes charged with electricity of like sign. If in performing the above experiment, while the charged body was influencing the cylinder, we had placed a conductor (say the hand or a rod of metal) in contact with the cylinder, preferably at its farther extremity, a transfer of electricity of like sign to that of the influencing body would have taken place from the cylinder to the hand or metal rod ; and then the rod or hand having been previously removed, if the charged body be taken away from its neighbourhood to the cylinder, this latter will be found charged with electricity of contrary sign to that of the influencing body. (For the future, in speaking of these different manifestations of electricity, for the sake of brevity, we shall indicate the electricity set up by glass as positive or +, and that set up by resinous bodies as negative or —, without implying or wishing to convey any idea of positiveness or negativeness.) It will be seen that the above phenomena present considerable analogy to those described at § 8, when treating of induction in magnetism. In point of fact this phenomenon goes by the same name, and is known in England, as electrical *induction,* in France by that of *influence.* We may define roughly induction as being "the action of a charged electrified body on another body separated from it by a non-conductor." As we do not propose to enter into the theoretical part of our subject until we have gathered together a sufficient number of facts on which to generalize, we shall defer explanations until later on, and proceed to describe some beautiful experiments which can be performed by the aid of induction, and to call attention to some very efficient electrical machines in the action of which induction plays a principal part.

§ 38. A modification of the simple form of induction experiment (illustrated at Fig. 31) should be performed by the intelligent student, as it will conduce to his comprehension of many results which otherwise would be difficult to understand. An empty beef-tin with the lid removed having been stood upon a clean, dry, inverted wine-glass (which acts as an insulating stand), it is placed in contact with the plate of a Bennett's gold-leaf electroscope, as shown at Fig. 32. A small metal ball, suspended from a long silken thread, is now charged positively by means of an electrical machine, and plunged into the middle of the tin, without touching the sides. As the ball descends, it, by induction, disturbs the condition of the tin, which becomes negatively charged on its inside, and positively charged on its outside, which consequently imparts a portion of its charge to the gold leaves of the Bennett's electroscope, producing a divergence thereof. On withdrawing the ball, provided the surface of the tin be not touched by any conductor, the tin falls back into its old condition, as indicated by the parallelism of the gold leaves. Should, however, the tin have been touched while the charged ball was hanging in its middle, the leaves would collapse at the moment of being touched, but would diverge again on the withdrawal of the inducing ball. If instead of using a single tin, four tins be employed of increasing sizes, so that No. 1 can be placed in No. 2 without touching, and No. 2 in No. 3, also No. 3 in No. 4, and these be separated from one another by glass marbles placed in the bottom of each, as shown at Fig. 32A, then on performing the same experiments it will be found that the + electricity set up on the outside

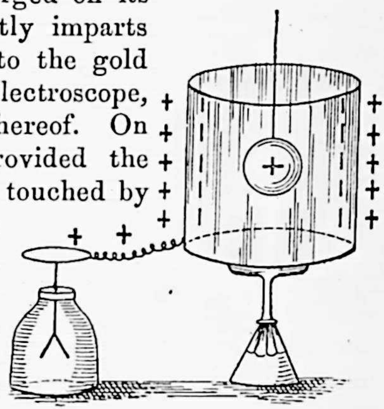


FIG. 32.

of tin No. 1 will induce — electricity on the inner surface of tin No. 2, and + at its outside, and this tin No. 2 in its turn will induce a negative condition on the inside of tin No. 3, and a positive condition at *its* outside, and so

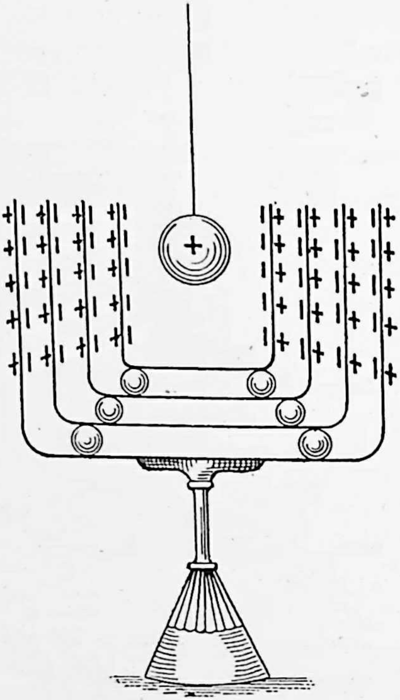


FIG. 32A.

on to the end of the series, showing that an induced body is itself capable of inducing.

§ 39. One of the first, and theoretically the most important of the instruments for the production of electricity by the aid of induction, is the *electrophorus*. This was invented by Professor Volta in 1774, and consists essentially, as shown at Fig. 33, in a disc, or cake, or sole, as it is usually termed, of any good insulator, A, such as ebonite, resin, sulphur, or glass, on which is placed a somewhat smaller metal disc, B, usually termed the shield or cover, furnished with an insulating handle, C, at its centre, by means of which it can be raised from

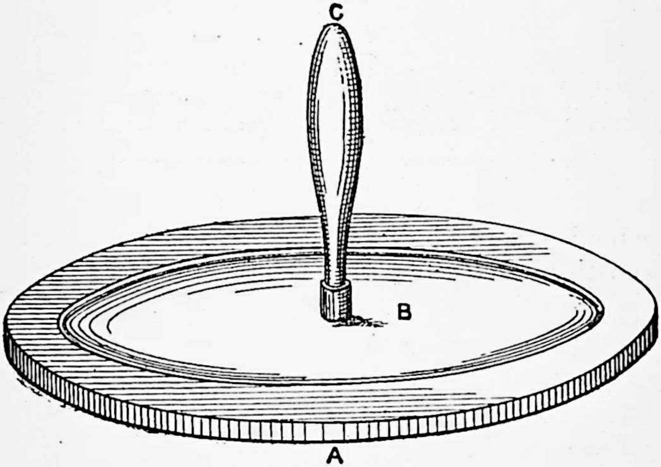


Fig. 33.

the cake without coming into contact with any conductor. To use this instrument the cake, A, is rubbed or beaten with a piece of dry warm flannel or fur,[1] so as to excite it negatively. Now it must be remembered that the cake is an insulator, and therefore does not part with its charge by

[1] A dry living cat rubbed over the surface while being held by her four paws will be found very efficacious in exciting the electrophorus.

simple contact, therefore if the cover be now placed on, holding the cover by the handle, C, the cake influences it

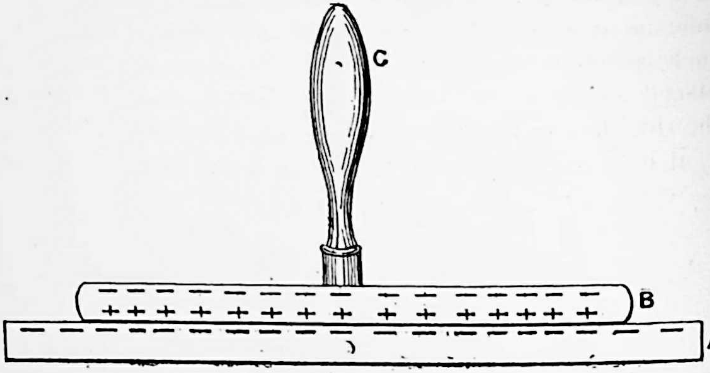


Fig. 34.

by induction, as is shown at Fig. 34, in which it will be noticed that the lower portion of the shield has become

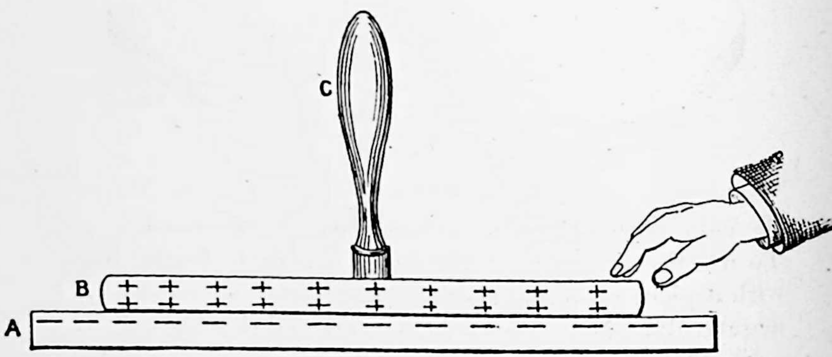


Fig. 35.

entirely + while the upper surface is entirely —. If now the shield be touched with the finger as at Fig. 35, the

— condition of the upper portion of the shield is communicated to the hand, and the whole shield becomes +. On removing the shield by raising it by means of its handle, as shown at Fig. 36, it will be found charged + and capable of giving a spark, or otherwise communicating its electricity to conducting bodies placed in contact with it. And since the cake or sole, owing to its

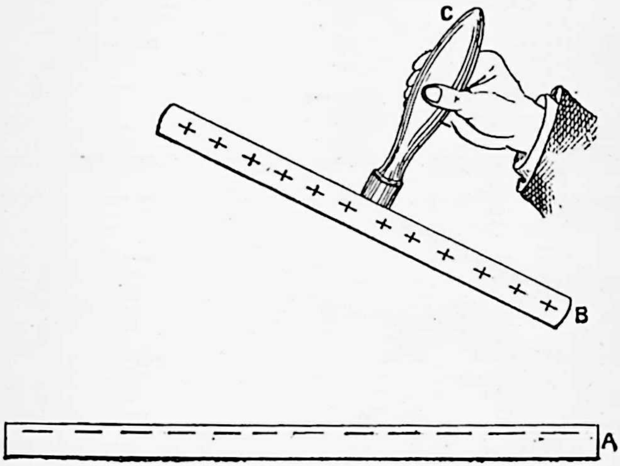


Fig. 36.

being a non-conductor, has lost none of its electricity in thus inducing electricity in the shield, the same cycle of operations may be performed for an indefinite number of times without any appreciable diminution in effect, so that the electrophorus is a very convenient instrument for the production of moderate electrical charges. The only precautions necessary in order to succeed in using this instrument are, that the surrounding air should be dry, the rubber, whether flannel, fur, or a cat, should be also dry and warm, and that the insulating handle, C, should be briskly rubbed before use in order to remove dust or moisture. It is also well to observe, in raising the shield from the sole, that the insulating handle should

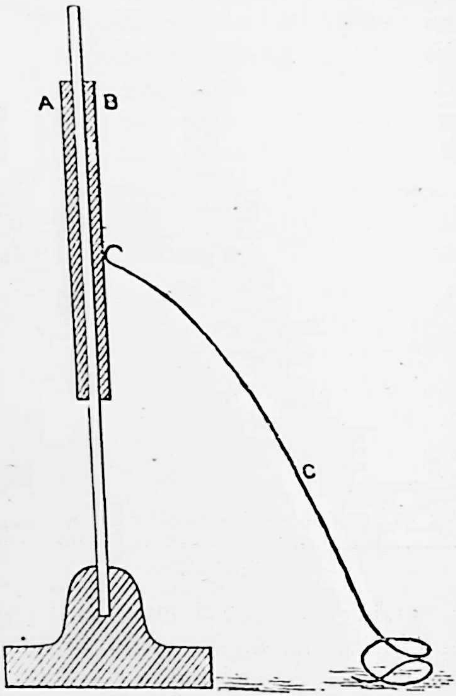


FIG. 37.

be grasped as far as convenient from the shield, in order that there may be no accidental transference of electricity from the shield to the hand, or to the sleeve of the operator. Owing to the attractive influence which the negative charge of the sole exerts on the positive charge of the shield, the most marked effects are obtained when the shield is raised to some considerable distance from the sole.

§ 40. This effect of induction, with its accompanying phenomenon of attraction between + and − charges, enables us to increase to a very great extent the charge which a given surface is capable of accumulating, by placing near it a similar surface in contact with the earth, or any other good conductor, but separated from the first surface by an insulator, such as air, glass, gutta-percha, vulcanite, paraffin, paper, etc. The name given to this arrangement is the "Condenser," the simplest form of which is delineated at Fig. 37.

It consists in two similar sheets of metal, say tinfoil, either square or circular, the form being of no particular moment, pasted one on each side of a sheet of glass which extends two or three inches beyond the tinfoil coatings all round, and is supported by a wooden foot. If now the coating, B, be placed in contact with the earth or any other conductor, by allowing a piece of wire, C, to rest against it, and the coating, A, be charged by means of a number of sparks imparted to it successively from an electrophorus or other electrical machine, it will be found that the coating A will be able to take up a far greater charge (as measured by the number of sparks it can receive) when the coating B is thus earth-connected than when C is removed. If the wire, C, during this experiment be removed at a small distance, say one-quarter inch from the coating B, it will be noticed that for every spark given by the electrophorus to the coating A, a corresponding spark will pass from the coating B to the wire C. And, as we shall see farther on, it is just in consequence of the capability of getting rid of the antagonistic strain on the opposite surface that this increased capacity for electrical charge in the coating A, when the coating B is placed in contact with the earth or any other good conductor, depends. This particular form of condenser is known as the "Franklin plate" or "fulminating pane," the latter name being due to the fact that if the coating B be placed in electrical contact with the coating A, by means of a loop of wire, as shown at Fig. 38, or otherwise, a bright flash, accompanied by a detonating noise takes place, when the two coatings will be found to have returned to their primitive condition, or to use the technical term, to be *discharged.*

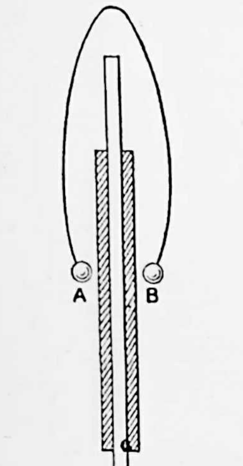


FIG. 38.

§ 41. This form of condenser is not the most convenient for general purposes, owing to the difficulty of holding and manipulating a flat glass plate. A modification of this instrument, known as the Leyden jar, from the place of its discovery,[1] is more usually employed. This, in an improved form is shown at Fig. 39, and consists in a wide-mouthed glass jar coated with tinfoil on

[1] Through the researches of Kleist, Cuneus, and Muschenbroeck.

its interior and exterior surfaces to within about two-thirds of its total height, with tin-foil; at the bottom of the jar (which is also covered inside and out with tin-foil) is glued a wooden disc, from the centre of which rises a brass rod carrying at its upper extremity a brass knob. This rod must penetrate through the wooden

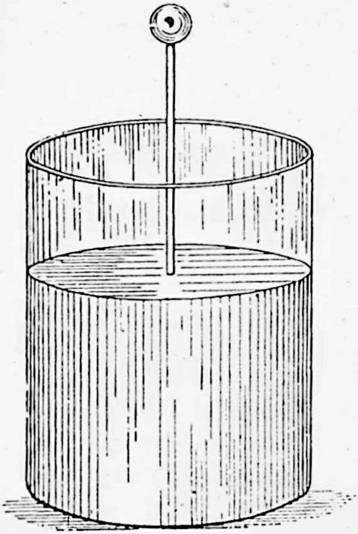


FIG. 39.

block, so as to make electrical contact with the inner coating of the jar, and should project above the rim of the jar at least one-third of its total height. It will be evident, on the most cursory observation, that the inner coating of the jar corresponds with the coating A in the fulminating pane shown at Fig. 37, and that the brass rod and ball are simply employed to enable the operator to charge the inner coating by placing it in contact with the electrophorus or other charged bodies, a feat which would be difficult were they not introduced. Owing to the ease with which the outer tinfoil coating can be grasped by the hand (itself a good conductor), without touching the uncoated glass surface, there is no necessity of employing a separate conductor or wire, as at C in Fig. 37, when charging a Leyden jar. With a jar thus

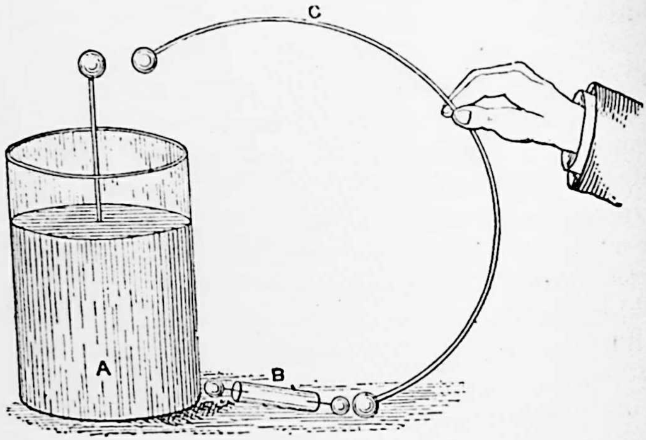


FIG. 40.

charged it is possible to produce many extraordinary effects; for instance, if by means of the bent wire illustrated at Fig. 38, which for the sake of preventing the dissipation of electricity should be made to terminate in round brass balls, connection be first made with the outer coating and then with the knob, a violent discharge will take place accompanied by light and heat; and if certain bodies be interposed in the line of discharge, they will undergo changes dependent upon the violent molecular motion set up by the discharge. For instance, if a small tube with a fine bore be filled with mercury or water, and two small wires be inserted one at each end, leaving some space between them, and the ends of the glass tube sealed, on passing the charge from the Leyden jar through the fluid contained in the tube, the commotion set up by the discharge will be so great as to shiver the tube. The mode of performing this experiment is illustrated at Fig. 40, wherein A represents the Leyden jar, B the tube, and C the discharging wire or rod. It will be noticed that in performing these experiments that the discharging wire or rod, C, must have one extremity first placed in electrical connection with the outer coating, and while it is in this position the other extremity must be quickly approached to the knob of the jar until it is within sparking distance, or as it is usually termed, striking distance. If a thin sheet of glass be held between the knob of the Leyden jar and the upper ball of the discharging rod, the discharge will fracture the glass if it be sufficiently thin, or the charge sufficiently powerful; and if, instead of glass, a stout piece of cardboard be held between the knob of the charged jar and that of the discharging rod, it will be found to have been perforated. So likewise if two wires be inserted into a piece of dry wood at its opposite extremities, reaching to about one-quarter inch of one another, and the discharge be effected as above described through the wood, the wood will be torn asunder. A very amusing modification of these experiments, in which the molecular motion and heat set up in air during the discharge is made to play a principal part, is that known as the electrical cannon. This is illustrated at our Fig. 41, and consists in a short cannon made of ivory, or any other fairly good insulator. Across the breach is a perforation through which are inserted two short wires reaching into the chamber of the cannon, but separated by an interval of about one-quarter inch; there is a little shoulder in the inside of the cannon to prevent the ball, which may be either of pith or cork, from reaching to the bottom of the breach. The ball, which should fit accurately, but without friction, having been inserted into the cannon,

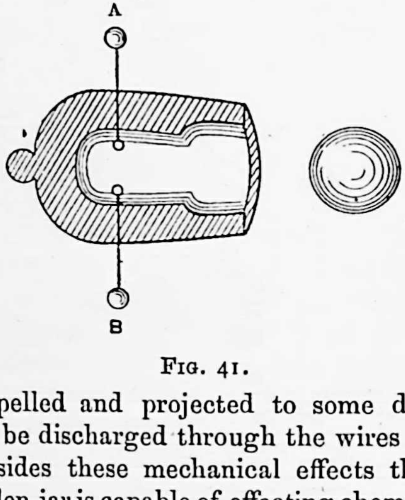


Fig. 41.

will be expelled and projected to some distance if a Leyden jar be discharged through the wires A and B.

§ 42. Besides these mechanical effects the discharge of the Leyden jar is capable of effecting chemical changes. For instance, a series of such discharges passed through moist air, especially in the presence of alkaline bodies such as potash, soda, lime, etc., bring about a union of the two elements contained in the air, namely, nitrogen and oxygen, with the production of nitric acid. In like manner a mixture of oxygen or atmospheric air with hydrogen is instantly fired and exploded by the passage of an electric spark or shock, water being the result of the union. On the other hand a series of discharges effects the decomposition of many solutions through which it is made to take place ; for instance, sulphate of copper dissolved in water and placed in an egg-cup with two copper strips plunging into the solution, facing but not touching one another, is split up into sulphuric acid on the one hand and copper on the other by repeated discharges from a large jar, the copper being deposited on that strip which is in contact with the negative coating of the Leyden jar, while the sulphuric acid attaches itself to that strip which is in connection with the positive coating. It may be stated as a general fact that the passage of an electrical discharge through a saline solution is accompanied by chemical decomposition.

In performing these experiments it is convenient to be able to place the bodies to be operated upon in the direct circuit of the discharge without having to hold them or to allow them to come into contact with any conducting body which might dissipate the charge. For this reason an appliance known as the Universal Discharger is frequently employed. It consists, as shown at Fig. 42, in a small ivory table, A, standing in the centre of a base, B, to which is attached a pillar, C, the stem of the table, A, being capable of sliding up or down in the said pillar, C, and set at any height therein, by means of the set screw, D. To the right and to the left of the central table are glass or ebonite pillars, E E, which support two straight brass rods, F F, capable of adjustment by means of ball and socket joints and thumb-screws, G G ; these two rods terminate in rings at H H, and in little balls at I I, these latter, however, can be removed so as to leave only the points at the extremities of the rods, if desired. To use this instrument the object to be operated upon is placed on the little table at A, and the two rods adjusted until their balls or points, I I, are within the striking distance (the distance at which the jar used is capable of bridging over during its discharge). By means of a chain or piece of wire one of the loops, H, is connected with the outer coating of the jar, the other loop, H, is then connected

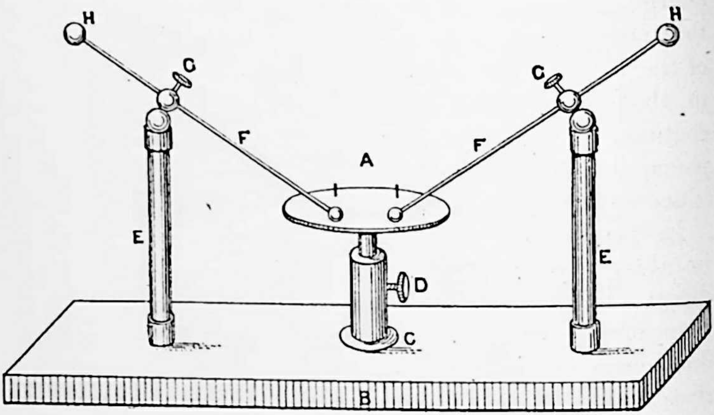


FIG. 42.

up to the knob of the jar by means of a bent wire terminating in knobs, as shown in Fig. 40C, or else by means of a jointed discharging rod with glass handle, as shown at Fig. 43. On an universal discharger similar to the above, spirits of wine, ether, or benzole, may be inflamed by causing the discharge to take place through these bodies and the air. In like manner gunpowder may be fired, and cotton-wool dipped in powdered resin may be inflamed.[1]

[1] If gunpowder has to be fired, it will be necessary to insert a few

It will not be surprising that the discharge of the Leyden jar, or any other form of condenser, through the human body should be accompanied by sensations which are more painful as the discharges increase in power. To quote Doctor Roget's words, "It is unnecessary to describe the sensations excited in the body by receiving electric sparks or shocks, since most persons in the present day are familiar with them. It is curious, however, to

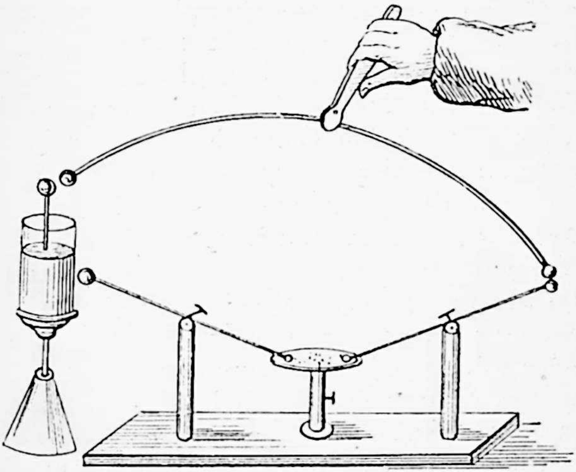


FIG. 43.

take a retrospective view of the mode in which the effects of the Leyden jar were announced to the world on their first discovery. The philosophers who first experienced in their own person the shock attendant on the transmission of electrical discharge, were so impressed with

inches of damp string in the circuit, which by increasing the resistance will increase the heating effect, and also prevent the gunpowder from being scattered by the discharge.

wonder and with terror by this novel sensation, that they wrote the most ridiculous and exaggerated accounts of their feelings on the occasion. Muschenbroeck states that he received so dreadful a concussion in his arms, shoulder, and heart, that he lost his breath, that it was two days before he could recover from its effects, and he declared also that he should not be induced to take another shock for the whole kingdom of France. M. Allemand reports that the shock deprived him of breath for some minutes, and afterwards produced so acute a pain along his right arm that he was apprehensive it might be attended with serious consequences. Mr. Winkler informs us that it threw his whole body into convulsions, and excited such a ferment in his blood as would have thrown him into a fever but for the timely employment of febrifuge remedies. He states that at another time it produced copious bleeding at the nose; the same effect was produced also upon his lady, who was rendered also incapable of walking." By inclosing a portion of the diaphragm in the circuit of the discharge, a large jar will cause the patient to emit a loud and involuntary shout; but if the charge be only small, a fit of convulsive laughter only is induced. With charges sufficiently powerful life may be extinguished; and it is a peculiar fact that the blood does not quickly coagulate after death from this cause, while, on the other hand, putrefaction sets in more rapidly.

§ 43. It is evident, on consideration of the electrophorus (§ 39), that if the shield could be made continuously moving away from the sole and as continuously returning to it when it had given up its induced charge, we should be in possession of a very convenient form of induction machine. There are in point of fact several such. The first constructed was Volta's own form, which he used for firing an issuing jet of hydrogen gas which formed part of a novel lamp. The illustration given at Fig. 44 represents the electrophorus only, as the other portion has no present practical interest. A is a sheet of resin melted into a metal tray which bears two curved rods, B B′, which serve as hinges on which turn two other insulating rods, C C′,

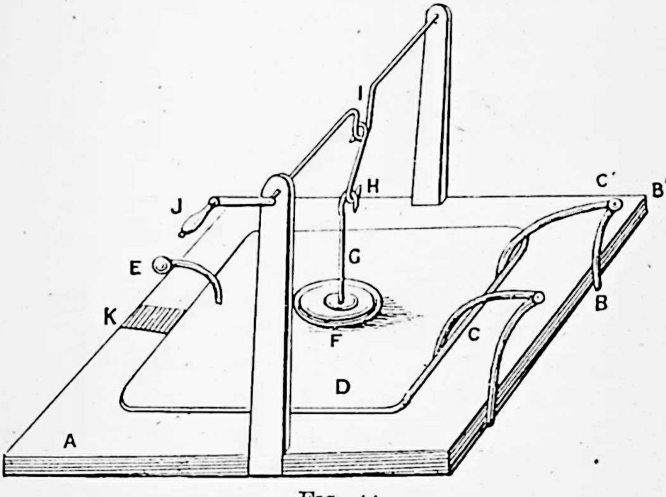


Fig. 44.

attached to the shield, D. At E is a brass rod and ball from which the spark can be taken. At F there is a boss of sealing-wax (which is a good insulator) from which rises a non-conducting rod, G, furnished with a hook at H that connects with a cranked arm, I, which can be rotated by means of the winch, J. A strip of tinfoil, K, reaches from the tray, A, to the shield, and this serves instead of a finger to touch the shield when it is lowered upon the surface of A. Owing to the fact that the distance between the sole, A, and the shield, D, can never be very great, the charge which can be given by this form of electrophorus is not large.

§ 44. There is another modification, known as the Bertsch machine, in which we have, as shown at Fig. 45, an insulating disc, A, made of glass or ebonite, capable of being

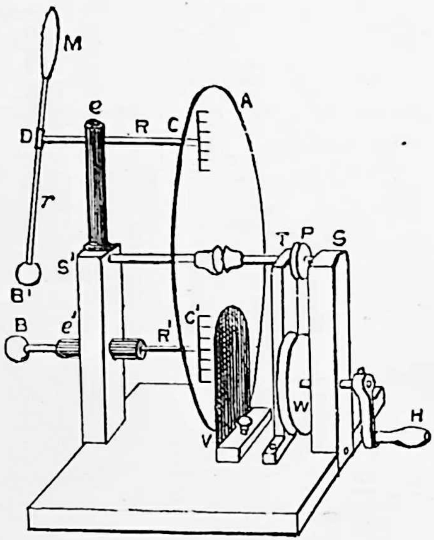


FIG. 45.

rotated on its axis by means of a driving-wheel, W, and a pulley, P. On one side of the rotating plate is a small piece of ebonite which can be placed close to and parallel with the rotating disc, and which, for this purpose, is fixed to a little wooden base, as shown at V, which in its turn can be screwed down upon or removed from the general base board of the machine by means of a small thumbscrew. Exactly opposite this ebonite *sector*, but on the other side of the rotating plate, is a metal comb, C′, supported at its centre by a brass rod, R′, which passes through an insulating collar, E′, and terminates in a brass ball at B. On the same side of the plate, but at a point diametrically opposite of its circumference, is another metal comb, C, supported by its rod, R, which traverses the insulator, E, and carries the sliding conductor, D R, terminating at one extremity in the ball, B′, and at the other by the insulating handle, M. To use this instrument the ebonite sector, V, is removed from the stand and excited by rubbing. It is found to be charged strongly resinously, or —, it is then replaced in its position before the glass plate. By induction it acts on the comb, C, drawing towards itself a + charge or strain which passes on to that portion of the glass plate which comes directly between it and the points during the rotation. The glass being a non-conductor cannot transmit the strain or charge to the other side, but each portion in passing before the comb becomes thus charged positively and carries its charge forward, leaving the comb, C′, in a negative condition. When each successive portion of the glass thus charged positively from the comb, C′, arrives before the comb, C, it parts with its + charge to the comb, C, in precisely the same manner as the electrophorus figured at 36 parts with its charge when raised from the sole towards the conductor; and if the balls, B and B′, be brought sufficiently close, an almost continuous spark, arising from the equalization of the strain between the + charged ball, B′, and the — charged ball, B, will take place on rotating the handle, H. The principal disadvantage connected with the Bertsch machine is the difficulty with which it is made to act in damp weather. This may be partly overcome by employing, instead of the fixed sector, V, in the last figure, a small rubbed disc, N N, Fig. 46, precisely similar in function, though proportionally smaller, to the glass disc in the ordinary plate machine illustrated at Fig. 30. This

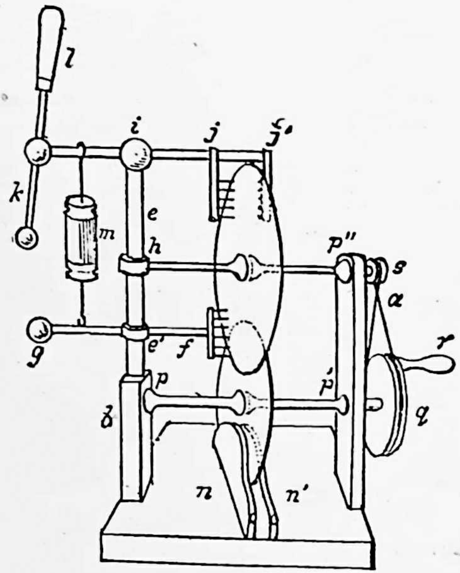


FIG. 46.

arrangement is known as the Carré electrical machine, and is well illustrated in our Fig. 46, in which P P′ is the spindle bearing the inducing plate, H and P″ that bearing the induced plate. As these must rotate in opposite directions, the driving-wheel, Q, and the driven pulley, S, are connected by a crossed band, A. The lower comb, F, acts as the finger which touches the plate of the electrophorus, at Fig. 35, or the strip of tinfoil at K, Fig. 44, while the combs, J J′, are the collectors acting like the knob at Fig. 36.

§ 45. Beautiful as this machine is, both it and the

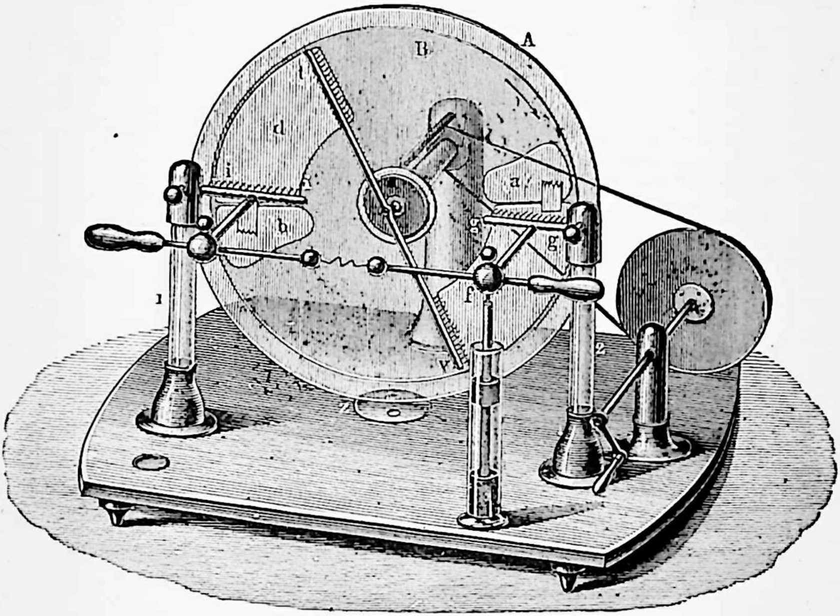


FIG. 47.

cognate Holtz machine, which is illustrated at Fig. 47, are far eclipsed in simplicity of design, in efficiency in action, and in non-susceptibility to atmospheric influences by the Wimshurst machine, of which we present our readers with an illustration at Fig. 48. This consists in two discs of glass capable of being rotated in opposite directions by

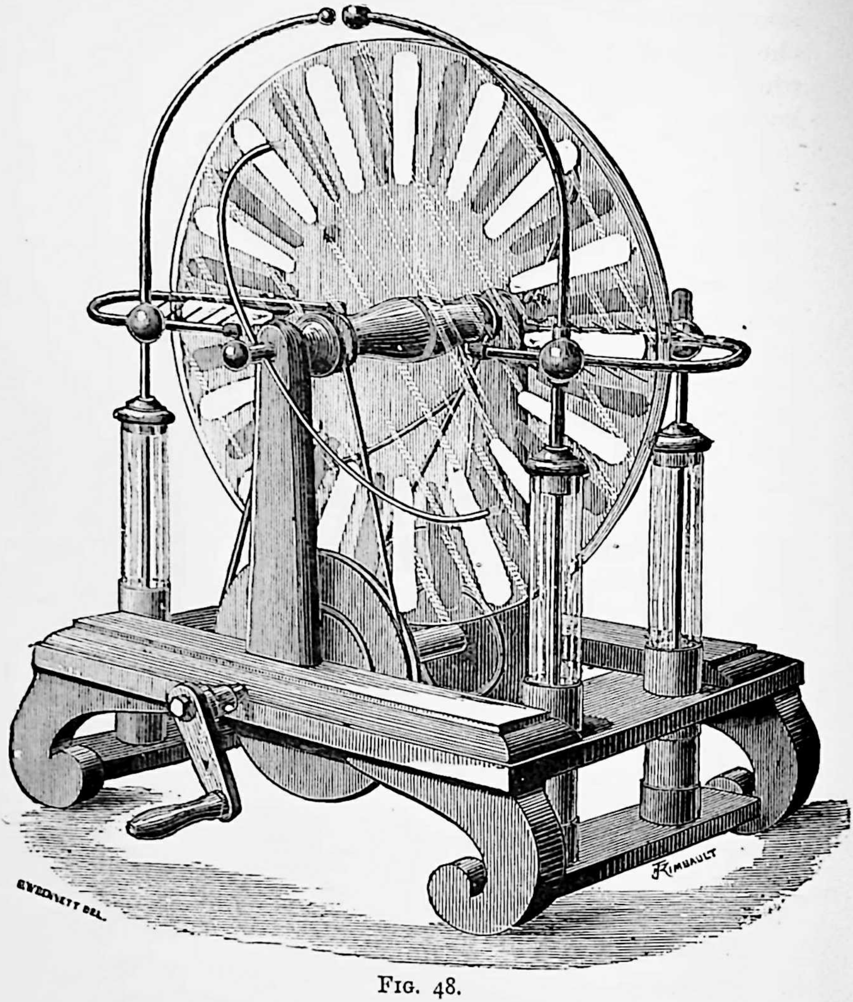


Fig. 48.

means of two driving-wheels on the lower spindle which actuate two bands, the front one uncrossed, the back one crossed. As the two glass discs, though running on the same spindle, are mounted on two different and independent tubes, they rotate in opposite directions. Around the circumference on the outsides of these discs are arranged narrow sectors of tinfoil, varying in number from 16 to 40, according to whether long large sparks or small rapid discharges are the desiderata. Acting as the touching finger in the electrophorus are two bent brass rods furnished with little sweeping brushes of very fine metal wire at each extremity, one of which rods just touches the surfaces of each plate at two points of its circumference at the same position as that at which the clock hands stand at 5 minutes to 5. On the horizontal line there is a comb arrangement, which embraces both plates, and which collects on to the prime conductors the electricity set up by the inductive influence of the plates on one another. On rotating the handle the little brushes sweep along the surfaces of the rotating glass and thereby set up a minute charge on the outer surfaces of the glass, and this acts inductively on the tinfoil sector which happens to be opposite to it on the other plate when it passes under the brush on the other side, and this in its turn induces electricity of opposite kind, on all the sectors on the opposite plate until it reaches the comb towards which it is travelling, when it gives up its charge to the comb, thereby becoming itself neutral and ready to undergo the same cycle of changes while passing under the influence of the lower brush. In the above sketch we have only followed one tinfoil sector, but it must be borne in mind that during one revolution, each tinfoil sector becomes induced, and in its turn induces electricity on the sectors opposite, so that the cumulative effect in one revolution of the glass plates is very great, indeed, with plates having forty or more sectors the slightest rotation elicits a perfect torrent of electricity.

§ 46. In the experiments previously described no particular mention has been made of the relation there is between the shape of a body and the condition of the charge at its surface. It is found that the tendency which electricity has to dissipate itself from any part of the surface of a charged body depends, to a great extent, on the distance of that part from the centre of mass of the body. If we agree to designate this tendency to escape by the term *electrical density*, or tension, we may state the same idea in other words by saying that points on the surface of a body which are at equal distances from the centre, will have the same electric density, those which are farther from the centre will have greater, while those which are nearer to the centre will have less density, tension, or charge. That this is actually the case can be verified by touching different points of a charged surface with a proof plane, and measuring the relative amounts of charges picked up at the different portions of the surface by means of a Coulomb's torsion balance, described at § 32. By this means we are able to show that in a charged sphere (standing in the centre of a room) the density of charge is sensibly equal at all points of its circumference; that in an oblate spheroid, or cylinder with rounded ends, the charge is less at its minor axis and greater at its major axis; that in a cube the right angles are the points of highest density, while in an elongated body terminating in a point, the density increases as the

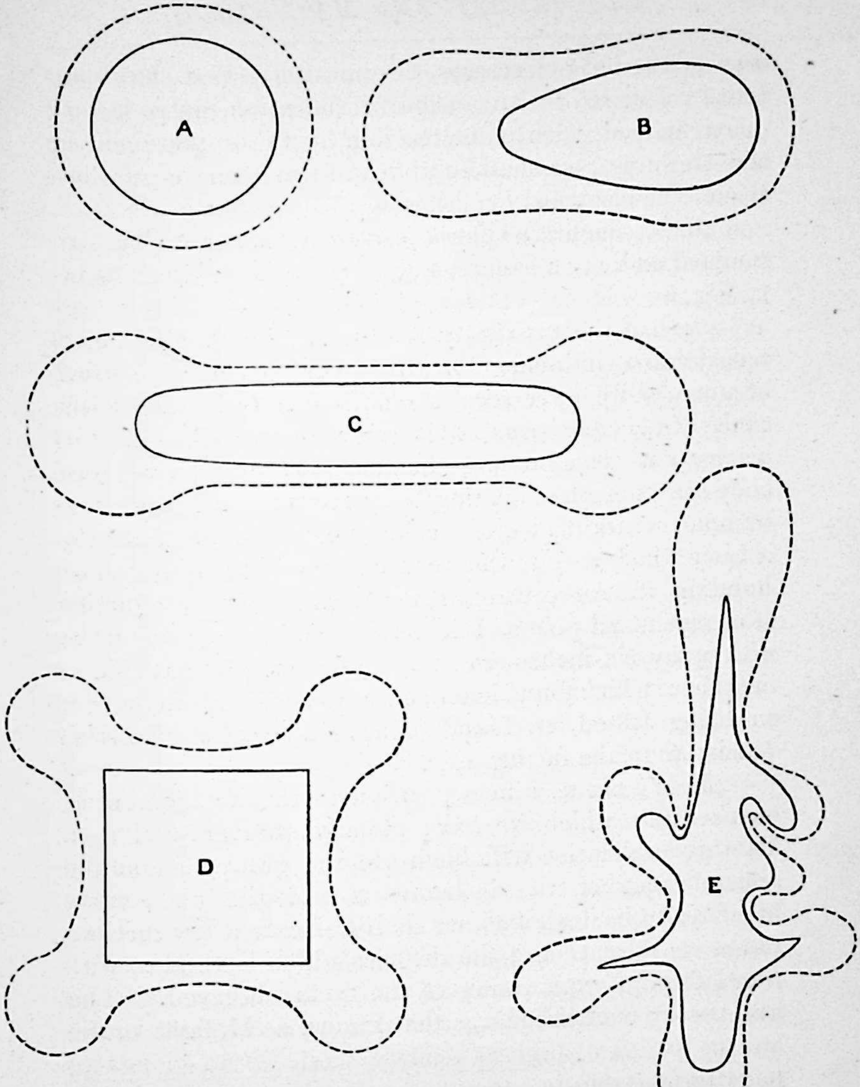


FIG. 49.

mass of the body decreases, becoming greatest at the extreme point. If, for the sake of illustration, we represent this density, or charge, or tension, by the space inclosed in dotted lines, we shall be able to form a fairly accurate idea of the electrical condition of charged bodies of different shapes, such as a sphere, A, an oval, B, a cylinder with rounded ends, C, a square, D, an irregularly shaped body, E, Fig. 49.

§ 47. But the proximity of surrounding bodies has a considerable influence on this distribution of charge, because, as we have seen, a charged body induces electricity in bodies near to it with a strength which is inversely as the square of the distance, and the induced body reacts on the inducing body and produces a greater tension or strain at the surface nearer to itself of the inducing body. For this reason, if a sphere, which when standing in the centre of the room showed equality of charge at all points of its surface, were approached to within, say, six inches of one wall of the room, that side of the sphere which found itself nearer to the said wall, would, on being tested, be found to have a greater electrical density than the farther side.

§ 48. We are now in a position to theorize somewhat on the facts which we have already studied, and as a little generalization will facilitate the grouping and the remembrance of the instruments and the phenomena hereafter to be described, we shall dedicate a few sections to the consideration of the theories which have been proposed for the explanation of the facts observed.[1] The first theory enunciated was that known as Dufay's, or the

[1] The following *résumés* of the two theories are condensed from Roget's "Electricity and Magnetism."

double fluid theory, and this supposed that electricity consisted in two fluids precisely similar in all their effects but one, and that these two fluids pervaded the earth and all other material bodies, being themselves devoid of any weight, and capable of moving with various degrees of facility through the pores or actual substance of different kinds of matter ; in some, as in those we call conductors or non-electrics, such as the metals, they move without any considerable obstruction ; but in glass, resin, and, in general, in all bodies called electrics or non-conductors, they move with great difficulty. These two fluids, which were designated vitreous and resinous electricity, have each when separate the same general properties, but in relation to each other there must be a complete contrariety in their natures, so that when combined together their actions on the bodies in their vicinity, or on the particles of electric fluid contained in those bodies are exactly balanced, and all visible action ceases. It is in this state of union, in which they perfectly neutralize one another, that they exist in bodies which may be said to be in their *natural state* with regard to electricity.

§ 49. Thus, then, may the problem be solved, in which it is required to conceive an agent, analogous, in many respects, to other known agents, and to assign to it such properties as will, in their results, correspond to all the observed phenomena. In order to apply to it this latter test we must trace all the consequences which flow from the suppositions we have made, and strictly compare them with the facts both as presented to us by nature and as resulting from experiment. These facts it will be recollected are reducible to the phenomena of excitation, attraction and repulsion, distribution, induction and transference.

§ 50. *Excitation.*—From various causes, of which the friction of surfaces is but one, the state of union in which the two electricities naturally exist in bodies, is disturbed; their latent powers are called forth by separation; the vitreous electricity is impelled in one direction, while the resinous is transferred to the opposite side, and each can now manifest its peculiar energies. When accumulated in any body, or part of a body, each fluid acts in proportion to its relative quantity, that is, to the quantity which is in excess of that which is still retained in a state of inactivity by its union with electricity of the opposite kind. Thus when glass is rubbed with metallic amalgam a portion only of the electricities at the two surfaces is decomposed; the vitreous electricity resulting from this decomposition attaches itself to the glass, the resinous to the amalgam. What remains in each surface undecomposed continues to be quite inert, and has no other influence on the phenomena than being ready, on the continuance of the decomposing action, to furnish a fresh supply of both fluids to the bodies in the vicinity.

§ 51. *Distribution.*—Each of these fluids being highly elastic their particles repel one another with a force which increases in proportion as the distance is less; and this force acts at all distances, and is not impeded by the interposition of bodies of any kind, provided they are not themselves in an active electrical state. The mode in which the electricity imparted to a conducting body, or to a system of conductors, is distributed among its different parts, is in exact conformity to the law experimentally found, that electrical attractions and repulsions are exerted with a force which is inversely as the square of the distance. The same observations hold good with regard to the attraction between these two contrary fluids.

§ 52. *Transference.*—Since the two electricities have this powerful attraction for each other they would always flow towards one another and coalesce were it not for the obstacles that are opposed to their motion by the non-conducting properties of electrics. When these obstacles are overcome, and a channel more or less free is open for the passage of the electricities, they rush into union with great force and velocity, producing in their transit and confluence several remarkable effects. After their coalescence their power seems to be at once annihilated, or, more properly speaking, it remains dormant until called into play by the renewed separation of the fluids.

§ 53. *Attraction and Repulsion.*—The repulsion which is observed to take place between bodies that are insulated and charged with any one species of electricity for other bodies similarly charged, is derived from the repulsive power which the particles of this fluid exert towards those of their own species. Let us suppose a body charged with electricity to be suspended in the air, or otherwise surrounded by a non-conducting medium, which allows it to move freely. As long as this body remains alone, the outward pressure which the electric fluid exerts against the insulating medium that confines it, will, by the laws of hydrostatics, be equal on all sides; and the body, thus balanced by equal and opposite pressures, will have no tendency to move. But if another body similarly circumstanced be brought near it, the repulsive action between the similar electricities contained in these bodies will diminish the outward pressure of each fluid against the sides of the bodies (*b*, *c*, Fig. 50) which are adjacent to each other; and it will, at the same time, increase the outward pressure on the opposite or remoter sides (*a*, *d*). Both these causes conspire to destroy the equilibrium; each body is impelled in the direction of the preponderating force, that is, in a direction from the other body, and an effect which may be called repulsion takes place. The very same explanation, it is evident, applies to both kinds of electricity, their properties being in this respect exactly alike. If, on the other hand, a body charged with vitreous electricity be presented to one that is charged with resinous electricity, the attraction of these two fluids will diminish the outward pressure on the remote sides of the bodies, and in-

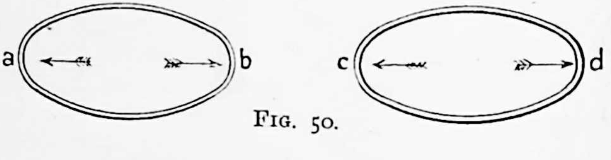


FIG. 50.

crease it on the adjacent sides; hence the bodies will be urged towards each other, and motions indicative of attraction will result. Thus, in all cases, do the movements of the bodies represent the forces themselves which actuate the particles of the developed electricities they contain.

§ 54. *Induction.*—The law of induction is a direct consequence of the hypothesis we are considering. Wherever one of the electricities exists in an active state it must repel the particles of the same electricity in all surrounding bodies and attract those of the opposite species, or in other words, it tends to decompose their united electricities, accumulating the electricity of the opposite species towards the nearest side, and impelling that of the same species towards the remote side. The body thus acted upon is no longer neutral, although it contains, on the whole, its natural quantities of both electricities ; but, in consequence of their partial distribution, electrical appearances will be exhibited in its different parts. The further prosecution of this branch of the subject must be postponed to a subsequent chapter, our present object being merely to point out, in a general way, the coincidence of the fundamental facts with the proposed theory.

§ 55. The next theory proposed was the *single fluid*, due to Franklin and to Watson, and perfected by Æpinus and Cavendish. According to this theory we set out, then, with supposing that there exists in all bodies a subtle fluid, which we shall call the *electric fluid;* that its particles repel one another with a force varying inversely as the square of the distance ; that they attract the particles of all other matter, or some specific ingredient in that matter, with a force following the same law of the inverse square of the distance ; that this fluid is dispersed through the pores of bodies, and from some unknown peculiarity can move through them with various degrees of facility, according as they are conductors or non-conductors. Bodies are said to be in their natural state with regard to electricity when the repulsion of the fluid they contain for a particle of fluid at a distance is exactly balanced by the attraction of the matter in the body for the same particle. In this state they may be considered as *saturated* with the electric fluid. Whenever they contain a quantity of fluid greater than this they are said to be *positively electrified*, or to have *positive* *electricity*. When, on the other hand, there is a quantity less than that required for saturation, the body is said to be *negatively electrified*, or to have *negative electricity*. In the former case it is the fluid that is redundant, or in excess; in the latter it is the matter which is left unsaturated that should be considered as the redundant principle. The state of positive electricity, then, consists in a redundance of fluid, or in matter that is *over-saturated*, as it has been termed; that of negative electricity, in a deficiency of fluid, or in matter *under-saturated*, or, what is an equivalent expression, in *redundant matter*. In mathematical language the former condition may be expressed by the sign *plus*, the latter by that of *minus*. In considering the mutual electrical actions of bodies, the portions in which the matter and the fluid mutually saturate each other need not be taken into account, since their actions, as we have seen, are perfectly neutralized, and we need only attend to those of the redundant fluid and the redundant matter.

§ 56. When a body contains more than its natural proportion of electric fluid, the surplus will, by the repulsive tendency of its particles, overflow and escape, if such escape be allowed, until the body is reduced to its neutral state. When under-saturated, the redundant matter will attract fluid from all quarters from which it can receive it until it is again brought to its neutral state. This efflux, or influx, is prevented either when the body is surrounded on all sides by substances through the pores of which the fluid cannot pass, or when the body itself is of that nature.

§ 57. The mutual recession of two positively electrified bodies is a direct consequence of the repulsion of the redundant fluids contained in each, which, being attached to the matter by their attraction for it, impel it in the direction of their own repulsion. In the same way the mutual approximation of two bodies in opposite electrical states is the immediate effect of the attraction of the redundant fluid in the one for the redundant matter in the other ; and *vice versâ*, for this attraction is mutual.

§ 58. A difficulty does, indeed, occur when we attempt to apply the theory to the case of two bodies which are both in a state of negative electricity, that is, in which there exists in both certain quantities of matter unsaturated with electric fluid. What action does the theory, as hitherto stated, point out as the result in this particular case? Plainly none. All those portions of the matter of each body which are still saturated, together with the fluid which saturates them, can have, as we have already seen, no effect either of attraction or repulsion. The only active element is the unsaturated matter, but the hypothesis does not assign any action of this matter upon other matter at a distance. Yet we learn from experience that the bodies, under these circumstances, actually repel one another. In order, therefore, to render the hypothesis conformable to fact we are obliged to annex to it another condition; namely, that the particles of simple matter, that is, of matter uncombined with the electric fluid, exert a repulsive action on one another. It is singular that so acute a mind as that of Franklin should not have discerned this defect in his own theory, or perceived that this further condition was absolutely requisite for the explanation of the phenomena. Without it, indeed, we should be unable to explain the want of action between two neutral bodies ; for the repulsion of the fluids in both bodies being balanced by the attraction of the fluid in the one for the matter in the other, the remaining attraction of the fluid in the second body for the matter in the first would be uncompensated by any repulsion, and the forces would not be held in equilibrium, as we find they really are.

§ 59. The law of electrical induction is an immediate consequence of the Franklinian theory. When a body charged with electricity is presented to a neutral body, the redundant fluid of the former exerts a repulsive action on the fluid in the latter body, and if this happens to be a conductor it impels a certain portion of that fluid to the remote end of this body, which becomes at that part positively electrified, while its nearer end, which the same fluid has quitted, is consequently in the state of negative electricity. If the first body had been negatively electrified, its unsaturated matter would have exerted an attractive force on the fluid in the second body, and would have drawn it nearer to itself, producing an accumulation or redundance of fluid at the adjacent end, and a corresponding deficiency at the remote end; that is, the former would have been rendered positive and the latter negative. All this is exactly conformable to observation.

§ 60. The phenomena of transference are easily explicable on this hypothesis, and they arise from the destruction of the equilibrium of forces which confined the fluid to a particular situation or mode of distribution.

§ 61. The modern theory of electricity, generally known as the *molecular* or *mechanical* theory, considers the phenomena which we have classed under the heading of electricity as being due to motion in the molecules of matter, similar in kind, but differing perhaps in direction, in amplitude, and rapidity to those which we know as sound, heat, and light. The fundamental idea is that during *excitation*, whether by friction, percussion, chemical action, or motion before the poles of a magnet, the normal condition of a body is altered, its molecules are set in motion, probably rotary, with the axes of rotation all in one direction, or "polarized," and this motion produces a kind of strain between molecule and molecule, in one direction in the excited body, and in the opposite direction

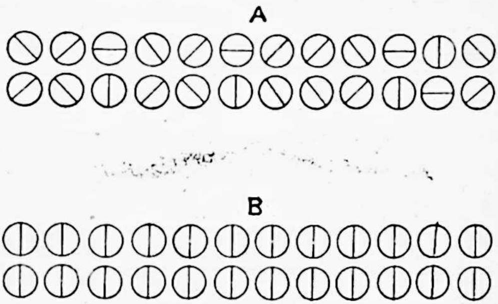


FIG. 51.

in the exciting body. This is shown in Fig. 51, where A represents the normal, or unpolarized, arrangement of the molecules; while B shows the strained or polarized condition which we know as "electrified." The phenomena of *conduction* is simply the facility possessed by good conductors, of their molecules reverting to their normal, unstrained, or unpolarized position. A non-conductor, on the other hand, is evidently a body, the molecules of which do not easily transmit or relieve themselves of the strain put upon them, and we can illustrate roughly, but with sufficient accuracy to convey a clear idea of the difference between the mode in which a conductor and a non-conductor act with reference to their power of transmitting this molecular strain, by slinging a dozen marbles in a row, suspended by threads fastened by sealing-wax to one point, as shown at Fig. 52. On raising one of the marbles, say A, and allowing it to fall against B, the strain imparted to this latter is rapidly transmitted along the line of marbles without causing them to enter into perceptible motion until it reaches L, which finding no farther resistance whatever, flies off until its force is overcome by the counteracting force of

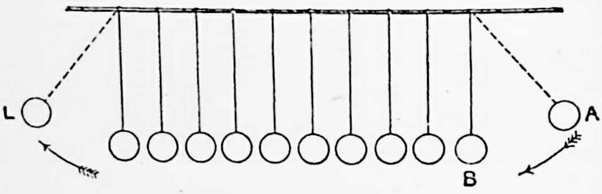


FIG. 52.

gravity and the resistance of the atmosphere. This condition of things illustrates fairly well the action of the strain, which we call electricity, on the molecules of a conductor, without, however, showing the rotary motion which is probably the cause of the strain. We may figure to ourselves the action in a non-conductor by replacing the marbles in the last experiment by a similar number of like pellets of *moist clay*. Here, owing to the plasticity of the material, the molecular movement is not transmitted from pellet to pellet so freely as in the case of the hard marbles, but is expended in performing other work, such as lateral dilatation, etc. But, in the same way, as we have no bodies that are so perfectly elastic as to transmit without loss the strain imparted at one end of a chain of marbles to the other, so in electricity we have no chain of molecules which transmits perfectly, and without internal loss in energy by conversion into some other form of motion, such as heat, etc., hence we have no perfect conductor: in like manner, as there is no body so perfectly inelastic as not to transmit some of the motion imparted to it to the adjoining pellets or marbles forming the chain, so there is no known body, the molecules of which, if submitted to sufficient strain, will not transmit this strain to neighbouring bodies with greater or lesser facility.

§ 62. From this it becomes evident that on rubbing or otherwise exciting a conductor, the strain set up on its surface is immediately dissipated in consequence of the facility with which it transmits the strain to those molecules in a less strained condition. If we agree to call the motion or strain when it exceeds the normal by the name of *positive*, and that motion which is less than the normal by the name of *negative*, we can readily locate the two forms of "polarized" motion which we call electricity by considering that in a rough rubber acting on a smoother surface, the greater strain will be set up on the surface of the smooth body, which will, therefore, be positive to the other. Be it noted particularly that this view of electricity leads us to consider it as simply an arrested form of mechanical motion, which instead of displaying itself in actual movement of the mass translates itself into rotary polarized motion of the molecules, or condition of strain. Now since all bodies are more or less capable of taking up that condition of strain, though not all are equally capable of retaining or transmitting the strain, it follows that all bodies are capable of excitation if motion, or a tendency to motion, be imparted to them and then arrested. This explains the excitation by friction and by percussion, the excitation by change of temperature such, for example, as is obtained by casting melted sulphur in a wine-glass, with a stick for a handle with which to withdraw it when cold. Here the sulphur will be found negatively electrified, while the glass remains positively electrified. Also the motion set up by the action of acids on metals translates itself into the molecular motion (electricity both in the remaining metal and in the fluid), and lastly the constrained and contrary motion imparted to masses of iron or metal moved before the poles of magnets sets up molecular motion in the iron or metal.

§ 63. But the strain once set up always tends to equilibrate itself, and the consequence is that even when surrounded by a good insulator a charged body sets up a strain in the particles of that insulator, though the latter may not be capable of transmitting or releasing the strain, or, in other words, of allowing the molecules which are now rotating in a set position, or "polarized," to fall back into their normal state. This effect of taking up the strained condition in obedience to the strain existing in any molecule, or chain of molecules, is called *polarization*, and invariably accompanies the production of a strain in any imperfect conductor or good insulator. So great is the tendency of this strain to equilibrate itself that a charged body will always tend to move towards any body which is in a less strained (less charged) condition than itself. This explains the phenomena of *attrac-*

tion, which is simply the strained condition of the charged body polarizing the atmosphere between it and the nearest body, and thus producing an opposite strain in the nearer surface, followed by mutual attraction of the two surfaces in conditions of opposite strain.

§ 64. It will be evident that the phenomena of apparent *repulsion* exhibited between two bodies electrified similarly (that is to say, strained to an equal degree) must be simply the result of their inability to get rid of their strain, the one to the other, and consequently their attraction of the nearer sides of the room or surrounding bodies. And, in point of fact, so true is this, that we can cause a pair of similarly charged pith balls to stand at almost any position with regard to one another provided we present to them, in different positions, masses of conducting surfaces. For this reason also little pieces of pith or paper placed between a charged disc and a sheet of insulating material are attracted towards the charged body, take up a portion of its strain and then fly back to the other surface, which being incapable of taking up the strain, or at least of passing it on, cannot discharge or equilibrate the strain imparted to the pieces of pith or paper by the charged body, leaving them (*id est*, the pith or the paper) charged similarly, that is, strained to the same extent as the original charged body. Consequently, after this apparent repulsion, there is no tendency on the part of the charged body to attract them again, since by so doing it could not pass on any of its molecular motion or strain. But if the same experiment be performed with the substitution of a conducting plate in the place of the insulating sheet, *then* the paper or pith, having been attracted by the charged disc, receives a portion of its molecular motion, and tends to impart this to the metal sheet below, which is in a state of less strain than itself. It therefore flies towards it, being apparently repelled by the charged disc, but in reality influenced solely by its tendency to pass on its molecular motion to the sheet below. Having

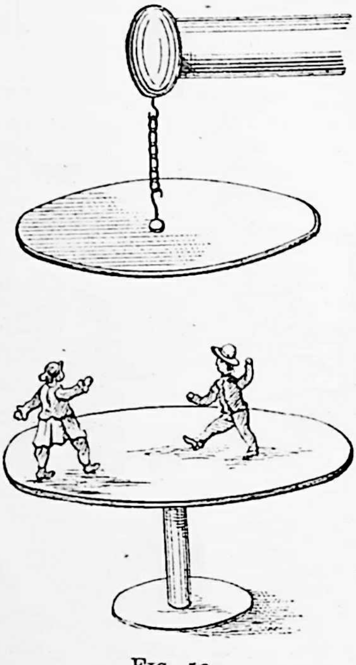


FIG. 53.

effected this, it is in a less strained condition than the upper disc, and is again ready to receive a fresh strain, it therefore flies to the charged body, again returns to give up its strain to the metallic sheet, and so on until the difference of strain between the upper and the lower bodies has been equalized. This experiment usually takes the form of an amusing toy, as illustrated at Fig. 53, where A is a charged disc hanging by a chain from the prime conductor in an electrical machine, and B a metal tray. Between the disc and the tray are placed light cork or pith figures, which being alternately attracted and repelled, simulate the actions of dancers very well.

§ 65. The phenomenon of induction is no less easily explained by this theory. A charged body, say, for example, a sphere, A, at Fig. 54, finds itself in a state of

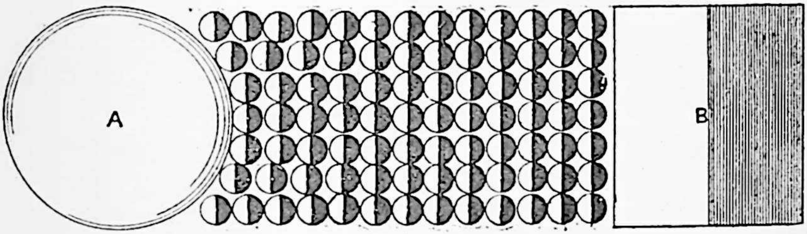


FIG. 54.

molecular motion, the strain is unable to pass and free itself through the air, but it sets up a strained condition in the molecules of the air lying between it and any other conductor, as indicated by the shaded halves of the spheres which represent the polarized molecules of the air. This strain in its turn communicates itself to the induced body, B, and if this is a conductor, the strain passes to that portion which is farther from the inducing body. Therefore, if the body, A, be in a state in which a greater number of molecules are in a condition of polarized motion than the surrounding bodies, or + electrified, it will set up through the intermediary of the air, or any other non-conductor (or *di-electric*, as the non-conducting substance lying between the inducer and the induced is called), a state of less strain or − in the surface nearer to itself, while there will be a state of greater polarized motion or strain at the surface farther from itself, of the body or bodies under its influence, if it or they be conductors. It must be borne in mind that when the body under the influence of a charged body is a non-conductor this effect of apparent separation into a + and a − condition is not evident, since, owing to the peculiar nature of the molecules of non-conducting bodies, these cannot transmit the motion from molecule to molecule, but simply set up a strained condition in the adjacent molecules without themselves losing their strain.

§ 66. If by any means, either by the nature of the body in which the molecular motion is set up being such as to permit of the relief of the strain by the molecules returning to their normal position, or by increasing the motion to such an extent as to render the reluctance of the molecules of the so-called non-conducting body to return to their normal position, unable to cope with the strain put upon them, then *conduction* or transference takes place and the strain relieves itself, or in other words, a discharge takes place along the line of least resistance. There are no bodies which can utterly resist the tendency to release themselves from the polarized molecular motion which we call electricity; and even the air, which is perhaps the best insulator we have, in other words, the body which best retains this molecular strain when imparted to it, will start into motion or "transmit electricity," provided sufficient strain be placed upon it. In some very beautiful experiments recently performed by Mr. Tesla, and repeated at the Crystal Palace Exhibition, 1892, by Messrs. Siemens on the one hand, and Messrs. Swinburne on the other, it has been shown that under the rapid and intense vibratory motion which can be set up by a pressure of from 50,000 to 130,000 volts,[1] the air between two conductors some six or eight inches apart, behaves itself like a conductor, and itself gives way under the enormous strain.

§ 67. Besides the instruments already described for the generation of electricity, there is one in which the mechanical disturbance set up by the rapid passage of steam, issuing from a narrow and constricted nozzle, gives rise to just that form of arrested motion (that is to say, arrested from motion of translation and converted into polarized molecular motion), which we designate electricity. In 1840 Mr. Seghill, an engine-man in charge of a boiler, noticed that on opening the safety-valve of his boiler, sparks frequently passed from the latter to his hand or other conductors in the vicinity. Mr. W. Armstrong, afterwards Sir William, had his attention directed to this peculiar phenomenon, and after some study was able to ascertain the circumstances which determined the production of these results, and perfected what is now known as Armstrong's hydro-electric machine. This is illustrated at Fig. 55, and consists in a boiler, A, supported on glass legs, B, B, B, B, and furnished with a row of nozzles, N, at its upper surface, through which steam can be blown at a pressure of between thirty and forty pounds to the square

[1] Volt, a measure of electromotive force, pressure, or strain.

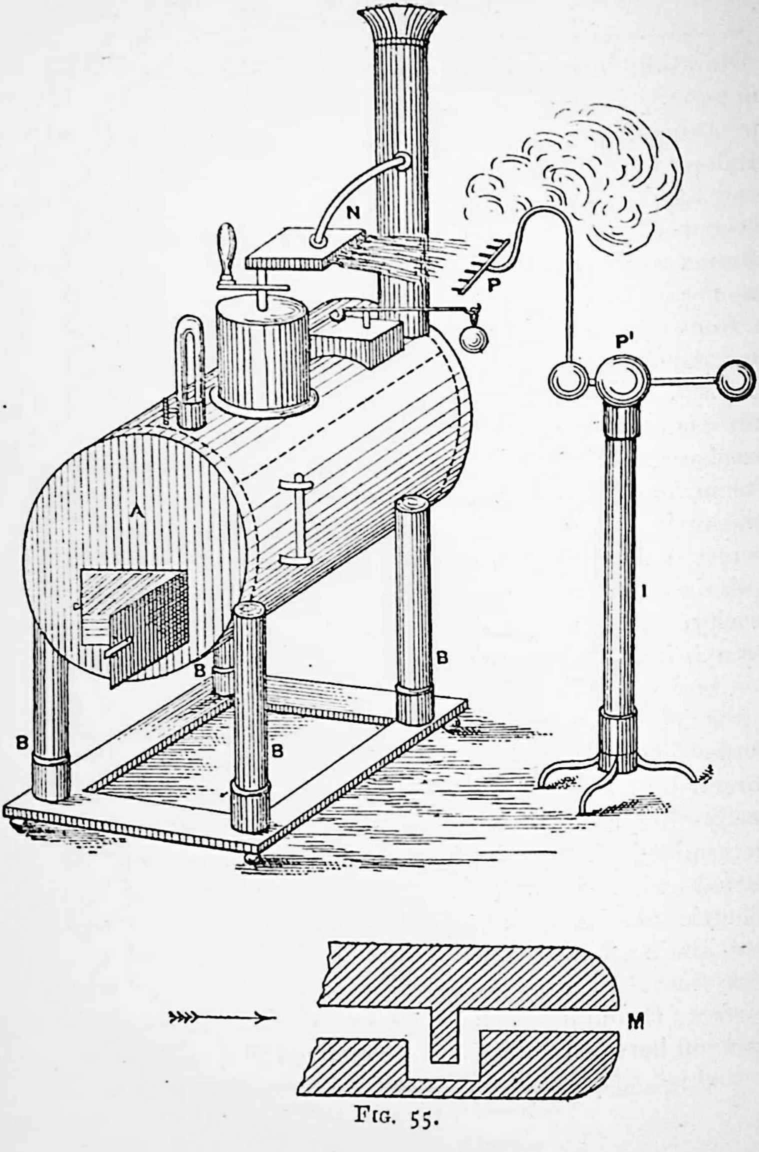


FIG. 55.

inch. The interior of the nozzles is so shaped (as shown on a larger scale at M) that the issuing steam meets with an obstacle as it escapes, and this appears to check its motion of translation, which becomes converted into electricity. Consequently the steam becomes positively electrified, and gives up its charge to a row of points connected to a metal cylinder and brass ball, P and P′, supported on an insulating stand, I, which can be placed in front of and near the issuing jet. It has been found that the slightest variation in the condition of the issuing steam is accompanied by a change in the direction of strain set up, or in other words, by a change of the electrical condition of the steam with respect to the boiler. For instance, if turpentine be added to the water in the boiler the boiler becomes positively electrified, while the issuing steam is negative. The production of electricity in this machine is entirely due to the friction of the condensing globules against the sides of the jet; and Faraday has been able to obtain similar results by employing a current of moist air.

§ 68. In all that we have hitherto considered, no attention has been given (with the exception of the cases of attraction and repulsion) to any quantitative results. Yet, since electricity is but a mechanical manifestation, it is evident that its effects can be measured and foretold precisely as is the case with any other mechanical agency. We have already seen that electrical attractions and repulsions are inversely as the square of the distances. We may add to this law and state that, the distance remaining the same, the force of attraction or of repulsion between two electrified bodies is directly as the product of the quantities of the electricity with which they are charged. When a given quantity of electricity is discharged through a body, heat is always set up in proportion to the resistance encountered. If the resistance remain the same, the heat disengaged in a given time is directly proportional to the square of the amount of electricity discharged through. Since electricity is but a modified form of motion, it is evident that only a determinate quantity of electricity can be evoked by the expenditure of a given amount of energy in producing this motion. With regard to the capacity of condensers or Leyden jars, and the length of spark or "striking distance" which these are capable of bridging over during discharge, it has been proved experimentally by Snow Harris and Riess that the striking distance is directly proportional to the quantity of electricity (extent of surface thrown into strain), and inversely proportional to the extent of coated surface, or in other words, the proportion of electrical density. Thus, in the case of a given surface of one jar being taken as unity, a battery of six such Leyden jars, charged by giving 100 turns of an electrical machine, would be capable of giving a spark, say, half an inch long; or in other words, would have a striking distance of half an inch, while a battery of four such jars, charged from the electrical machine with 120 turns, would have a striking distance of ·9 inch. Since:

$$\frac{100}{6} : \frac{1}{2} :: \frac{120}{4} : x = 16{\cdot}6 : 30 :: \frac{1}{2} = \frac{15}{16{\cdot}6} = {\cdot}9.$$

The law which regulates the amount of condensation or strain which can be set up while another conductor is in the proximity of the first plate or coating, may be expressed as.

$$\frac{1}{1 - m^2},$$

in which m is a fraction less than unity and which varies with the distance which the two plates are from each other, and the nature of the di-electric. In practice there are two functions which limit the condensing capacity of any condenser or Leyden jar, and these are,

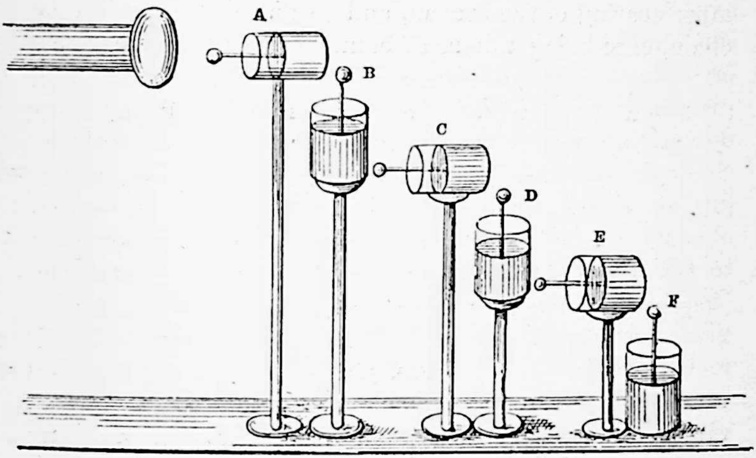


FIG. 56.

first, that the strain set up in the condensing plates becomes as great as that of the machine giving rise to the strain; and, secondly, the fact that under a given strain (which differs, of course, for each di-electric) the resistance to motion breaks down and the di-electric becomes perforated or otherwise ruptured, thus allowing the strain to pass away.

§ 69. Owing to the fact, as we have already seen at § 40, that for every increment of pressure imparted to the one coating of a condenser or Leyden jar, a corresponding pressure is produced by induction on the opposite coating, which pressure tends to transmit itself to other conductors placed in contact with this second coating, it is possible to charge a large number of Leyden jars at the same time by placing them *in series*, that is to say, with the outer coating of the first in contact with the inner coating of the second, and so on till the end of the chain, care being taken, of course, that every jar *except*

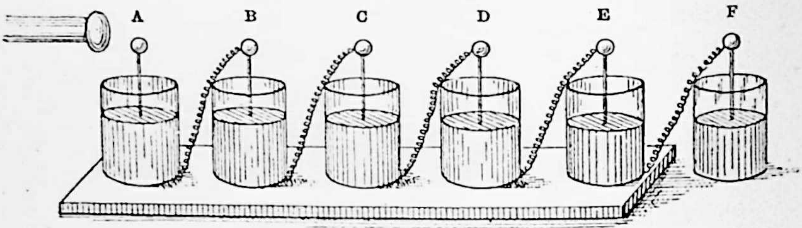


FIG. 56*a*.

the last should be insulated from the earth. This arrangement is known as the CASCADE arrangement, and is illustrated at Fig. 56 and 56*a*. If a spark be caused to enter at the knob of the jar, A, a corresponding spark of induced electricity passes from the outer coating of A to the knob of B, and this in its turn induces the outer coating and causes a spark to pass from the outer coating of B to the knob of C, and so on to the end of the chain until the last jar is reached, when the outer coating of this latter discharges the induced strain set up in it to earth or any other good conductor with which it may be in contact.

The whole series of jars may be fully charged by continuing the operation. The jars may be discharged either by leaving the arrangement in the position it was when charged and then connecting the outer coating of the last jar with the knob of the first, by means of a discharging rod (see Fig. 43), in which case the contrary effect takes place to that which took place in charging, namely, the strain of the inner coating of A relieves itself on to the outer coating of the last jar (which was in a — condition), the other surfaces falling back into their original unstrained condition on the relief of the strain of the two extreme surfaces. Or the jars may be placed one by one (beginning by the last jar) on a sheet of metal and their knobs being connected together by another sheet of metal, or by wires (not touched by the hands or any conductor), and then the discharging rod caused to connect up any one of the outer coatings with any one of the inner coatings or knobs. In this latter case the + strain existing in the inner coating of every jar relieves itself directly by equilibrating the — condition of the outer coatings. A moment's consideration will show that in this latter case the whole of the inner coatings are acting together as one large coating, while the whole of the outer coatings form but one large outer coating. There will evidently be, however, a difference in the mode in which the strain equalizes itself, as far as regards the effect which the discharge has upon the body through which the discharge takes place. In the former case the strain or motion imparted to the discharging rod at the moment of discharge is evidently only that of one extreme + surface passing on its strain to the other extreme or — surface, whereas in the second case the molecular strain or movement of the entire six inner coatings discharges itself through the rod, while equilibrating the — strain of the six outer coatings in their entirety. In the older form of speech these results were known as "tension" and "quantity" effects; and, to a certain extent, the terms may be used with convenience if only we bear in mind that by "quan-

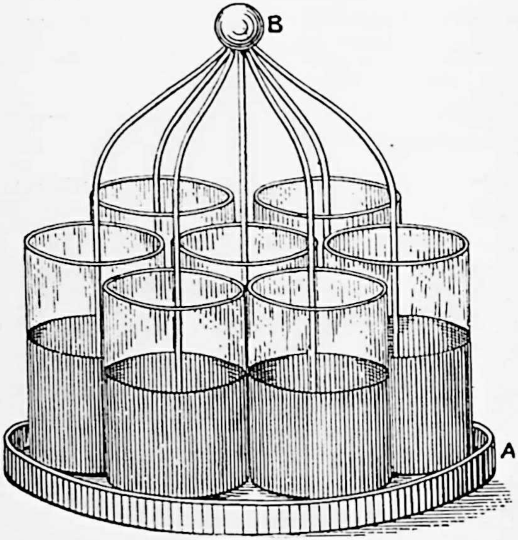


FIG. 57.

tity" we do not mean electricity, but simply the relative amount of matter thrown into the state of motion or strain.

§ 70. As it is sometimes more convenient to connect up a large number of comparatively small jars or plates, so as to form one large surface of inside coating and another of outside coating, than it is to construct one large jar or sheet, devices have been arranged to effect this purpose, of which Fig. 57 represents one known as the battery of Leyden jars, in which it will be seen a number of Leyden jars have their outer coatings connected together by standing them in a metal tray, A, the inner coatings having their individual rods brought into contact with one central knob, B. This arrangement can be charged by placing the knob, B, in proximity to the prime conductor of any electrical machine, the tray, A, being placed in contact with the earth or any other good conductor by means of which it can get rid of the induced strain.

§ 71. Another modification of the condenser, in which all the advantage of a very large surface can be obtained in a very limited space, is that known as *Fizeau's condenser*. This consists in a number of sheets of tinfoil interleaved with paraffined paper, or some other good insulator, which should extend beyond the tinfoil leaves one-sixth of their dimensions on all sides. A narrow strip of tinfoil is laid on each square of tinfoil, when placed over the subjacent paraffined paper, in such a manner as to extend an inch or two beyond the paper, and these strips are placed alternately to the right and the left hand of the condenser, and serve as terminals to unite all the unevenly numbered sheets together, so as to form one large sheet on the one hand, while the strips on the opposite side form a terminal by means of which all the evenly numbered sheets are united together on the other. That is to say, if the projecting strips or lugs which lie upon the sheets 1, 3, 5, 7, 9, etc., are brought out on the left-hand side, those connected with the sheets 2, 4, 6, 8, 10, etc., are brought out on the right-hand side. By this means, howsoever large may be the number of sheets used, all the unevenly numbered sheets will form virtually but one large sheet, while the evenly numbered sheets form another large sheet, separated from the other by a layer of insulating substance. This form of condenser is shown at Fig. 58, and when complete is generally inclosed between two slabs of glass bound together with paraffined tape binders. Sometimes, though more rarely, this condenser is rolled tightly round

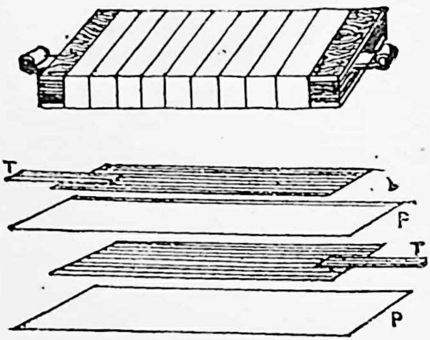


FIG. 58.

upon itself and inserted into a cylindrical ebonite case, having its terminals brought out at opposite extremities of the cylinder. In making experiments with condensers it was early found that using plates of the same dimensions, and placed at the same distance apart, that the capacity for setting up the induced condition is dependent (all other things being equal) on the nature of the substance placed between the two plates. We have already seen that no true induction takes place in the mass of a metal, but rather conduction, or the levelling up of the momentum strain between the molecules which constitute the conductor. The greater or lesser capacity which the different insulators evince for permitting the inductive effect through their mass is known as "specific inductive capacity," or as Professor S. P. Thompson suggests as the better term, "specific inductivity," and is usually measured by means of the apparatus figured at 59, which consists essentially of two concentric spheres of metal, the smaller one of which is inclosed by the larger, from which it is insulated, and of which the space between the two can be filled with air or with the di-electric (non-conductor), the specific inductive capacity of which it is desired to compare with that of air. It will be seen that this is virtually a Leyden jar in which the coatings are fixed, but in which the intervening di-electric can be changed. To ascertain the specific inductivity of any body, two such condensers or jars are employed in the following mode. One of the condensers has the space between the two coatings filled with dry air, the other with the substance under examination. One is now charged and then placed with its knob, or inner coating connection, in contact with the knob of the other jar, the outer coatings being also placed in contact. By this means the charged jar will share its charge

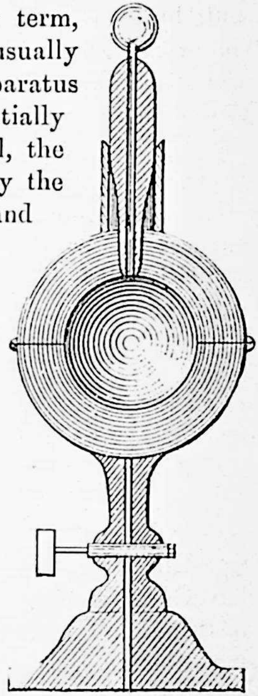


Fig. 59.

with the uncharged jar, and if the specific inductive capacity be the same in both, the charge, as tested by the torsion balance, will be equal ; but if the specific inductivity be different, the charges will be also found to be different. The following table gives a summary of the experiments made by Gordon on this subject, and gives the results of his experiments when the specific inductivity of *air* is taken as unity. It must be borne in mind that owing to the fact to which we have already adverted, that all matter is capable of transmitting a motion which we call electricity, in a greater or lesser degree, provided either sufficient strain or sufficient time be brought to bear upon it, these results, owing precisely to the varying degrees of facility with which the strain can be transmitted, will vary, not only with the initial strain put upon the dielectric, but also with the time that the strain is allowed to act.

§ 72. *Table of Specific Inductive Capacities.*

Air	1·00.
Glass	3·013 to 3·258.
India-rubber	2·220 to 2·497.
Ebonite	2·284.
Gutta-percha	2·462.
Paraffin (solid)	1·9936.
Shellac	2·74.
Sulphur	2·58.
Turpentine	2·16.
Petroleum	2·03 to 2·07.
Bisulphide of carbon	1·81.
Sulphur dioxide gas [1]	1·0037.

[1] The last five figures are due to Boltzmann, Ayrton, and Perry.

Olefiant gas	1·000722.
Carbon dioxide	1·000356.
Hydrogen	0·9996.
Good vacuum	0·9994.

§ 73. As a farther proof that there is real and undoubted molecular movement during the state we call electrification, and which, of course, is more noticeable when the strain is kept up for some time between a strained surface on the one hand, and one having less strain on the other, separated by some substance which with difficulty transmits this strain, as is actually the case in the Leyden jar or any other condenser, we may mention that it was long ago observed by Fontana and Volta that the internal capacity of a Leyden jar is increased when the jar is charged. It has been shown that the amount of apparent expansion is inversely proportional to the thickness of the glass, and varies as the square of the difference between the pressure or strain set up by the charge on the two surfaces. It has also been shown that the motion set up in glass and some other insulators evinces itself in a different manner to what it does in resinous and oily bodies, and that while the former seemed to expand laterally, and consequently diminish in thickness under the effects of the strain or molecular motion, the latter seemed to contract laterally, and consequently to increase in thickness when subjected to an electric strain or stress. It will be evident to the observant reader that these phenomena are by no means isolated, but that they stand in close relationship to similar phenomena which manifest themselves when any kind of molecular motion is imparted to matter. We have seen this relationship in the case of the motion set up in iron or steel at the instant of magnetization (see end of § 23); we see it also in the case of the tension set up in a body during the transmission of the waves of sound, and the varying properties of certain transparent bodies with regard to their power of giving rise to the phenomena of double refraction of light (which is another form of molecular motion) when subjected to mechanical, magnetic, or electrical strain point in the same direction; and, lastly, the very fact of the expansion of bodies, when their molecules are thrown into that mode of motion which we call heat, is yet another argument in favour of the belief that electricity, like the other so called imponderables, is nothing else but a mode of motion in the constituent molecules of all matter. Another argument in favour of our view of the purely mechanical cause of the effects which we term electricity may be found in the fact that a perfect vacuum, or at all events as perfect as we can make it, will not transmit electricity, or in other words, where there is no matter to be set in motion no motion can take place, and in fact it is possible to produce a vacuum so good, so free from matter, that the most powerful electrical machine cannot cause a spark to traverse even two-fifths of an inch of the vacuous space. On the other hand *partial* vacuums, in consequence of the freedom with which the molecules of matter in them can move, conduct better than gases at the ordinary pressure; and, *per contra*, by increasing the pressure, so as to render the play of the molecules less easy, the conducting power is greatly lowered; and Cailletet found that when dry air is compressed to between 600 and 700 lbs. to the square inch it resists the passage of even a very considerable difference in electrical pressure.

§ 74. Advantage is taken of the former property, namely, the superior conductivity of partial vacuums, in the production of pieces of apparatus known as "Geissler" or vacuum tubes, of which we present a few forms in our figure 60. These consist in tubes, either straight, or con-

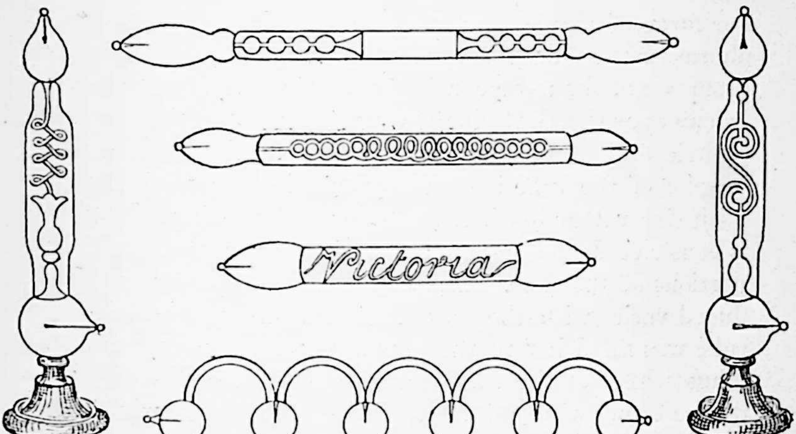


Fig. 60.

voluted, or bent to make fanciful designs with or without the interposition of bulbs of uranium or other fluorescent glass, furnished with platinum terminals sealed into the opposite ends of the tubes, from which the air is exhausted by means of a Sprengel or other air-pump ; the aperture from which the air has been extracted being afterwards sealed by fusing the glass at this point. Platinum is the only metal admissible for making connection between the interior of the tube and its outside, since its coefficient of expansion by heat is almost exactly that of glass, so that the two can be heated up to the degree necessary for the fusion of the glass, and consequently for the perfect adherence of this latter to the platinum, without there being any fear of their breaking away from each other during cooling. When a discharge of electricity takes place through such a tube, whether in the form of single sparks, as furnished by the electrophorus, or the older form of electrical machine, or whether by means of the more continuous strain furnished by such machines as the Bertsch, the Carré, the Holtz, the Hydro-electric, or, better still, the Wimshurst machine, the whole interior of the tube is seen to glow with a beautiful purplish tint, rather brighter at those portions where the tube is constricted, and more nebulous in the larger or bulbous portions of the tube. The colour of the glow thus produced varies with the nature of the gas with which the tube was filled before the partial vacuum was produced. Thus while, in the case of air, the — electrode or conductor glows with a bluish or violaceous tint, while the positive is indicated by a bright star, in nitrogen gas the — conductor glows more brightly violaceous, while the light in the remainder of the tube tends to rosy. In hydrogen the general tint of the glow is bluish, crimson being seen at the points of constriction in the tube. With a carbonic acid vacuum the light is found to be remarkably white, so much so that it was proposed many years ago to use these carbonic acid vacuum tubes in conjunction with an induction coil (to be described farther on) as illuminants in mines, etc.

§ 75. The analogy between the electric spark, and more especially between the explosive discharge of the Leyden jar, and atmospheric lightning and thunder, is too obvious to have escaped notice, even in the earlier periods of electrical research. It had been observed by Dr. Wall and by Gray, and still more pointedly remarked by Abbé Nollet. Dr. Franklin was so struck with the many points of resemblance between lightning and electricity that he was convinced of their identity, and determined to ascertain by direct experiment the truth of his conjecture. A spire which was being erected at Philadelphia suggested itself to him as affording probable assistance in this inquiry; but, while awaiting its completion, the sight of a boy's kite, which was being flown for amusement, immediately presented to his mind a readier means of attaining his object. Having constructed a kite by stretching a large silk handkerchief over two sticks in the form of a cross, on the first appearance of an approaching storm, in June, 1752, he went out into a field accompanied by his son, to whom alone he had communicated his design. Having raised his kite, and attached a key to the lower end of the hempen string, he insulated it by fastening it, by means of silk, to a post, and waited the result with intense anxiety. A considerable time elapsed without the apparatus giving any signs of electricity, even although a dense cloud, apparently charged with lightning, had passed over the spot on which they stood. Franklin was just beginning to despair of success when his attention was caught by the bristling up of some loose fibres on the hempen cord; he immediately presented his knuckle to the key and received an electric spark. Rain now fell in torrents, which, rendering the string conductive along its entire length, enabled sparks to be obtained from the key in great abundance.

Other experimenters soon followed in the wake of Franklin; the most notable of whom was perhaps Professor Richman of St. Petersburg, who having erected a large pointed conductor (insulated) projecting from the roof of his observatory, was killed on the spot, on the 6th of August, 1753, by a discharge of electricity from the lower end of this rod, while he and his draughtsman Sokolow were examining the effects of a storm on the electrometer.

The practical application of the knowledge thus obtained of the identity of lightning and electricity has been the lightning-rod, which consists of a stout copper rod, at least one inch in section, terminating at its upper extremity in a point (which, as we have seen, prevents the attainment of any great degree of strain or "tension" in neighbouring bodies), while the lower extremity is carried to moist earth or any other good conductor. The rod should be higher than all the buildings it is intended to protect. The source of atmospheric electricity is in all probability the evaporation of water from the surface of the earth.

CHAPTER III.

CELLS AND BATTERIES.

§ 76.

HITHERTO we have studied the phenomena produced by electricity as elicited by means of friction or percussion. But this is not the only mode by means of which electricity can be set up; a change of temperature, from hot to cold, or *vice versâ*, will, by setting up motion, give rise to electrical disturbance; chemical action, such as the action of acids or alkalies on metals, will also produce similar results, and the motion of bodies before the poles of magnets, in such a direction as to cut the lines of force, is likewise a fruitful source of electricity. In the cases which we have already been studying, the electricity set up has been confined by being surrounded by insulators, and even when the effects have been accumulated, very great resistance has been presented to the equalization of the strain, since air, glass, or resins have been the substances through which the generated electricity has manifested itself previous to discharge, and when the discharge has been allowed to take place, it has done so suddenly through the intermediary of a good conductor, so that the strain has equalized itself with great rapidity, giving rise to violent effects. Owing to the presence of the non-conductors in the path of the generated electricity or motion, these effects may be likened rather to the sudden release of a coiled spring, previously held by a detent, than to the gentle and continuous motion of a stream of water or of sand subjected to continuous and equal pressure. We are now about to study the action of electricity when set up under other conditions, namely, those in which the exciting cause is continuous and in which the resistance to the discharge is, comparatively speaking, small.

§ 77. If we take a strip of copper and a strip of zinc and lay one above and the other below the tongue, we shall, as long as the two extremities do not touch, perceive no particular taste ; but if the outer extremities of these strips be brought into contact, a sharp and somewhat alkaline taste will be perceptible. So also if we place a small piece of zinc wire just touching the moist corner of the eye, and touch the opposite corner with a similar piece of silver wire, no particular sensation will be felt as long as the free ends of the wire are kept separate, but on bringing these into contact a bright flash of light will be seen before the eye. Again, if a strip of copper be placed upon the bared crural nerve of a dead frog and a similar piece of zinc be laid on the lumbar muscle, on bringing the two free ends of the metal strips in contact, the muscle contracts, and the leg is thrown into spasmodic motion. The first of these experiments was due to Sultzer, who described it in 1767 in a work entitled "The General Theory of Pleasure," and who attributed the sensation on the tongue to some vibratory motion set up in the metals. Professor Volta, of Pavia, by dint of pure reasoning, was enabled to foresee that by increasing the generating surfaces of this vibratory motion the resulting effects would also be increased ; and, as a consequence, succeeded in constructing that form of continuous electricity generator known as the Voltaic pile. In its simplest form it consists of a sheet of copper and a sheet of zinc immersed in any saline or acidulated water, the lower extremities being kept separate, while the external ones are brought into contact; this form is shown at Fig. 61, in which Z represents the zinc plate, and C the copper, the arrows denote the direction in which the vibratory motion, or electricity, set up by the action of the acid on the zinc, traverses the liquid and passes from the one plate to the other in restoring equilibrium. It will be evident that this electrical disturbance will continue so long as the acid continues to act on the zinc, and the two plates are in contact above, to admit of the equalization of the strain set up. We find ourselves, therefore, in face of a different train of circumstances to those which we have hitherto been studying.

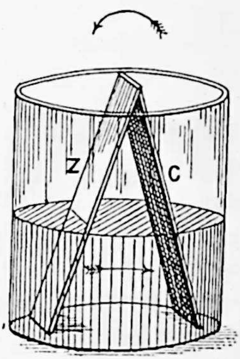


FIG. 61.

Since the pressure or strain of the molecular motion is being continually kept up on the one hand, and as continuously passed on through the intervening conductors to the point of lesser strain on the other, the result is a rapid succession of impulses, which is generally called the electric current. A modification of this form of *battery* or *pile* is that illustrated at Fig. 62, in which connection is made through two wires, of which one of each is soldered to the zinc and copper plates respectively.

No current (no equalization of strain) can pass unless the two wires are brought into contact either with each other directly, or through the intermediation of another conductor, when the current flows in the direction indicated by the arrows, that is to say, the strain set up by the action of the acid on the zinc passes on to the copper, and thence through the wires back again to the zinc.

§ 78. Volta found that by increasing the number of

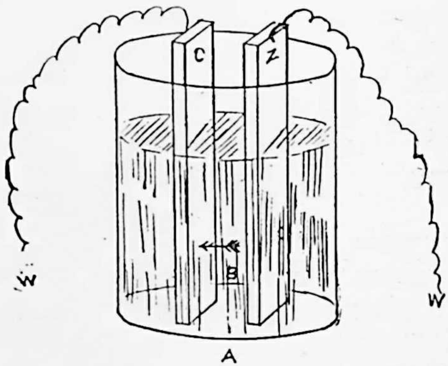


Fig. 62.

alternations of zinc and copper he was able to increase the effects, and by constructing an apparatus which has become famous as Volta's pile, which is illustrated at Fig. 63, he was able to give shocks and to produce sparks as in the apparatus which have formed the subject of our last chapter, with this difference, that the effects produced in the Voltaic pile are continuous so long as the action of the fluid on the zinc lasts, while they are discontinuous in those instruments in which the electricity set up depends on friction. Volta's pile consists of a number of discs of copper and zinc about $\frac{1}{16}$ of an inch thick and three inches in diameter, each zinc and copper pair being separated by smaller discs of cloth previously soaked in salt water or dilute acid as an excitant. The elements are arranged in the following order: zinc, cloth, copper, zinc, cloth, copper, and so on, until a pile of a hundred or more alternations has been built up. To prevent the pile tipping over it is

FIG. 63.

usually built up between three upright glass rods fixed to a base. On making contact between the lowest zinc and the highest copper, with the moistened fingers of each hand, a continuous shock is felt, due to the current of electricity passing through the body; and contact being made by means of stout copper wire between the two extremities of the pile, a small continuous light may be obtained if the alternations are in sufficient number. The inconvenience due to the awkward form of the pile, and to the necessity of dismounting the whole in order to supply fresh salt water or acidulated water to the cloth discs as these latter dried, was overcome in the modification known as the *couronne de tasses*, in which a number of vessels similar to those shown at Fig. 62 were arranged in a circle and con-

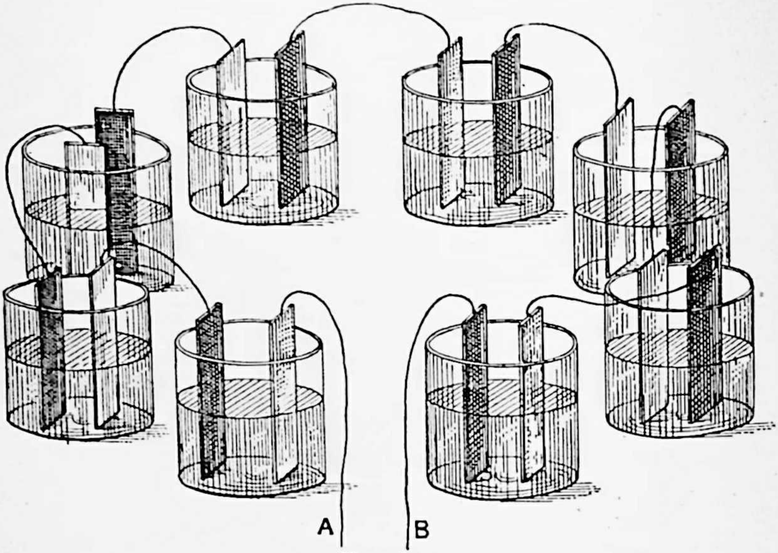


Fig. 64.

nected together, the zinc of the one to the copper of the next as shown in our Fig. 64, the circuit being left open at the points A and B, where contact could be made by means of the connecting wires. Numerous modifications of the battery or pile have since been made, but in order that the principle on which the construction of an effective *cell* (the name given to a single pair of elements) depends may be clearly understood, it will be well for us to consider what chemical effects are produced during the action of the acid upon the zinc or other metal which gives rise to the molecular motion.

§ 79. When a plate or rod of *perfectly pure* metallic zinc is immersed in dilute sulphuric acid *no action takes place.* If in the same solution a plate of copper or of silver, or, in point of fact, of any other good conductor not acted on by the acid, be now immersed into the fluid, provided it do not touch the zinc, still no apparent effects result, but if the zinc be allowed to touch the copper, either directly or by means of another conductor, such as a copper wire, etc., a quantity of bubbles are seen to leave the zinc, to carry themselves over to the copper plate and to rise to the surface of the liquid round the copper plate. On breaking connection between the two plates this action ceases. If the plates be allowed to remain in contact for some time the copper plate will be found to become coated with this gas, and the action will be greatly diminished. Expressed chemically, by means of symbols, the chemical action is as follows:

$$Zn + H_2SO_4 = ZnSO_4 + H_2,$$

or in words, zinc and sulphuric acid give rise to zinc sulphate and free hydrogen gas. Now this free hydrogen gas, which adheres to the copper or silver plate, seriously interferes with its conducting power, and prevents it passing on the strain set up by the action of the acid on the zinc; so that as soon as this effect takes place the action of the cell, as a source of electricity, is greatly impaired. This effect is known as *polarization,* and many devices have been put into execution in order to overcome the evil effects resulting from this accumulation of hydrogen gas on the collecting plate in the cell. If we repeat the experiment above-mentioned, substituting for perfectly pure zinc the ordinary commercial article, which contains a certain percentage of other metals, we shall find that the acid will act on the zinc at once without any other plate being inserted into the fluid. For this reason ordinary zinc in its usual condition is not adapted to the construction of batteries, since it is evident the zinc would be

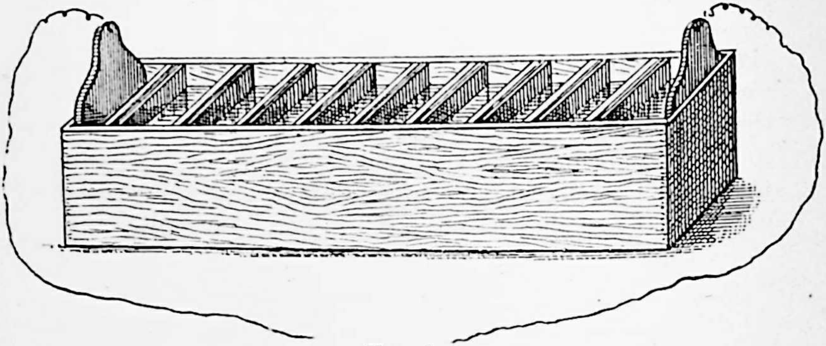


FIG. 65.

consumed whether the battery were doing useful work or not. It is found, however, that by coating the surface of the zinc with *mercury*, or " amalgamating the zinc," as it is termed, the effect of the other metallic impurities is annulled, and, in point of fact, a sheet or rod of amalgamated zinc is as indifferent to the action of dilute acids as if constructed out of the pure metal. For this reason, in all the best forms of batteries in which acids are used as the excitants, rolled amalgamated zinc is employed. We will now pass in review a few of the more important forms of cells, pointing out the means that have been employed to get rid of the injurious effects of polarization.

§ 80. Passing over the Cruickshank trough battery, of which we give an illustration at Fig. 65, and the Wollaston, shown at Fig. 66, which are simply modifications of the *couronne de tasses*, and which have been superseded in use by more practical forms, we come to the "Smee," which con-

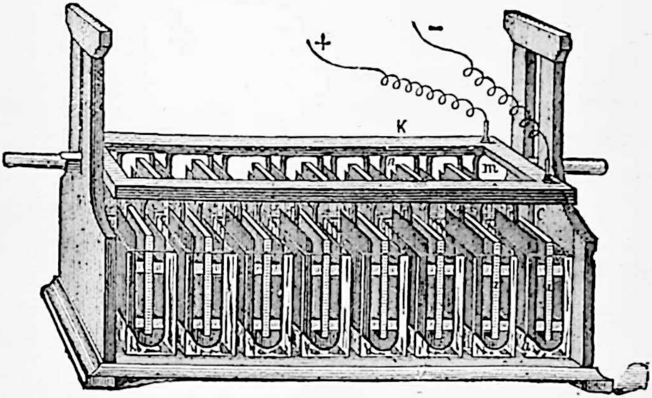


FIG. 66.

sists, as shown at Fig. 67, in a plate of thin platinized silver, A, placed between two sheets of amalgamated zinc, B, B. These two latter are electrically connected together by means of the brass clamp, C, but are insulated from the silver by the varnished wooden cross-piece, D. The whole arrangement is immersed in a vessel of dilute sulphuric acid of the strength of one part of acid to twelve parts of water. The rough surface produced on the silver by being platinized facilitates very markedly the escape of the hydrogen gas, which, as we have seen at § 79, is evolved during the working of the battery, and for this reason the Smee battery is much more constant in its

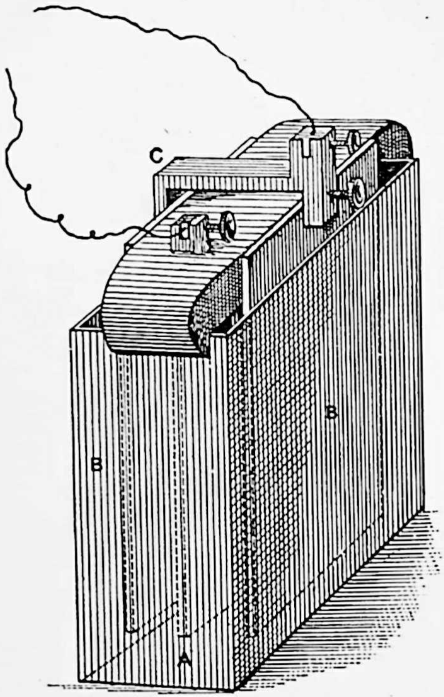


FIG. 67.

action than any of those which preceded it, and has been extensively used for electroplating on the small scale.

§ 81. Another very similar form of battery, in which the platinized silver plates are replaced by platinized graphite,[1] is even more efficient than the Smee. This is the "Walker," and were it not for the fact that the graphite plates from their porosity allow the acid slowly but surely to creep up and corrode the brass clamp, and so spoil the electrical connection, this battery would be much more extensively used, being cheaper in first cost and more efficient in action than the Smee, especially if the zinc plate be placed between the two graphites instead of *vice versâ.*

§ 82. The first battery in which the hydrogen evolved was entirely got rid of by chemical action was the "Daniell," so named from its inventor. This consists, as shown at Fig. 68, in a copper cylinder, V, which usually forms the containing vessel itself, in which case it has a bottom fitted to it, but which may be contained in an outer glazed earthenware jar. This copper cylinder has a perforated copper ledge at S, on which are placed crystals of sulphate of copper. A porous cell, P, of unglazed ware stands in the copper jar, and in this is placed an amalgamated zinc rod, Z. Along with the zinc rod is placed a dilute solution of sulphuric acid (one part acid to twelve of water). In the outer cell, that is along with the copper, is a saturate solution of sulphate

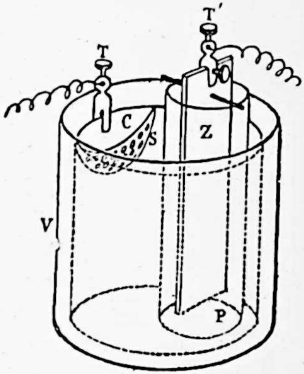


FIG. 68.

[1] Graphite—a form of carbon, the result of the decomposition of coal during the manufacture of gas, and which incrusts the inside of the gas retorts; hence also called retort scurf.

of copper, which is maintained saturated by the crystals of sulphate of copper on the ledge or shelf, s. Two wires, w and w', which are attached to the zinc and copper respectively, serve to form connections or "poles" for attachment to any outer circuit through which it is intended to pass electricity. The working of this battery, in so far as the action of the sulphuric acid on the zinc is concerned, is precisely the same as those hitherto considered; that is to say, in the porous cell we have

$$Zn + H_2SO_4 = ZnSO_4 + H_2,$$

and the hydrogen thus evolved is carried on along with the electric impulses through the porous cell and into the copper sulphate solution; but here, since free hydrogen has a greater affinity for the sulphuric acid radical SO_4 than has copper, the result is that it displaces the copper from the copper sulphate, giving rise on the one hand to metallic copper, which is carried forward along with the electricity to the copper vessel to which it adheres, and to sulphuric acid on the other, which remains in solution. Thus:

$$H_2 + CuSO_4 = H_2SO_4 + Cu,$$

in which *Cu* stands for *cuprum*, the Latin name for copper. It follows from this that no hydrogen whatever adheres to the copper surface; hence, as long as the battery is in action, and there is any zinc to be dissolved, or any solvent to dissolve it, electricity is generated at one even rate, for which reason this cell was originally known as Daniell's "constant" cell.

§ 83. Closely allied to the above is the cell known as the "Grove's," which is shown in detail at Fig. 69. Here

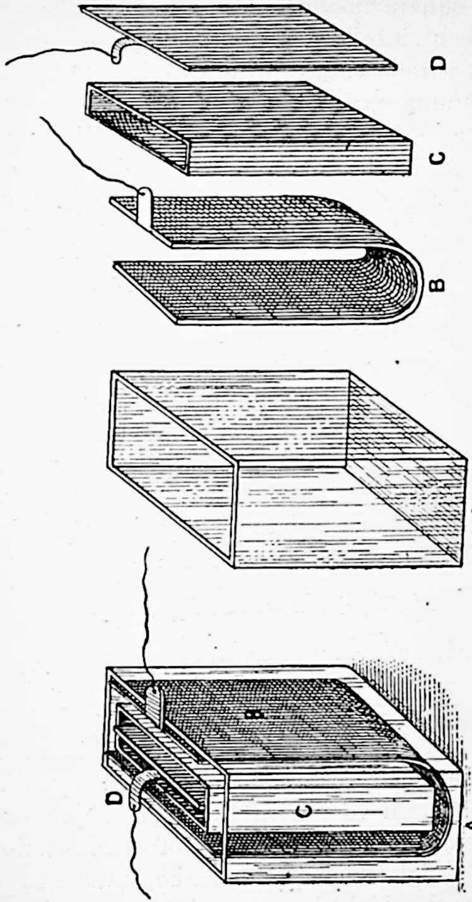


FIG. 69.

we have a glass containing vessel, A, usually, but not necessarily, square in outline, in which is placed a plate of zinc, B, bent into the form of a U. In this stands a flat, square, porous cell, C, which in its turn contains a sheet of platinum, D. These are shown separately in the same figure at *a*, *b*, *c*, and *d*. The usual dilute sulphuric acid is placed in the containing vessel along with the amalgamated zinc, the porous cell being filled with strong nitric acid, in which is immersed the platinum plate. The action which takes place is similar to that in the case of the Daniell cell, with this difference, that when the hydrogen, which is evolved by the action of the sulphuric acid and the zinc, has passed through the porous cell it meets with the nitric acid, and this body being rich in oxygen yields up a portion of its oxygen to the nascent hydrogen, converting it into water and giving rise at the same time to fumes of nitrous acid. This interchange is shown symbolically in the following equation. In the zinc compartment:

$$HSO_4 + Zn = ZnSO_4 + H_2.$$

In the nitric acid compartment:

$$H_2 + 2HNO_3 = 2NO_2 + 2H_2O.$$

The Grove cell is a most powerful form of battery, owing to the small resistance presented by the nitric acid, but although very constant it is objectionable in consequence of the injurious fumes of nitrous acid, which are not only deleterious to breathe, but also corrode everything with which they come into contact.

§ 84. A modification of the Grove cell known as the "Bunsen," and shown at Fig. 70, consists in a glazed or glass jar in which is placed a cylinder, a zinc, then a porous cell, and lastly a block of graphite. The acids used are precisely the same as in the Grove cell, and the chemical reaction which takes place is also the same. In efficiency the Bunsen has perhaps a trifling advantage

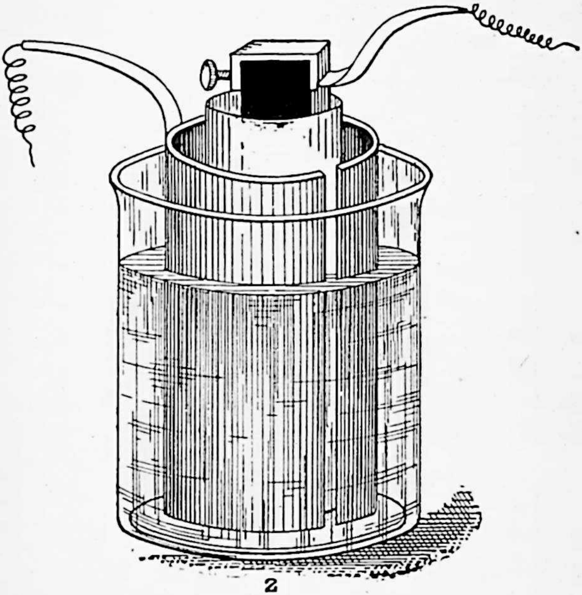


FIG. 70.

over the Grove, inasmuch as the rough superficies of the carbon or graphite present a larger surface, and consequently less resistance to the passage of the current. On the other hand the battery is more bulky, and the tendency of the acid to creep up the carbon and destroy the connections renders frequent overhauling necessary. The first cost is considerably less, but this is counterbalanced by the fact that the platinum in the Grove's is not consumed, and is always saleable. The defects and advantages are the same in both in every other respect.

§ 85. If for the nitric acid in the Bunsen cell we substitute a solution of chromic acid in water, acidulated with sulphuric acid in the following proportions, namely:

Chromic acid	3 parts	by weight,
Water	20 parts	
Sulphuric acid, Sp. Gr. 1·84	4 parts	

we get the double fluid chromic acid battery which has all the advantages of the Bunsen cell, as far as regards constancy and high electro-motive force,[1] without the attendant disadvantage of the nitrous fumes. By adding one part, by weight, of chlorate of potash to the above solution, its constancy is still farther enhanced; but chlorine is generated while the battery is at work. This is not injurious, but is disagreeable to some, and attacks any brass work which may be in the vicinity.

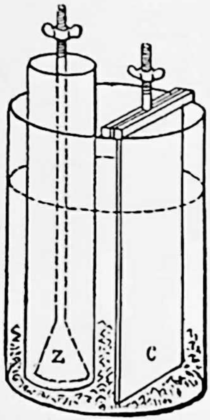


FIG. 71.

§ 86. The "Fuller" cell, which we represent at Fig. 71, is almost precisely similar to that just described; but as it is intended to give a comparatively small current, extending over a long period of time, no acid is used along with the zinc outside the

[1] Electro-motive force, or E.M.F., the power of setting up a current of electricity.

porous cell, and this latter is painted over with melted paraffin wax on its outer surface, except a streak of about half an inch in width extending along its whole length, through which the water contained in the outer vessel can permeate, and thus establish electrical communication with the fluid within the porous cell.

§ 87. In both these batteries, and in fact in all batteries in which chromic acid is used, bichromate of potash, or the corresponding soda salt may be employed, and the final result will be the same, since, on the addition of sulphuric acid to either of these salts, the acid seizes upon the base (soda or potash) and liberates the chromic acid which is the real depolarizer. Although the bichromates of potash and soda are about twenty-five per cent. cheaper than chromic acid the cost of working the cell comes to about the same, since more sulphuric acid must be used when these salts are employed; besides, when chromic acid alone is used no crystals form in the liquid or attach themselves to the carbon plates, whereas in the other case chrome alums are formed, and these crystallize on the plates and on the inside of the jar to the detriment of the working of the battery. In all chromic acid batteries the chromic acid acts by yielding up a portion of its oxygen to the hydrogen set free at the zinc plate and converting it into water, while it is itself reduced to the state of chromium sesquioxide, as indicated by the following equation:

$$2H_2CrO_4 + 3H_2 = 5H_2O + Cr_2O_3,$$

or in other words, two molecules of chromic acid in the presence of three molecules of hydrogen give rise to one molecule of chromium sesquioxide and five molecules of water

§ 88. Another cell which is excellent for short runs, not exceeding three hours in duration, and which, owing to the low resistance presented by the fluids employed gives a very powerful current, is the *single fluid bichromate*, or chromic acid cell, of which we figure two forms at 72 and 73. In the former we have a zinc plate attached to a brass rod which can slide up and down

FIG. 72.

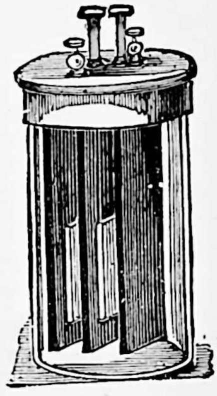


FIG. 73.

through a hole in the cover, and can be held in any position of its travel. This is in connection with one terminal ; on either side of this zinc plate is a long graphite plate reaching almost to the bottom of the bottle. These two carbon plates are connected together and to another binding screw which forms the other terminal. The chromic acid mixture is placed in the bottle and should be allowed to reach only to such a height that it does not touch the zinc plate when this is drawn up into the neck of the bottle by raising the central rod. The other form is not usually made with lifting zincs, but the cover may be removed bodily along with the zincs and carbons which are attached to it when the battery is not in use. In this latter case it is advisable to plunge the zinc and carbon plates for a few seconds in boiling water, after use, as far as the acid has reached. This treatment will greatly conduce to keeping the cell in working order, as the heat thus imparted to the plates causes them to dry rapidly, and prevents to a great extent the absorption of the acid by the carbons, which inevitably culminates in the corrosion of the junction of the carbon plates to the terminals, and consequently in the failure of the action of the battery. In this latter form of the bichromate cell several carbon and zinc plates may be attached to the cover, provided they be connected together so as to form one large zinc plate on the one hand, and one large carbon on the other.

§ 89. We now pass to a form of cell which for convenience, where small currents are required at intermittent periods extending altogether over long intervals of time, is perhaps unequalled. This is known as the "Leclanché," and consists, as shown in our Figure 74, in a porous cell standing in a square glass vessel, with a wide round mouth in which is an indentation or lip to admit a zinc rod. In the porous cell stands a carbon plate, the top of which is capped with lead and fitted with a binding screw ; the space round the carbon plate and the interior of the porous cell is packed with a mixture of about equal parts of manganese dioxide in the granular form and roughly-crushed graphite. It is essential that neither the carbon (graphite) nor the manganese should be in *fine* powder, otherwise they would offer a considerable obstacle to the action of the battery. The fluid used in this battery is a half saturate solution of ammonium chloride (sal-ammoniac). The action which takes place

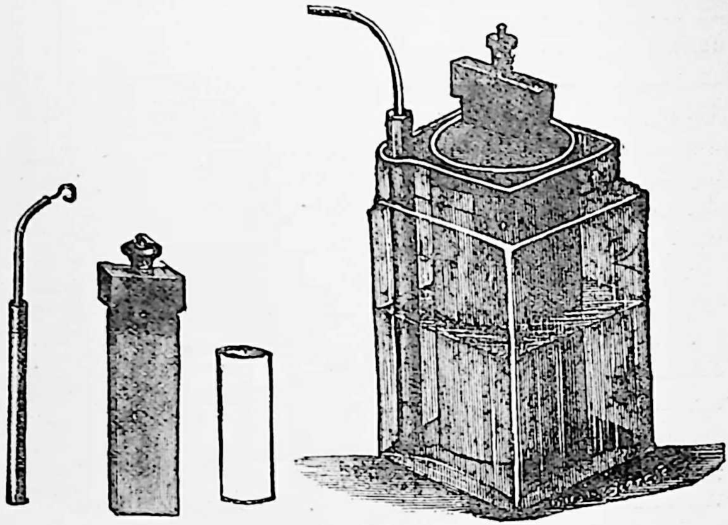


FIG. 74.

in this cell is shown by the following equation. In the zinc compartment:

$$Zn + 2NH_4Cl = ZnCl_2 + 2NH_3 + H_2.$$

In the manganese dioxide compartment:

$$H_2 + 2MnO_2 = Mn_2O_3 + H_2O.$$

Here we see that the liberated hydrogen finding itself in the presence of the manganese dioxide robs it of a portion of its oxygen, being itself converted into water. As the manganese sesquioxide thus produced appears to have the power of re-absorbing oxygen, this cell slowly recovers itself even after being worked continuously for some time, say twenty minutes, provided sufficient time be given for it to recover itself. Hence, though not adapted to give large currents for any lengthened period, this cell is, as we have already said, eminently useful in all cases in which small currents are wanted at intervals spread over a long period, such as bell-ringing, signalling, testing, etc.

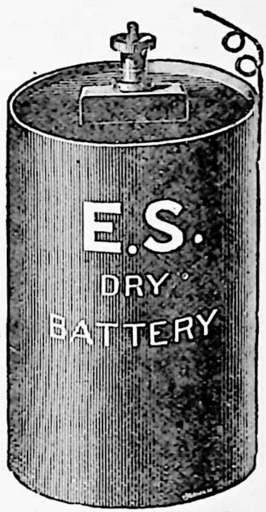


FIG. 75.

§ 90. Latterly the Leclanché has undergone a modification by means of which it has been rendered even more convenient on the score of portability without losing any of its efficiency. In this modification, which is known as the "dry cell," Fig. 75, a *lux a non lucendo*, the graphite plate is surrounded as before with the mixture of crushed graphite and manganese dioxide, and stands in the centre of a stout zinc pot. Instead of being separated from this by a porous cell, the space between the carbon plate and its accompanying depolarizing mixture[1] is filled in with a moist magma of plaster of Paris, mixed with water, gelatine, glycerine, and chlorides of

[1] Any substance which readily gives up its oxygen to the liberated hydrogen is termed a depolarizer.

zinc and ammonia, the whole being sealed in with a thick layer of pitch.

§ 91. In the "Marié Davy" battery we have a plate of zinc and a plate of graphite, the latter being covered with a paste of sulphate of mercury, both plates lying horizontally in a flat trough, as shown at Fig. 76, where the graphite plate lies at the bottom of the cell with an insulated wire connected to it as shown at A, the zinc plate, B, resting on ledges in the cell, and having its wire at C. The sulphate of mercury, D, acts as the depolarizer,

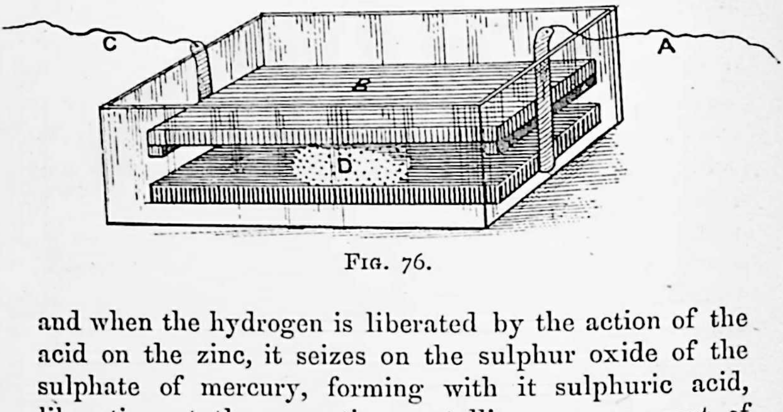


Fig. 76.

and when the hydrogen is liberated by the action of the acid on the zinc, it seizes on the sulphur oxide of the sulphate of mercury, forming with it sulphuric acid, liberating at the same time metallic mercury, part of which passes on to the zinc and helps to keep it amalgamated, while a part falls to the bottom of the vessel and assists the conducting power of the graphite plate. This battery is very extensively used for working small pocket coils.

§ 92. Of the multitude of batteries which have been devised, the others are only modifications of the ones already described, with the exception of the one known as the "Upward" chlorine cell, in which a stream of chlorine gas is kept circulating through the cell in which is a carbon plate packed with carbon, separated from the zinc plate by a porous partition. Chlorine gas is fed into the cell on one side by a supply tube, and sucked out of it on the other by means of an aspirator.

§ 93. From the above descriptions the reader will gather that the essentials for a galvanic cell are :—1st. A plate of metal (generally zinc) or other substance readily acted on by the acid or exciting fluid used. 2nd. An acid or fluid capable of acting on the said plate, and itself a fairly good conductor of electricity. 3rd. A plate of metal or other substance which is a good conductor of electricity, not acted on by the acid, and which serves to collect and transmit to the outer circuit the electricity or strain set up by the action of the acid on the zinc. It will be evident that the larger the surfaces of the zinc acted upon, and those of the collecting plate in each cell, the larger will be the current of electricity set up, and, for this reason, large surfaces are necessary where large currents are required. On the other hand, the actual power of overcoming resistance must evidently be limited by the chemical energy exerted in each cell, so that to obtain effects of great electrical pressure several cells must be united in series (that is to say, the zinc of the one cell with the collecting plate of the next, and so on), so that the cumulative effect of the pressure or strain may be brought to bear on the resistance presented in the outer circuit. Another point, which is not absolutely an essential, but which tends greatly to the constancy of action, is the presence of some means of getting rid of the liberated hydrogen either mechanically by means of agitation, ebullition, or lifting the plates, or else chemically by means of a depolarizer.

§ 94. In studying the effects produced by the electricity set up in a battery, it will be well to commence by noticing that we are enabled to measure much more accurately the amount of electricity passing, and the pressure at which it passes, than in the case of that evolved by frictional means, since, in the former case, the action of the acid on the zinc, which is the exciting cause of the mode of motion which we designate electricity, is more continuous and consequently gives us more time to measure its effects. It has been found as the result of careful experiment, and verified by everyday experience, that the amount of electricity flowing in a circuit is dependent on two factors only, namely, first, the amount of action which sets up the motion, known as electro-motive force, abbreviated as E.M.F., and secondly, the resistance presented by the circuit which the electricity has to traverse before it can equilibrate itself. The formula usually employed to express this relation is, $\frac{E}{R} = C$, in which E stands for the electro-motive force, whatever that may be, R for the resistance in circuit, and C for the current.

§ 95. As a measure of electro-motive force, electricians have agreed to employ the *Volt*, which is very nearly that pressure set up by the action of sulphuric acid on zinc in the Daniell cell.[1]

It must be borne in mind that the electro-motive force

[1] The exact E.M.F. in the Daniell cell is 1·079 of a volt.

set up in a body is the *rate of motion* of its particles amongst one another, and that it is independent of their number, that is, of the size of the body, but dependent only on the intensity of the action which sets up this motion, be it friction, chemical action, or magnetism. Consequently, no increase in the size of a given battery can increase its electro-motive force, this result can only be attained by increasing the intensity of the chemical action, either by strengthening the acid, or by substituting some other acid which acts more violently on the zinc, etc.

§ 96. The measure of resistance usually employed is the *Ohm*, which, as the result of various conferences between several learned societies of Europe, has practically been fixed as the resistance presented by a column of mercury one square millimetre in section and 1·063 metres in height. For the purpose of experiment it will be sufficient to say that this is nearly equal to the resistance presented by one foot of iron wire, No. 36 B.W.G., or by six feet, No. 36 B.W.G. copper wire.

§ 97. Our measure for current is the *Ampère*, and this is the amount of current which can be forced through a resistance of one ohm by a pressure or E.M.F. of one volt. It is possible to measure the amount of current flowing through any circuit by the work it will do ; and it is found in practice that a current of one ampère passing through a solution of sulphate of copper for the space of one hour will decompose the solution, and cause the deposition of 18·36 grains of copper ; or if silver nitrate be employed instead of the copper solution, the result will be the deposition of sixty-two grains of silver for every ampère passing per hour.

§ 98. From the above considerations it therefore follows that given any two of the above data we can immediately calculate the third; for example, supposing we had at our disposal from a given battery, or any other generator of electricity, an electro-motive force, or "molecular movement strain," of 10 volts, with a total resistance in circuit of 5 ohms, and it was desired to know the amount of current that would pass in the circuit. Then by Ohm's Law, since $C=\frac{E}{R}$, and our $E=10$, our $R=5$, the equation becomes $\frac{10}{5}=2$. In other words, under these circumstances we should get a current of 2 ampères flowing through the circuit. Let us suppose, *per contra*, that we desired to send a current of 100 ampères through a resistance of 2 ohms, and it were required to know what E.M.F. would be needed. Here again we see that by multiplying the number representing the current in ampères by the number representing the resistance in ohms, we should get at the number of volts required to furnish the required current, since $2 \times 100 = 200$, and $\frac{200v}{2r} = 100a$.

As a last example, let us suppose that we have an E.M.F. of 50 volts, and we find that a current of 2 ampères is traversing the circuit, and that it is required to ascertain the resistance of the entire circuit. Then since $\frac{E}{R} = C$ and our E is known to be 50, while our C is 2, it follows that the R must be 25, since $25 \times 2 = 50$.

§ 99. It is interesting in this connection to note what every intelligent mind will at once perceive, that if a number of conductors of equal conductivity be joined end to end, so as to form one long conductor, the resistance will increase as the number of individual portions; but if these conductors be placed side by side, or "in parallel," so as to bridge over between the points of highest and lowest pressure, the resistance will fall in proportion to the number of conductors so placed. Conductors placed end to end are said to be in "series," when placed side by side they are said to be "in multiple arc," "in parallel," or to form "derived circuits." The joint resistance of a derived circuit, made up of a number of conductors having different resistances, may be easily calculated by adding the reciprocals[1] of the separate resistances together, the sum being a number which is the reciprocal of the joint resistances. Let us suppose we have three conductors, *A*, *B*, and *C*, *A* having a resistance of 20 ohms, *B* 10 ohms, and *C* 5 ohms. Let these be placed "in parallel" (like the rungs of a ladder) in a circuit. What is the joint resistance of the three?

According to our rule we take the reciprocals of the resistances of *A*, *B*, and *C*, which are respectively $\frac{1}{20}$, $\frac{1}{10}$, and $\frac{1}{5}$, and add them together, which gives $\frac{7}{20}$; inverting this (since it is the reciprocal of the joint resistance) we get 2·85 ohms as the joint resistance.

§ 100. The above considerations will enable us to calculate immediately the current which a given cell, or a given number of cells, can cause to pass through a stated resistance, according to how the cells are connected to one another. What, for instance, would be the current in ampères which a cell having an E.M.F. of two volts,

[1] The reciprocal of a number is 1 divided by that number.

with an internal resistance[1] of $\frac{1}{10}$ ohm, could send through an external resistance of $\frac{1}{50}$ of an ohm. By Ohm's Law, $\frac{E}{R} = C$, we get for E 2, and for R $\frac{1}{10}+\frac{1}{50}=\frac{6}{5}$; hence $\frac{2}{\frac{6}{50}}$ or $\frac{12}{\cdot 12} = 16\cdot\dot{6}$ ampères. Let us now suppose that we have joined 6 such cells *in parallel*, in this case the E.M.F. remains the same, but the internal resistance falls (as we have seen in our last section) to $\frac{1}{6}$ of that of the single cell, that is to say, to $\cdot 01\dot{6}$ of an ohm, and as the external resistance remains the same, we get $\frac{2}{\cdot 016+\cdot 02}$ or $\frac{2}{\cdot 036} = 55\cdot\dot{5}$ ampères. So we see that against a small outer resistance we gain by connecting cells *in parallel* (or what amounts to the same thing, in using a single cell of large dimensions), but in proportion as the external resistance is increased the gain becomes less; until at last, if the external resistance be equal to or greater than that of the cell, there is no appreciable gain in adding more cells in parallel or in using larger cells.

§ 101. When, on the contrary, cells are coupled *in series*, that is to say, the positive element of the one to the negative element of the next, and so on, the electro-motive force of the first cell is added to that of the next, *et sequitur*, throughout the series: but, as we have already seen, as the conductors (the elements themselves and the fluid between them) are placed in series, the resistance also is additive, so the actual current flowing through a small outer resistance is not greater than if a single cell

[1] Internal resistance—the resistance presented by the fluid and materials of the battery itself.

were employed. A moment's consideration will show the truth of this statement. Let us suppose, as before, that we have a single cell with an E.M.F. of 2 volts, and an internal resistance of ·1 ohm, then $\frac{2}{\cdot 1}$ will give 20 ampères on the short circuit; but no greater currrent will be got by adding five more cells in series since $6 \times 2 = 12$ and $6 \times \cdot 1 = \cdot 6$ and $\frac{12}{\cdot 6} = 20$ as before. A different result however is obtained if the external resistance exceed that of the battery itself, *then* we gain by adding cells until we have brought up the resistance of the cells themselves equal to that of the outer resistance. Therefore a single cell as above will send only a current of ·327 ampères through a resistance of six ohms, while six cells in series will send a current of 1·81 ampères through the same resistance, as shown by the two following examples:

$$(a)\ \frac{2}{\cdot 1 + 6} = \cdot 327;\ \text{and}\ (b)\ \frac{6 \times 2}{6 \times \cdot 1 + 6}\ \frac{12}{6 \cdot 6} = 1 \cdot 81.$$

Consequently, to get a larger current with a low external resistance, we must either increase the size of the cells so as to decrease the internal resistance, or, what amounts to the same thing, we must couple a number of cells in parallel, whereas if we have to deal with a high external resistance, we must either increase the electro-motive force of the cell,[1] or else couple a sufficient number of cells in series to furnish the required electro-motive force.

§ 102. The effects produced by the continuous flow of electricity set up by batteries are very similar to those

[1] There is no known cell which will give more than three volts.

produced by the discharge of frictional electricity, the chief differences being those due to the lesser strain and more continuous effect of the discharge resulting from the battery. Owing to the continuity of the current (and by the word current must be always understood the molecular movement set up in the conductor) the effects are more easily studied and take place more gradually under our eyes, and this facility is favoured by the fact that as the E.M.F. set up by batteries is usually not so great as that obtainable from machines of the frictional and inductive class, the insulation of the conductors carrying the current is more easily made sufficient for the purpose. Perhaps the most striking of the effects of current electricity is that of evincing *magnetism* tangentially to its flow; that is to say, that a wire carrying a current is itself magnetic at right angles to the flow of the current, and such a wire will attract iron filings all round itself, as if it were magnetized on its circumference. If such a wire be brought over a poised magnetic needle, as shown at Fig. 77, the current flowing from the spectator, the north pole of the suspended needle pointing originally to him, the needle

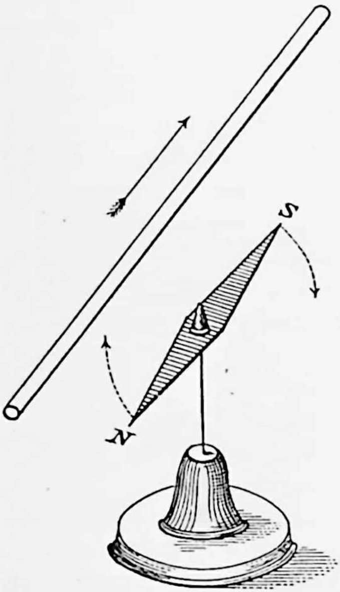


FIG. 77.

will be impelled out of its position and its north pole deflected to the left of the observer, just as if the wire had along its lower surface a bar magnet at right angles to it with its south pole to the left. If the direction of the current be reversed, that is to say, the wire still being above the needle, the positive current (the point of highest tension) be caused to enter at the end of the wire farthest from the observer, the needle will be deflected in the opposite direction, in other words, its south pole will now turn to the left. In like manner if the wire be placed below the needle while the current is entering at the nearer end, the north pole of the needle will be deflected to the *right*, while the contrary effect will obtain if the current be sent in the opposite direction. Based on the above described facts we can formulate the following rules for the behaviour of a freely suspended magnetic needle with regard to any current passing in its vicinity:—Let the observer imagine himself to be swimming *in the direction* of the current with his *face* turned to the *needle*, then the *north pole* of the needle will be deflected to his *left* hand.

§ 103. The magnetic property of the current is rendered more evident if we coil the conductor in the shape of a helix, so as to multiply its tangential action, such an arrangement is called a solenoid, and is shown at Fig. 78, connected as it often is for this purpose to a pair of zinc and copper plates attached to a cork by means of which it can be floated on dilute acid, and supplied simultaneously with current.

Such an arrangement, when floating on dilute acid, takes up a position north and south, and is attracted and repelled by a magnet precisely in the same manner as a poised magnetic needle. By inserting in the helix a bar of soft iron these effects are intensified, and the magnetism set up rendered apparently more powerful. This is due to the fact that the inductive effect of the current passing through the wire helix instead of spreading itself through space is concentrated on to the iron core.

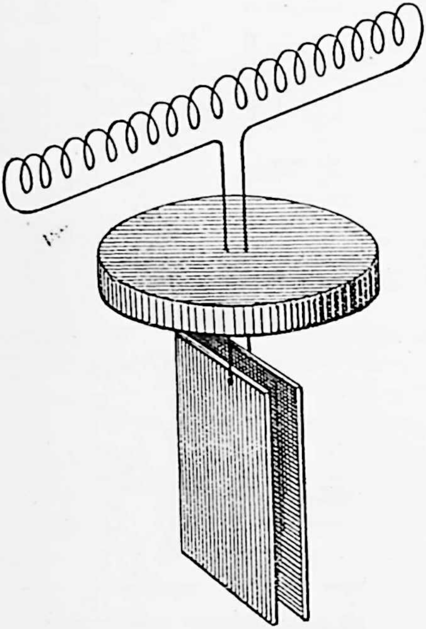


Fig. 78.

§ 103*a*. A very effective mode of showing the magnetic properties of the current is based on this principle, and gives rise to that useful instrument known as the *electro-magnet* of which we present two illustrations at Fig. 79, in which *a* represents an electro-magnet of the horse-shoe form, and *b* one of the square form usually employed for electric bells and similar pieces of apparatus. They consist in a soft iron core, *d d′*, coiled with insulated wire, the free ends of which, *c c*, serve for connection to the battery or other source of electricity. It is essential, to obtain the best effects, that the core should be of the softest possible iron, since not only is soft iron capable of a much higher degree of magnetisation (nearly forty per cent. more) than hard iron, but also has less *magnetic*

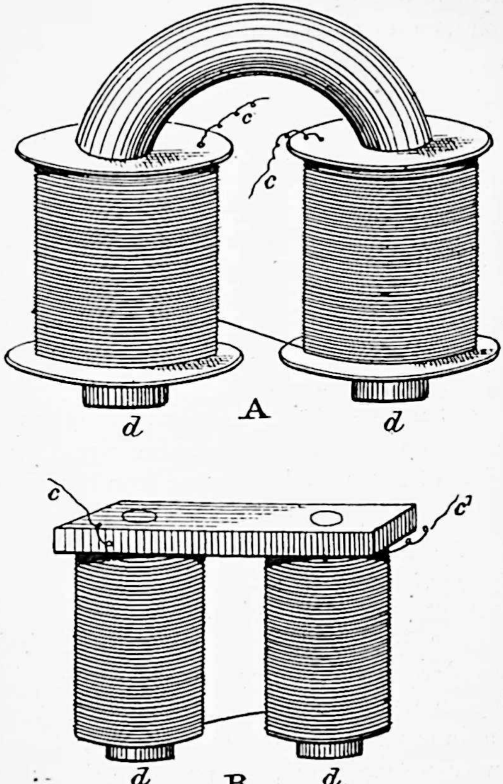


FIG. 79.

memory; that is to say, when the current is cut off it loses much more perfectly the magnetism imparted to it by the current, and this is of the highest importance in many of the applications to which electro-magnets are put.[1] The intensity of magnetisation which can be imparted to a given mass of iron by this means is dependent, up to a certain point, on the current which flows around the iron; when that point, which is known as the limit of saturation, has been reached, an increase in current is not accompanied by a corresponding increase in magnetisation. One peculiar thing in connection with the electro-magnet is that the same result can be obtained by causing a given amount of current to circulate through one turn of wire, as by causing a fractional portion of that current to circulate round a helix consisting of as many turns as the number serving as the denominator of the fraction. Say we had a current of one ampère circulating around a single coil of wire encircling a bar of iron, and that this enabled the bar to sustain one pound weight; it would be found that one-tenth of an ampère circulating round a helix of ten turns, round the same iron bar, would give precisely the same portative power. In other words we get precisely the same effect from a helix of a thousand turns, carrying $\frac{1}{1000}$ of an ampère, as we do from a single turn carrying one ampère. It is therefore usual to speak of the coils of an electro-magnet as consisting of so many "ampère turns." From this it will be evident that in winding an electro-magnet we have to take into consideration, in order to get the best results, the amount of current we can supply, and the pressure at which we can supply it, so that if the current be large we will use few turns of a coarse wire; if the current be small, the E.M.F. high, we will use many turns of a fine wire.

[1] See "Electric Bells" and "The Dynamo" for practical applications of the electro-magnet.

There is no advantage, as regards portative power, in having the cores of the electro-magnet long in proportion to the diameter, and the amount of wire that is coiled on should not greatly exceed, when wound, twice the diameter of the core itself, since the outlying coils from their distance from the core have but little magnetising effect, and the increased resistance opposed to the passage of the current more than compensates for any increase in magnetic effect. A well-constructed horse-shoe electro-magnet consisting of a bar of soft iron about 1 foot in length and 1 inch in diameter, bent into the shape of a horse-shoe, the poles about 3 inches apart, if energized by the current of about 24 ampères is capable of sustaining from 60 to 80 lbs., according to the quality of the iron. Large electro-magnets have been constructed capable of sustaining a ton. From some experiments instituted by Bidwell it would appear that the utmost portative power or limit of saturation is reached at about 226 lbs. per square inch of sectional area of polar surface.

§ 104. During magnetisation, as we have already seen at § 23, the iron undergoes molecular change, the diameter being lessened and its length increased, and while this takes place a very distinct sound is emitted. Of course the change in diameter and length is only temporary, and lasts only as long as the current is passing round the encircling coils; the iron returning to its normal length and diameter on losing magnetisation on the cessation of the current, when the magnetic note or sound is repeated as the molecules fall back into their old position.

§ 105. Since electro-magnets are much more powerful, in proportion to their size and weight, than permanent steel magnets, it will be evident for the preparation of artificial magnets by the means previously described (see § 12) that electro-magnets can be used to great advantage. It is, however, not even necessary, though often convenient, to employ a complete electro-magnet; in many instances, and specially in the case of straight bar magnets, whether cylindrical or square, the employment of a simple solenoid, into the interior of which the

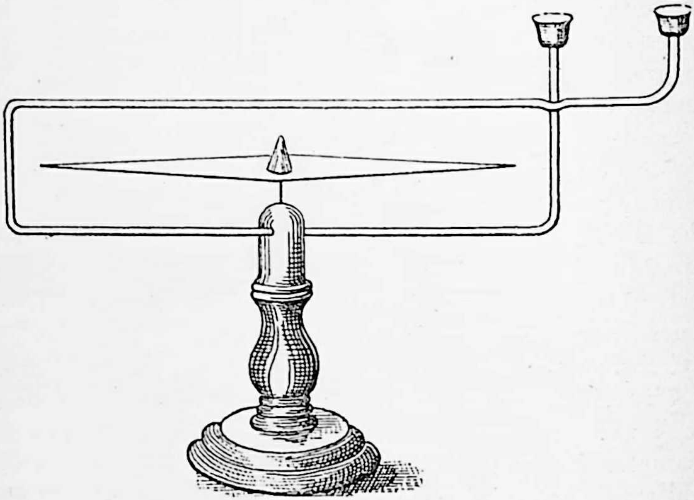


FIG. 80.

bar to be magnetised is plunged while the current is circulating round the solenoid, answers every purpose.

§ 106. Based on the magnetic properties of the current, galvanometers, or instruments for the detection of minute currents of electricity, are constructed. The galvanometer consists essentially in a horizontally poised magnetic needle placed between one or more coils of wire, as shown at Fig. 80. When this instrument is connected to any circuit through which it is suspected that electricity is flowing (the coil being in a line with the needle), if any current passes, the needle will be deflected out of its usual north and south position, and take up one which will be nearer east and west, as the current is stronger. By increasing the number of turns in the coils which encircle the needle greater sensitiveness can be imparted to this instrument, which is then sometimes called a multiplier, from the fact that the multiplication of the number of coils multiplies the effect of the current on the needle. By employing an astatic combination (see § 21), of which one needle is inside the coil and one out (see Fig. 81), since the combination is no longer restrained by the earth's magnetism the delicacy of the instrument is still farther enhanced, and minute currents, amounting to only $\frac{1}{50000}$ of an ampère, can be readily detected. It will be perceived that although this instrument is usually designated a *galvanometer*, yet it has really no claim to the title, since it does not *measure* the current, but only indicates its presence, and that a better name would be galvanoscope. It is possible, however, to construct a galvanometer on the above lines which shall actually measure the amount of current passing.

§ 107. In order to do this with any degree of accuracy it is necessary that the conductor which passes over or under the needle, and which carries the current that deflects the needle, should have a resistance so small, as compared to that of the remainder of the circuit, as to be practically negligible. For this purpose in the *ammeter*, as this instrument is called, the conductor may conveniently take the form of a stout strip of copper, to each extremity of which is attached a binding screw for connection to the circuit. From the centre of this copper strip, but insulated from it, rises a sharp-pointed needle which supports a pivoted magnetic needle. Over the copper strip, but under the needle, is placed a graded circular card, the zero points of which coincide with the

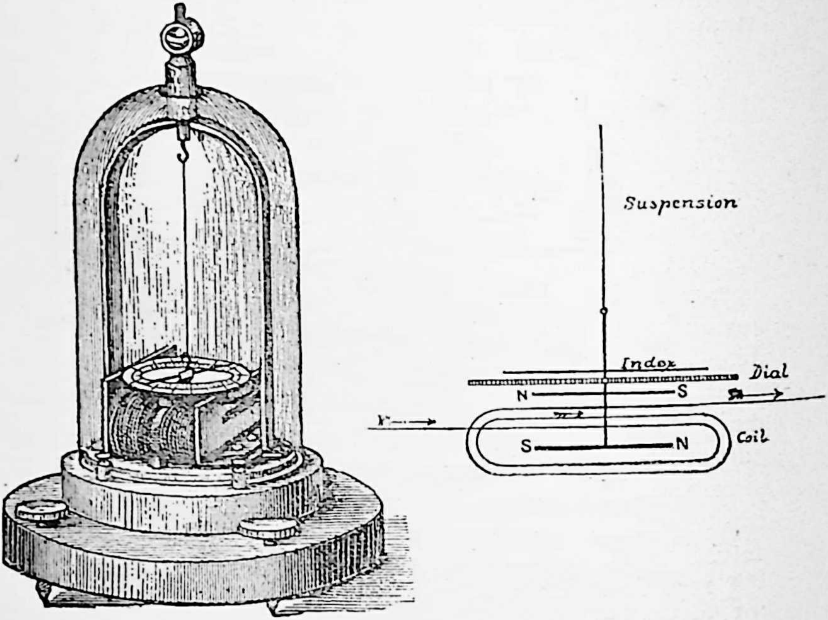


FIG. 81.

length of the said copper strip. If the instrument be placed in the magnetic meridian, and turned so that the zero point on the card is in a line with the needle when it points north and south, then by noting the deflection which the needle gives when connected to a battery and decomposition cell depositing 18·35 grains of copper per hour, the deflection indicated by the needle will correspond to one ampère of current; and by increasing the battery power until the deposition of copper takes place at the rate of 36·7 grains per hour, the deflection will indicate two ampères; and higher readings can be obtained by increasing the battery current until as many desired multiples of 18·35 grains of copper are deposited,

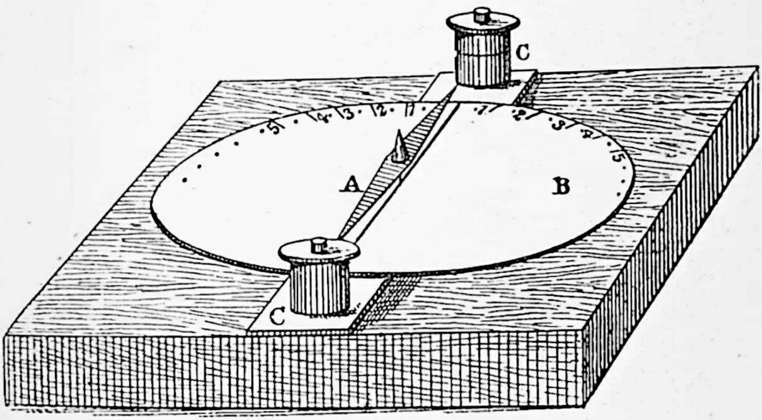


FIG. 82.

each multiple being equal to an increase of one ampère of current. It will be noted in grading such an instrument by these means (and the deflections should be marked as ampères on the graded circle) that although the readings are fairly equal until they reach about 20° of arc, yet beyond this point they rapidly fall off, so that an increase of current does not produce a corresponding increase in deflection. This simple form of ammeter is illustrated at Fig. 82, in which A is the magnetic needle, B the graded card, and C the ends of the strip of copper with the terminals affixed thereto. To protect this instrument from air currents it should be furnished with a glass cover, or the whole may be inclosed in a circular brass box with glazed front, similar to an ordinary compass needle. This form of instrument, though easy to construct and convenient for battery work, is not well adapted for general use for the following reasons. First, the presence of iron, steel, or magnetic bodies in its neighbourhood falsifies its readings by attracting the poised magnetic needle; secondly, the needle itself may lose or gain magnetism by being subjected to the effect of strong currents or other causes; thirdly, the pivot may become abraded, and consequently present greater friction, which will necessitate a larger current being required to produce the same deflection; and fourthly, the degrees which represent the higher currents will be found to run so closely together as to render them almost illegible; and lastly, the very delicacy of suspension, which is an advantage in reading very minute currents, becomes a disadvantage in ordinary workshop use, as the long time for which the needle oscillates before coming to rest entails a great loss of time in obtaining the readings. For this reason, except for "milliampère-meters" such as are used by medical men for measuring minute currents of thousandths of an ampère, this form is not much used.

§ 108. For practical purposes ammeters are constructed in which advantage is taken of the attractive power that a solenoid exerts on small masses of iron placed near it, and which tends to suck the iron into its interior with a force directly as the strength of the current energizing the solenoid. Fig. 83 illustrates an ammeter of this description, in which A is a curved solenoid wound with coarse wire; B a scythe-shaped piece of thin iron, suspended by a delicate pivot at C; D is a pointer travelling over the quadrant of a circle

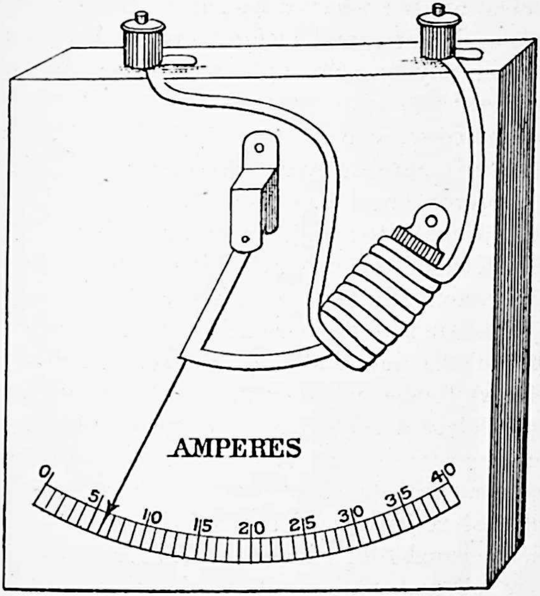


FIG. 83.

inscribed on a card; E and E′ are the terminals of the solenoid. When this instrument is connected to a circuit by means of the terminals, E E′, the solenoid becomes magnetic and attracts the blade of the scythe piece, B, into its interior to a lesser or greater extent, dependent on the volume of current passing, and in so doing causes the pointer to indicate on the graded scale the number of ampères. This instrument can of course be graded either by means of a constant battery and decomposition cell, as previously described, or else by comparison with another standard ammeter. Instruments of this class are not affected by the proximity of masses of iron or of magnets, and, owing to the fact that they do not contain any permanent magnets, do not require recalibration.[1]

§ 109. Since we can ascertain the E.M.F. (in volts) which sets up a current by noting the number of ampères that it can force through a given resistance, it follows that provided we make the resistance in circuit so large that the resistance of the generator itself, be it battery or other, be practically negligible, we can construct a *voltmeter*, or instrument for measuring the pressure in volts, on either of the lines indicated above. In practice, the coils of a voltmeter, whether made of the galvanometer or of the solenoid type, are made of fine German silver wire having a resistance of at least 50 ohms for every volt to be measured. Under these circumstances, since the internal resistance of any of the usual sources of electricity capable of giving an E.M.F. of 1 volt lies between ·08 and 5 ohms, it results that with such a margin of resistance as above stipulated, namely, 50 ohms for each volt to be measured, the total error in the reading cannot exceed ·2 per cent. of the entire indications.

Let us say, for example, that the E.M.F. of the generator were 1 volt, with an internal resistance of ·05 ohm,

[1] To recalibrate—to verify the readings of instruments by comparison with other standard instruments.

this with the resistance of the voltmeter itself would amount to 50·05 ohms, and this gives $\frac{1}{50 \cdot 05} = \cdot 0199$ ampère as the current passing through. Again, let us suppose the case of a generator giving 1 volt with an internal resistance of 5 ohms; here the total resistance would be 55 ohms, and the resulting current $\frac{1}{55} = \cdot 018$ of an ampère, so that even in these extreme cases a total error would not reach 2 per cent.

§ 110. With regard to the chemical effects of the current supplied by the battery, these are the same in kind as those produced by the frictional and influence machines, differing only in degree and in the facility with which the effects can be observed, owing to the continuous effects of the more constant current. We may say roughly that all solutions of compound bodies which can conduct the current are split up into their constituents; primarily into less complex forms, and finally, if the E.M.F. and volume of current supplied be sufficient, into the elements which constitute the compound, and that those compounds, consisting of two or more elements, or groups of elements, which are themselves electro-positive or electro-negative are split up by the current and carried along with it.[1] The electro-negative constituents depositing themselves on or around the positive pole of the battery, while the electro-positive elements are carried on to the negative pole. Based on these facts we have the art of electrotyping, in which a deposit in copper, iron, or other metal is caused

[1] This phenomenon is known as "the migration of the ions."

to form on the surface of a mould previously faced with plumbago or other good conductor of electricity, which is then immersed in a bath containing a solution of the metal to be deposited, the mould itself being connected by a conducting wire to the negative pole of the battery, while a sheet of similar metal to that which it is intended to deposit is connected to the positive pole of the same battery and also immersed in the fluid of the bath. Under these circumstances, when the current passes, the metallic solution is decomposed, the metal being deposited on the mould while the solvent collects around and dissolves the metal plate or "anode" which forms the positive pole or "electrode."

§ 111. In the process of *electroplating* the mode of procedure is almost exactly the same, except inasmuch as it is intended to cover a baser metal with a nobler one, or at least with one which is not so susceptible to rust or tarnish, and consequently a perfect adherence between the body of the object to be coated and the electrically deposited coating is of the highest importance. For this reason the object to be coated has to be polished, and rendered chemically clean before immersion into the bath containing the solution of the metal to be deposited. It would be out of place here to enter into details of these processes, of which many excellent and cheap handbooks give every information.[1]

§ 112. Another and a most important application of the decomposing effect of the electric current is that of the extraction of metals from their ores by means of electricity. We need only advert to the preparation of aluminium,

[1] See Bonney's "Electroplaters' Handbook."

and to the extraction of copper in an extremely pure form by means of "electrolysis," as this decomposition by electricity is termed. So great is the advance in this branch that aluminium with a purity of 97 to 99 per cent. guaranteed can be bought at five shillings per pound, and copper can be prepared, having a purity of 99 per cent., as a commercial article. It is found that owing to the inherent force of chemical attraction existing between different compounds, different amounts of E.M.F. are required to separate the constituents. The following table will give a general idea of the electro-motive force required to separate various metals from their compounds, and the amount deposited per ampère per hour.

Table of the Number of Volts required to effect the Decomposition of Metallic Solutions, with the Amount deposited per Ampère per hour.

Names of Metallic Solutions to be Decomposed.	Volts required to effect Decomposition.	Grains deposited per Ampère hour.	Grammes deposited per Ampère hour.
Copper (from sulphate) . .	0·5	18·36	1·19
Copper (from cyanide) . .	5· to 7·	18·36	1·19
Zinc (from sulphate) . . .	1·	18·95	1·23
Zinc (from cyanide) . . .	4· to 5·	18·95	1·23
Iron (ferrous solutions) . .	5· to 6·	16·2	1·05
Nickel (from cyanide). . .	6· to 9·	17·36	1·125
Nickel (from ammonio sulphate)	5· to 7·	17·36	1·125
Silver	1·	62·9	4·0825
Gold	1·	38·18	2·475
Tin (stannous solutions) . .	0·5	34·4	2·23
Brass	5·	18·65	1·21

§ 113. Another noteworthy property of the electric current is its power of producing heat during its passage through bodies. The student will at once recognize in this fact another instance of the correlation of energy; and in point of fact the heat evolved is simply a transformation of that mode of motion in the molecules of bodies, which we designate *electricity*, into the other form of molecular motion known as heat; so that whatever be the amount of heat generated, the corresponding amount of electricity disappears. The amount of heat set up by an electrical current in any circuit depends on two factors: first, the amount of current; secondly, the resistance in circuit. In other words, it may be expressed algebraically as: $H = C^2 R$, in which H stands for heat, C for the current, and R for the resistance; so that if one ampère produced a rise of temperature of 10° in a wire having a resistance of one ohm, two ampères passing along a similar wire, would effect a rise of 40°. If, the current remaining the same, the resistance of the wire were doubled, the heat would simply be doubled also. The reader will notice that to get the same amount of current to pass through a wire having twice the resistance of the former wire the E.M.F. will have to be doubled. So that another way of expressing the same fact is by the formula $H = \frac{E^2}{R}$; or in words, the heat evolved is equal to the square of the electro-motive force divided by the resistance. Hitherto no very important applications of the heating effect, *per se*, of the current have been made, if we except only the process of welding metallic rods, which is effected by causing a heavy current to pass between the two pieces to be joined, which are placed in juxtaposition; and the measurement of the E.M.F. and quantity of current by means of the elongation due to the heat set up in a wire stretched between two springs, as in the Cardew voltmeter and ammeter. The "electric cautery" is also an application of the heating effect of the current, and consists in a platinum wire, of about No. 22 B.W.G., through which a current of twenty ampères is caused to pass. This is sufficient to raise the platinum wire to very nearly a white heat, so that flesh can be cauterized, or a small tumour excised, without any blood exuding, since the wound is cauterized at the same time as the excision takes place.

§ 114. Since the phenomena of light are so closely allied to those of heat, and seem to be due to a higher rate of vibration only, it will not be surprising that light as well as heat can be set up by the electric current. This phenomenon is best studied in substances which present a comparatively high resistance to the passage of the current, and which are not easily melted. If a current of about 25 ampères be caused to pass through a platinum wire of about No. 22 B.W.G., the wire will become brilliantly incandescent. This was the principle of Edison's first lamp; the chief difference being that the platinum wire was inclosed in a bulb of glass from which the air was extracted with a view to prevent the disintegration of the metal: but the incandescing or light-giving point of platinum lies so close to its fusing point that these lamps never came into general use, because either the light was insufficient, or else the platinum gave way. A better material for exhibiting the lighting effect of the current is carbon, and this forms the filament in the modern incandescent lamp, of which we present an illustration at Fig. 84, in which A is the glass bulb, C C′ two platinum wire loops, with extensions sealed into the glass bulb, and attached by means of a carbonaceous paste to the bent carbon filament B, D being the point at which the air is extracted and which is afterwards sealed by melting the glass.

§ 115. A very powerful source of light is the electric arc, and this takes place when two rods of carbon, through which a current of electricity is passing, are separated from one another to a small distance in air so as to cause the current to pass through the air, the molecules of which are thrown into rapid motion and become heated to whiteness, giving rise to a light of the most dazzling brilliancy. The first arc light was displayed at the Royal Institution, by Sir Humphrey Davy, in the year 1801. A battery of 2,000 elements connected in series was employed, and this gave an arc between two carbon pencils of about four inches in length. In modern arc lamps refined mechanical and electrical appliances are introduced in order to maintain the carbons at an unvarying distance, or to regulate that distance (within certain limits) to suit any variation in the current.[1]

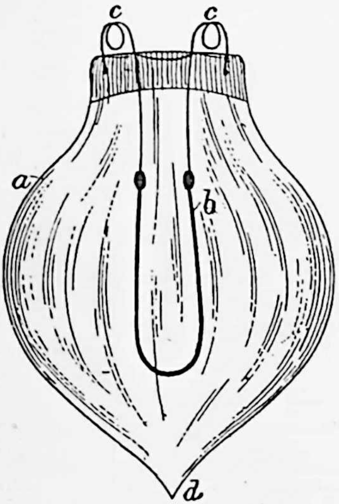


FIG. 84.

[1] The reader will find full illustrated descriptions of arc lamps in "A Guide to Electric Lighting."

§ 116. With regard to the physiological effects of the current, it must be noted that, owing to the high resistance of the skin, batteries capable of furnishing considerable E.M.F. must be employed (unless indeed some very sensitive portion of the body be included in the circuit, such as the tongue, the eye, or an open wound) in order that the current may be felt. Under these circumstances if any considerable portion of the human body form a part of the circuit of a Voltaic pile or battery, a separate shock is experienced every time a connection is made or broken with the poles of the apparatus, provided the skin through which the electric current is to pass be sufficiently moist to allow its being transmitted. The shock experienced from a Voltaic battery is similar to that resulting from a large Leyden jar very weakly charged, and its intensity is greater in proportion to the number of elements placed in series. Forty volts are generally sufficient to give a shock which is sometimes felt in the arms, with 80 volts the sensation extends to the shoulders. Independently of the shock felt on making and breaking contact with a battery, the continued flow of current through the body, as long as it forms part of the circuit, is generally accompanied by a continuous aching pain and contraction of the muscles. The painful nature of this continuous discharge becomes intensified with the increase in the quantity of current passing through the body, and death will ensue if a current of a few ampères be passed through the nervous system. As however the skin presents a resistance of about 4,000 ohms on a square inch of section, it requires a pressure of at least 10,000 volts to effect this result. Still, as by including a larger surface less resistance is interposed, it is never wise to expose oneself to be placed in circuit with any battery or generator giving more than 200 volts. The impression made by current electricity on some of the nerves of the face when they form part of the circuit is accompanied by the sensation of a vivid flash of light. The simple application of a piece of zinc and one of silver to the tongue or lips frequently gives rise, at the moment of the contact of the metals, to this perception of a luminous flash; but the most certain way of obtaining this result is to press a piece of silver as high as possible between the upper lips and the gums, or to insert a silver probe into the nostrils, while at the same time a piece of zinc is laid upon the tongue, and then to bring the two metals into contact. If the pupil of the eye be watched by another person while this effect is being produced, it will be seen to contract at the instant of making and breaking contact with the two metals. As we have already noticed, at § 77, a peculiar taste is perceived when the weak current set up by the contact of two small strips of similar metal joined together at one extremity with the tongue. This taste may be partly due to the excitation of the gustatory nerves by the current itself, but it is also owing in part to the decomposition of the saliva, which gives rise to hydrochloric acid on the one hand, and soda on the other. However this be, the electric taste is a very delicate test of the presence of weak currents, so much so that a small current, which would not give any indication with an ordinarily constructed galvanometer, will be distinctly tasted if the electrodes are applied to the tongue.

§ 117. Convulsive movements can be excited by current electricity in the muscles of an animal, even after death, as long as they retain their contractility; the effects thus produced are most striking, and in large animals, if powerful batteries be employed, are such as to give an impression that life has returned to the inanimate. In the case of the head of an ox or of a sheep, if the electrodes of a battery are inserted into the ears, strong muscular motions will be excited in the muscles of the face every time the circuit is completed or broken. The eyes are seen to open and shut spontaneously, they roll in their sockets as if again endued with vision, the pupils being at the same time widely dilated ; the nostrils vibrate as in the act of smelling, and the movements of mastication are imitated by the jaws. If the same experiments are performed on a dead human subject—as was done by Aldini on the body of a criminal executed at Newgate—very similar effects are produced, but owing to their conveying the more terrific expressions of human passions and human agony, they were necessarily of a more impressive character. It is not our province here to enter into a detailed account of the mode in which the stimulating effects, set up by the vibration imparted to nerves and muscles, by the application of the electric current, can be made subservient to the cure of diseases ; this will be found in the special works on electro-therapy. It will be sufficient to say that there are few diseases, ranging from toothache on the one hand, to cancer on the other, in which electric treatment has not been proposed and which, in some instances at least, has not been found beneficial.

§ 118. There are other sources of current electricity besides those dependent on chemical action ; the mere contact of two dissimilar metals is sufficient to set up electricity, and although this source is not practically brought into use, owing to the small E.M.F. set up, yet it is interesting as having been for a long time a bone of contention between the two rival schools of theorists, headed by Volta on the one hand, and by Galvani on the other; the former sustaining that the action of the battery was due entirely to the dissimilar metals being in contact; the latter holding the view that the electricity manifested was due to chemical action only.

§ 119. If two dissimilar metals are placed in contact at one extremity, the other two extremities being connected to any delicate instrument for determining the presence of a flow of electricity, it will be found that on heating the points of junction between the two metals a current of electricity will flow from one metal to the other round the entire circuit, the direction of the current set up being dependent on the nature of the metals used and the temperature to which the junctions are raised. The following table will give an idea of the direction of the current set up between the different metals at different temperatures tested; from which it will be seen that the direction of the current actually reverses itself in some cases when a critical temperature has been reached:—

Temperature of Junctions in Degrees Centigrade.	Names of Metals (Lead taken as Standard).										
	Lead.	Aluminium.	Tin.	Platinum.	Palladium.	Iron.	Brass.	Copper.	Silver.	Zinc.	Cadmium.
0°	0	0	0	3·−	5·+	15·−	0	1·−	1·5−	1·5−	2·5−
50	0	0	0	2·−	7·5+	13·−	0	1·5−	2·−	2·−	4·−
100	0	0	0	1·−	9·+	11·−	1·−	2·−	3·−	4·−	6·−
150	0	0	1·+	0	11·+	8·−	1·−	3·−	3·5−	5·−	7·5−
200	0	0	1·5+	1·+	12·5+	6·−	1·5−	4·−	4·−	7·−	10·−
250	0	·5+	1·5+	2·+	14·+	4·5−	2·−	4·5−	5·−	9·−	12·−
300	0	·75+	1·75+	3·+	16·+	2·−	2·5−	5·−	5·5−	10·−	14·−
350	0	·75+	2·5+	4·+	18·+	0·−	2·75−	5·25−	6·−	12·−	16·−
400	0	1·+	3·+	5·+	19·+	2·5+	3·−	6·−	7·5−	13·5−	18·−
450	0	1·+	3·+	6·+	21·+	4·+	3·25−	6·5−	8·−	14·−	20·−
500	0	1·+	3·+	7·+	22·5+	6·+	3·5−	7·−	9·−	16·−	22·−
550	0	1·5+	3·5+	8·+	24·+	8·+	3·75−	8·−	10·−	17·5−	25·−
600	0	2·+	3·5+	9·+	26·+	10·5+	4·−	9·−	11·−	20·−	30·−
	Difference of potential in microvolts (millionths of a volt).										

The meaning of this table is that if we place a piece of palladium in contact with a piece of lead, the junctions being kept, say, at 0° cent., a difference of electro-motive force or strain will be set up and a pressure of 5 microvolts would be exerted from the platinum to the lead, and that this difference of pressure would rise uniformly up to 26 microvolts as the temperature rose to 600° cent.; but if we were to employ iron instead of palladium in contact with the lead we should find the lead to be positive to the iron to the extent of 15 microvolts at 0° cent., the difference in pressure gradually decreasing as the temperature rose till it reached 350° cent., at which point there will be no difference in pressure between the two metals, and consequently no electro-motive force. On farther increasing the temperature a change in pressure will again exhibit itself, the iron now being positive to the lead, so that at 400° iron would be 2·5 microvolts higher than the lead, and so on until the temperature reached 600°, at which point the iron would exert an E.M.F. of 10·5 microvolts. It will be evident, therefore, that by choosing among the various metals mentioned in the above table it will be possible to construct a thermopile which shall give the best possible results if the junctions are kept at a given difference of temperature. The reason why this table has not been extended beyond 600° is because lead melts at that temperature.

§ 120. This arrangement of two metals is known as a thermopile, of which the simplest form is shown at Fig. 85,

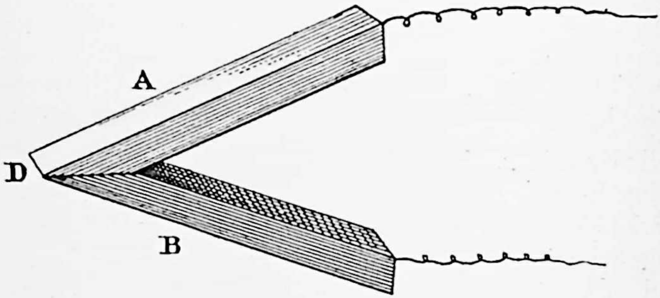


FIG. 85.

in which A is a bar of bismuth and B one of antimony, joined at their lower extremities and furnished with wires, C, C, for the convenience of conveying the current evolved in any desired direction. On heating the junction, D, a current is set up which flows from the bismuth to the antimony, thence through the wires back again to the bismuth. If several of these couples be joined together by their opposite extremities, as shown at Fig. 86, and the junctions, D, D, D, D, D, are heated while C, C, C, C are kept cool, we get a thermo-electric battery in which we get the cumulative effect of the heating of all the junctions, or in other words, a higher electro-motive force.

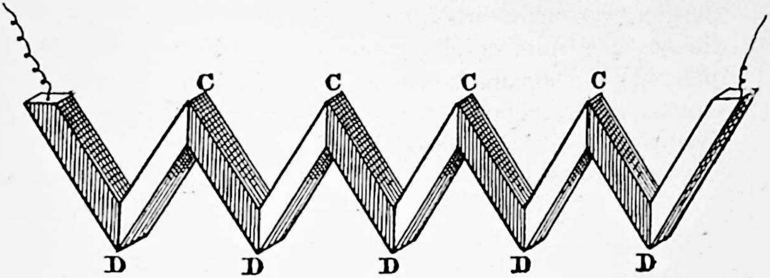


FIG. 86.

One of the best modern forms of thermopile is shown at Fig. 87, and is known as the "Clamond." It consists of alternations of iron and zinc arranged in an annular form in stories one above the other, leaving a central space wherein heat can be applied to one set of junctions while the outer junctions remain cool.

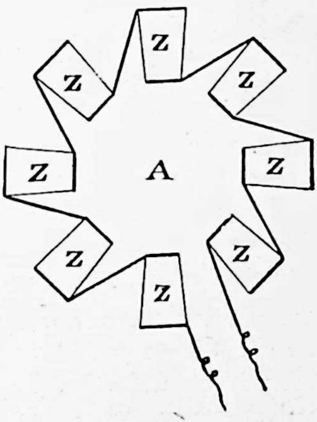


FIG. 87.

§ 121. Up to the present time, owing to the fact that thermopiles gradually lose their efficiency in use, a defect due in all probability to some "set" taken by the molecules of the two dissimilar metals, these instruments have not found any very extended applications in the arts. The only really serviceable instrument in which the thermopile plays an essential part is a very delicate form of thermometer, which we illustrate at Fig. 88, and which consists in a number of antimony and bismuth couples inclosed in a square box open at each end, which constitutes the thermopile proper, and which is connected by two wires to a delicate galvanometer. By this means

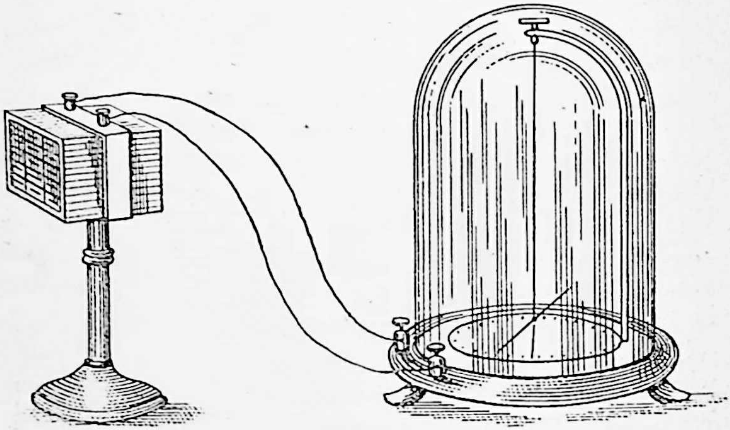


FIG. 88.

if either of the extremities of the thermopile have its temperature changed while the other remains the same, a current is set up and the degree of heat denoted by the amount of deflection imparted to the needle of the galvanometer. So sensitive is a well-made "Melloni's thermomultiplier" (the name by which this instrument is known) that a hand held at a distance of a yard from one of the open ends of the thermopile supplies sufficient heat to give a good deflection of the needle of the galvanometer. This instrument has also been used to measure the radiant heat of the moon. Owing to the fact that the entire circuit in the thermopile is constructed of metals, or at least of bodies possessing good conducting properties, and, therefore, in which any strain set up is almost immediately lost by rapid transferrence from molecule to molecule, the electro-motive force of the thermopile is, as compared with the Voltaic battery, very low, so that it requires eighteen couples of a Clamond thermopile to give an E.M.F. of one volt, which is about the voltage of a single Daniell cell.

§ 122. When a current is traversing a conductor, other bodies in the vicinity of this conductor are inductively affected by the flowing current. Precisely in the same way as a positively charged sphere will influence a metallic sphere in its vicinity and produce a negative state in the nearer surface, and a positive one at the farther; or if the second sphere be placed in contact with earth, so that the induced strain can communicate itself to earth and thus release itself, giving rise to a momentary current, so will a current flowing along a given wire set up a momentary current in a neighbouring conductor (if the circuit of this latter is closed) at the instant that it is approached to, or receded from, the wire carrying the current. It must be noted that this effect is only momentary, and is simply the result of the release of the strain set up by the inducing current on the induced body; and that these results having once been produced, no farther effects are noticeable until either the inducing wire is removed from its proximity to the induced body, or, what amounts to the same thing, that the current in the inducing wire is stopped or reversed;

in which case, the inducing strain being relieved, a current flows through the induced body in the opposite direction.

§ 123. This phenomenon can be easily studied, and the fundamental principles grasped by performing the following simple experiments, as illustrated at Fig. 89. Let A represent a galvanometer, and B a piece of wire about three feet long, with its two extremities connected to the terminals of the said galvanometer. A portion of this wire is straightened out, as shown, and is placed close

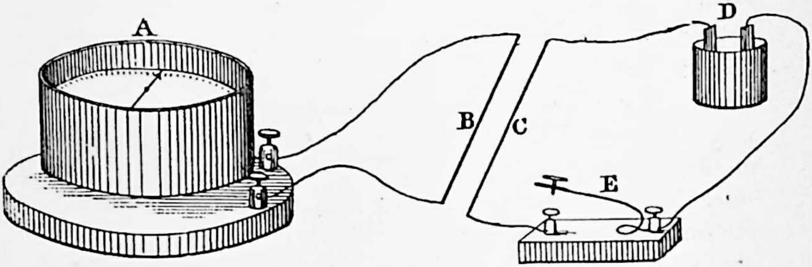


FIG. 89.

to and parallel with the primary wire, C, connected at the one extremity with one terminal of the battery, D, and on the other to the opposite terminal of the same battery through the intermediary of the "tapping key," or contact breaker, E. Now if, while the needle of the galvanometer is at rest on the O point, contact be made between the battery and the primary wire, C, by depressing the key at E, the galvanometer will immediately give evidence of the passage of a momentary induced current in the wire, B, by suddenly starting away from the zero point. If now the key be kept depressed, the needle of the galvanometer will come to rest at zero, showing that the induced secondary wire having taken up a polarized condition, which is maintained by the influence of the induction of the primary wire, C, no farther current flows; since, as we have seen, a current is "a release from a state of strain." But if now we break the circuit by releasing the tapping key, E, so as to stop the current in the primary wire, C, the molecules of the secondary wire, B, being relieved from the straining influence, revert to their original position, and a current in the opposite direction traverses momentarily this wire, as evidenced by a new deflection of the galvanometer needle in the opposite direction to that originally manifested.

If in performing these experiments the opposite ends of the primary wire, C, be connected to the poles of the battery, the same sequence of results will follow, with this exception, that the deflections of the needle will be in the contrary sense to those given in the first experiment. As might be expected from our knowledge of the laws which govern induction, the direction of the induced current in the secondary wire is *opposite* to that which flows along the primary wire at the instant of *making contact:* on the contrary, it flows in the *same* direction in the secondary wire at the instant of *breaking contact.*

If a number of wires be arranged in proximity to each other, disposed relatively as B and C in our illustration, Fig. 89, it will be found that the induced current in the secondary wire can, in its turn, set up a current in a third wire, and that this third can do likewise in a fourth, etc., there being, of course, a loss of energy at each fresh induction.

§ 124. The induced current thus set up by the action of a primary on a secondary is (neglecting the inevitable loss due to the distance between the two conductors) equal in energy to that of the primary. That is to say, if we send a current of one ampère at one volt pressure along a wire coiled into a spiral of four inches diameter, and place in proximity to this another precisely similar spiral (having the same length and the same resistance) we shall induce in it a current of one ampère at one volt pressure (deducting, of course, the effect of distance and the resistance of the secondary wire).

But if instead of employing the same length of secondary wire we had employed twice the length, since both the spirals would have been acted on inductively by the current in the primary spiral, an E.M.F. of two volts would now be set up, while the current would be diminished in proportion to the increased resistance due to the increased length of the secondary spiral or coil. In like manner, if the secondary coil be so constructed as to have only half the resistance of the primary inducing wire, the E.M.F. or voltage or "strain" set up will be only half that of the inducing current, while the current in ampères will (with the previously noted proviso referring to distance between the inducer and induced) be doubled.

§ 125. Based on the principles involved in the above phenomena, apparatus for raising or lowering the tension (E.M.F. or voltage) of any given current are constructed. These are known as "transformers," "induction coils," "medical coils," etc., according to the particular purpose to which they are applied. By *transformers* are generally understood such apparatus as will induce an alternating current of low E.M.F., and large volume in ampères, when supplied with an alternating current of high E.M.F., but of few ampères. Induction, or "Rhumkhorff," coils are those which, when fed by large currents of low E.M.F., give rise to currents of very high E.M.F., but of correspondingly small ampèrage. Medical coils partake of the character of these latter, inasmuch as they transform currents of low tension to those of higher; but the transformation is not carried so far, as too high a voltage is not of service in therapeutics; while certain devices for regulating the strength of the induced currents are introduced which are not needed in the two other forms.

§ 126. In order that the reader may form an intelligent idea of the construction of a transformer, we describe the very good type known as the "Hedgehog." This consists essentially in a gun-metal central rod, as support, which is cross-shaped in section. Into the four recesses of this cross are laid parallel four bundles of iron wire.[1] These are taped over and well insulated. The coarse secondary wire is now coiled, like cotton on a reel, round this composite core, carefully insulated, the two ends being brought out and attached to two terminals on an ebonite terminal board at the head of the coil. This secondary wire is now carefully enveloped in two layers of sheet ebonite, and the primary wire (which in this case is *finer* than the secondary) is wound on, and its ends likewise brought out to separate terminals at the head of the coil. This construction is shown at our right-hand illustration

[1] The effect of the presence of the iron is to heighten the inductive action of the primary current by concentrating the lines of force. This will be noted more fully in another section.

in Fig. 90, while to the left is figured the coil inserted (for protection) in an outer case which is made of stoneware, since if of iron it would become magnetised by the effect of the current flowing, and thus produce injurious perturbations in the inductive action of the inducing current. If the case were of any metal the current would induce currents in the case also, and this would likewise be

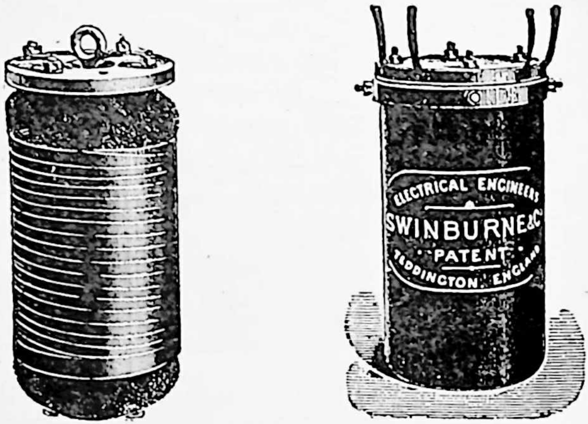


Fig. 90.

detrimental to the concentration of effect on the secondary wire.

Of course, to work such a transformer, the current supplied to the primary must, as we have already seen, § 122, be one consisting either of a number of interrupted waves in the same direction, or else of a series of rapidly succeeding waves in alternately opposite directions, or "alternate currents," as they are termed. By the aid of this instrument the E.M.F. in volts of any given current can be lowered, while the volume of current in ampères can be increased at will, by varying the relative sizes of the wires employed to form the primary and secondary circuits. Thus if both the wires are the *same size*, and make the *same number* of turns round the frame or core, the E.M.F. in volts of the induced currents in the secondary will be the same as in those supplied to the primary. By decreasing the number of turns, while increasing at the same time the section of the wire em-

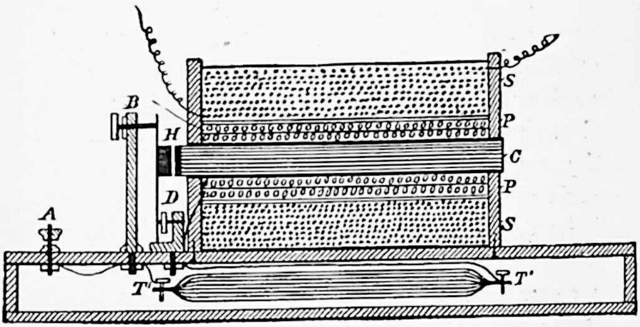


FIG. 91.

ployed to form the secondary coils, the E.M.F. is lowered and the ampèrage increased in like proportion.

§ 127. In the *induction coil* the object in view is to obtain from *a large current* of, comparatively speaking, *low E.M.F.* a *small current* of very *high E.M.F.*, and as these instruments are generally employed in conjunction with batteries, etc., giving continuous currents, induction coils contain in themselves an arrangement whereby the said continuous current can be rapidly interrupted. The general appearance and arrangement of the parts in an ordinary induction coil will be grasped on inspection of Fig. 91, which presents a sectional view of this instrument. An iron core, C, consisting of a cylindrical bundle of soft iron wires, is placed as a central core between two vertical insulating heads, such as stout sheet ebonite. Around this core are wound two layers of coarse wire, P P, for the primary. One end of this wire is connected to a terminal on the base board (this is in a line with the terminal, A, and is therefore not shown); the other end of this primary wire, as shown by the black curved line, is connected to an elastic metallic spring, D, which bears at its upper extremity, H, a soft iron boss, immediately facing the end of the soft iron core, C. This spring, in its normal position, rests against an adjustable screw at the end of the brass pillar, B, which is directly connected with the terminal, A. Now when a battery, or other source of current electricity, is connected to the terminal, A, and the other terminal (not shown) which is attached to the ending wire of the primary coil, the current travels from A to B, thence through the spring, D, to the beginning of the primary coil, circulating round the coils, and returning to the battery by the other terminal. In thus passing round the iron core it *magnetises it*, and the result is, that the said core attracts the boss, H, pulls it away from the screw of the pillar, B, and thus breaks contact. Contact being thus broken, the iron core loses its magnetism ; the elasticity of the spring, H, reasserts its power, and again the spring falls into the normal position of resting against the screw, B. Again the circuit is complete, and again the current flows, re-magnetising the core and producing the same cycle of effects. Consequently this contact breaker automatically produces, by virtue of the rapidly alternating magnetisations and demagnetisations of the iron core, that succession of interrupted currents which is essential to the production of these induction effects. Around the two layers of primary coarse wire is coiled a large number of layers of very fine wire (very carefully insulated both from the primary and also between each layer) which forms the secondary coil, as shown at S S. The ends of this secondary wire are brought out from the heads of the coil and attached to well insulated terminals. In order to absorb the induced current which is set up in the turns of the primary wire itself, and which would act detrimentally to the efficiency of the coil, a condenser, consisting of tinfoil interleaved with paraffined paper, is placed in the base of the coil and connected at its two opposite coatings to the break pillar and spring respectively, as shown at T and T′. When such an instrument is connected up to a suitable battery the contact spring, H, immediately starts into oscillation, vibrating at from 400 to 500 times per second, and thus gives rise to a very rapid succession of interruptions in the circuit of the primary wire, P P′. Consequently powerful induction effects are set up in the coils of the secondary, S S, and if wires attached to the terminals proceeding from these coils are brought into proximity, a continuous stream of vivid sparks is displayed; or if one or more vacuum tubes be placed in the circuit (according to the strength of the coil) they can be brilliantly lighted up.

§ 128. In general features the *medical* coil is very similar to the "sparking" induction coil just noticed. The salient points of distinction are: 1st, the means by which the strength of the induced current can be regulated without altering the battery; 2ndly, adaptations for allowing the extra current in the primary itself to be used by the practitioner ; 3rdly, the non-employment of a condenser; and 4thly, the use of a commutator in order to reverse the direction of the current in the primary at will: this is also employed in the better class "sparking" or Rhumkorff coils. At Fig. 92 we give a sectional view of an ordinary medical coil, in which R represents the regulator, consisting of a thin brass tube, sliding over the central bundle of iron wires, this tube is furnished with a knob or stud by which it can be drawn off or pushed in over the iron core. When pushed quite in it prevents

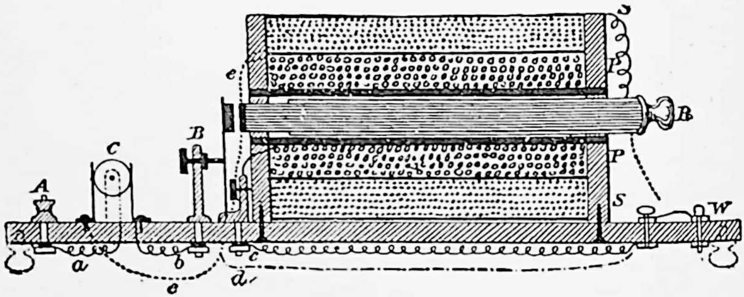


FIG. 92.

(by the induction currents set up in itself) the magnetisation of the iron core, and consequently lessens the inductive effect of the primary upon the secondary. The primary coils are shown at P P and are connected at one end to the clapper spring of the contact breaker, B, while the other end goes directly to a terminal (not shown) behind the terminal A. The secondary wires are brought out at S, where they couple up to the handles, rheophores, etc., used for the distribution of the induced secondary current. The battery current, on its way to the contact screw post of the contact breaker, B, is caused to pass through the commutator or current reverser, C, so that according to the position given to this latter the direction of the inflowing current may be reversed. At W is a switch, by means of which connection can be made between primary and secondary coils, or broken, at will, and by the aid of this device and the relative connected wires, *a*, *c*, *d*, and *e*, the effects of the "extra" current in the primary (set up by induction between its adjacent coils) can be joined to those of the secondary, and thus utilised. Fig. 93 shows the same coil in plan. The

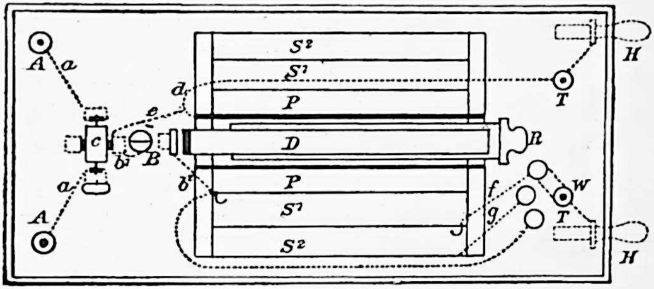


FIG. 93.

service which the medical induction coil has rendered to suffering humanity is indubitable ; but it should never be used without duly qualified advice. Its good effects seem to depend upon the involuntary vibratory motion into which the muscles, and probably also the nerves, are thrown while influenced by the molecular motion we designate electricity.

§ 129. It will be evident from the facts that we have noticed at § 102, that the phenomena of *magnetism* are dependent on a peculiar manifestation of *electricity* ; or, to express oneself in a familiar manner, magnetism is current electricity viewed from another standpoint. We have seen that the heating, the lighting, the chemical, and the physiological effects of electricity manifest themselves along the line of motion; its magnetic effects are displayed at right angles, or we may say, tangentially, to the direction of the flow. Therefore whenever a current of electricity is set up along a conductor, a magnetic "field" is simultaneously produced around the conductor of a strength which is directly as the number of ampères which is passing through the conductor. So that we may consider a magnet to be a body, the molecules of which are surrounded by currents of electricity circulating at right angles to the direction of the poles. An illustration of a single such molecule, with its circulating current and consequent magnetic polarity, is given at Fig. 94. How these continuous currents are kept up in the natural lodestone, and in permanent artificial magnets, we know not; we know that we can cause hard steel, cast iron, nickel, cobalt, etc., to become magnetised by the action of a current sent round bars, etc., made of these metals, which currents appear to induce similar molecular currents in the mass of the metals, as evinced both by the acquisition of magnetic properties, by the shortening of the bars, due to new molecular arrangement, and by the magnetic "note" simultaneously elicited. We have proof that these circulating currents do exist in the fact

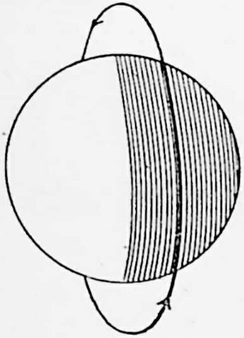
N  S

FIG. 94.

that we are able to induce other currents in conductors by approaching them to, or causing them to recede from the poles of permanent or temporary magnets, however produced. We may therefore consider a magnet as a body having its molecules disposed as illustrated in our Fig. 95, so that the direction of motion, or strain, is the same in each and every molecule, consequently the polarity exhibited at the free extremities is the same as shown in the single molecule at Fig. 94. From this it would appear that those bodies which are capable of per-

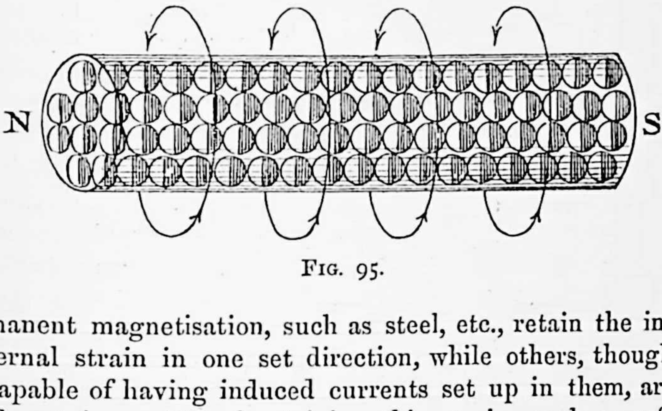


FIG. 95.

manent magnetisation, such as steel, etc., retain the internal strain in one set direction, while others, though capable of having induced currents set up in them, are almost incapable of retaining this strain, such as soft iron; others again seem unable to take up in any degree the individual molecular induced currents which constitute the magnetic state.

§ 130. Since we may roughly define magnetism as being the *tangential manifestation of current electricity*, it will not be difficult to understand that in the same way that a current of electricity can disturb the condition of a neighbouring conductor, and produce a current in the said conductor by induction, on approach to or recession from the inducing current, or on the commencement or cessation of the inducing current, so currents may be set up in conductors by causing them to approach to, or recede from, the poles of permanent or temporary magnets. To the immortal Faraday we owe the discovery of the identity of electricity and magnetism, which he proved in the following simple manner. A horseshoe magnet, as shown at Fig. 96, was fitted with a soft iron armature, B, around which was coiled several feet of insulated copper wire, the extremities of which were brought almost into contact at C. On bringing the armature, B, suddenly into contact with the poles of the magnet, A, or by separating them as suddenly when once in contact, a momentary current was found to be set up in the coils surrounding B, which rendered itself evident by the production of a

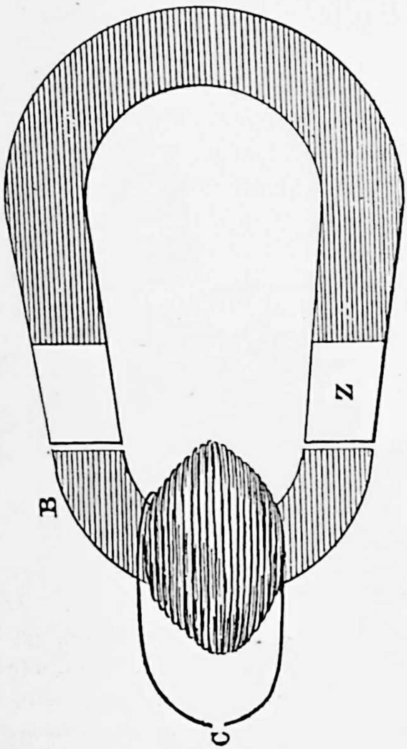


FIG. 96.

brilliant spark at C. On farther examination it was found that the direction of the current set up in *making* contact between the armature and the magnet was in the reverse direction to that elicited when contact was broken. It was soon found that actual contact and disruption were not necessary to the production of these effects, and that currents were always set up when the conductor (which in this case took the form of the coil of wire) was moved in any manner which would cause it to pass from a weaker to a stronger, or from a stronger to a weaker magnetic field. The idea that approach and recession were indispensable to the production of these induction effects has been neatly embodied in the following lines, by a contributor to "Blackwood's Magazine," which are here reproduced with a view to the retention of the facts in memory:

"Around the magnet, Faraday
Is sure that Volta's lightnings play;
But how to draw them from the wire?
He took a lesson from the heart:
'Tis when we meet, 'tis when we part
Breaks forth the electric fire."

§ 131. The honour of having applied this discovery to the construction of the first machine by means of which current electricity was obtained from a magnet is due to H. Pixii, who in 1832 devised the instrument illustrated at Fig. 97, in which two soft iron cores, wound like an electro-magnet, with one continuous length of insulated copper wire, are attached to the top cross-bar of a rigid rectangular frame. Below these is placed a powerful horseshoe magnet supported on an upright central spindle, capable of rotation on its axis, in such a position that its poles face the iron cores, and just clear their extremities. This spindle, and consequently the magnet, can be made to rotate rapidly on motion being imparted to the geared wheel at the lower end of the frame. The ends of the wire coiled round the cores are led to binding screws on a central terminal board, as shown. To these binding screws, wires may be connected to lead to the outer circuit, as shown. Of course, since the current set up in the coiled wire is in *one* direction while the magnet's limbs are approaching the cores, and in the *opposite* while they are leaving them, the currents given by this machine are *alternate* in direction. The chief defect in this machine was that of having to rotate a heavy magnet, since the mere vibration set up by rotation tends to weaken, if not to destroy, its magnetism.

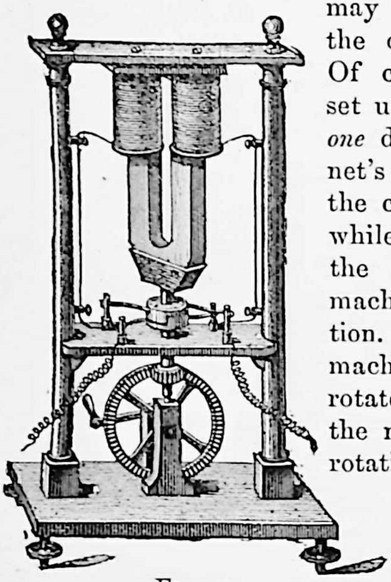


FIG. 97.

§ 132. In 1833 Mr. Saxton had the happy idea of making the magnet to be the fixed portion, while the lighter coiled cores (or "armature" as the combination is called) were caused to rotate. This enabled him also to apply a device termed a "commutator" to the rectification of the opposite currents, and to turn them, so to speak, in one direction only to the outer circuit. Bearing in mind that it is the armature, with its accompanying coil of wires, that rotates, and that this with the commutator are attached to the same spindle, the student will have no difficulty in following the mode by which the alternate currents are rectified if he refers to Fig. 98, which represents the coils of the armature attached to the commutator (the core being removed for clearness) at three different periods of its rotation. As will be seen, the commutator consists essentially in a short cylinder of metal divided into two halves, A and B,

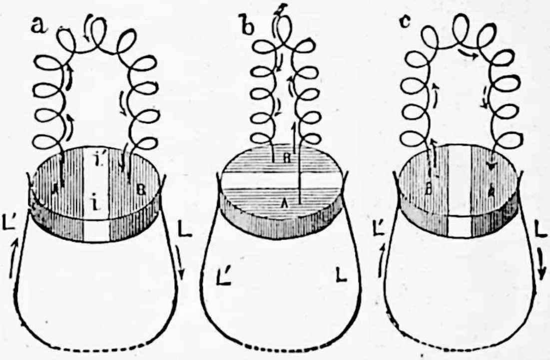


FIG. 98.

separated electrically from each other by some insulating material, such as ivory, ebonite, etc., as shown at I I. Two metal springs, L L′, connected to the terminals which lead to the outer circuit, press against the periphery of this cylinder or commutator. Now let it be supposed that the armature with its coils, *a*, is in a transverse position with regard to the poles of the fixed magnet, and that motion be imparted to it so as to cause it to approach them, or, in other words, to stand in a line with them; during this approaching motion a current will be set up in the coils in the direction from A to B, as shown by the arrows in the left-hand figure. When the armature arrives in a line with the magnet poles, and is therefore about to recede from the said poles, a change in the direction of the current will take place; but *now* the collecting springs, L L′, are resting on the insulating portion (left white in our illustration), as shown at *b*; the consequence is that momentarily *no current passes to the outer circuit*. But as soon as the armature has passed this (which we may conveniently term the "currentless" or "dead" point), a current is set up, owing to the retrocession, in the opposite direction, namely, from B to A; but owing to the fact that the portion B now finds itself at the opposite side of the circle, the current in the springs (or "brushes," as these are usually termed) is flowing in the *same* direction as before, viz., from L to L′. Thus are the two opposite currents, generated during each complete revolution of the armature, made to flow in the same direction in the outer circuit by means of the commutator.

§ 133. Many forms of magneto-electric machines have been devised since the days of Pixii, Saxton, and Clarke, but the grandest discovery, and that which led to the construction of the modern *Dynamo*[1] *electric machine*, is that of Soren Hjorth, who in 1854 perfected a machine similar in many points to the one last described, except that instead of employing powerful *permanent* magnets wherewith to set up the current in the armature, he used *cast-iron magnets* with soft iron polar extension, and these

[1] By dynamo is now understood a machine which converts the motion energy into electrical energy by means of *electro* magnets, in contradistinction to *permanent* magnets.

be coiled with wire, so as to be able to use them like electro-magnets ; and the current set up by the armature was made to pass, in its way to the outer circuit, around the coils of these electro-magnets. The passage of this current around these coils rendered the iron powerfully magnetic, and induced more powerful currents in the armature. The larger currents thus produced, again reacting on the electro-magnets in their passage through the coils, superinduced a higher state of magnetism in them, and this again exalted the electricity set up in the armature, this interaction increasing until a limit, depending on the magnetic saturation of the iron, was reached.

§ 134. It is not our province here to detail the many modifications which the different portions of the *dynamo* have undergone; it will be sufficient for our purpose to state that by giving the armature a cylindrical, or a ring shape, and by winding this said ring or cylinder longitudinally with continuous coils of wire, having connections brought out and connected with a many sectioned commutator, it is possible to produce currents from dynamos, which currents are practically continuous.[1] At Fig. 99 we illustrate a good form of dynamo, the right and left-hand cylindrical portions being electro-magnets, coiled with insulated wire; these electro-magnets are furnished with iron prolongations at the top and bottom, technically known as *pole pieces*, and these embrace, as shown, the central rotating armature, also coiled with wire longitudinally. The ends of these coils are elec-

[1] The student who is desirous of making further acquaintance with the *modus operandi* of dynamo making is referred to the author's book, "The Dynamo, How Made and How Used."

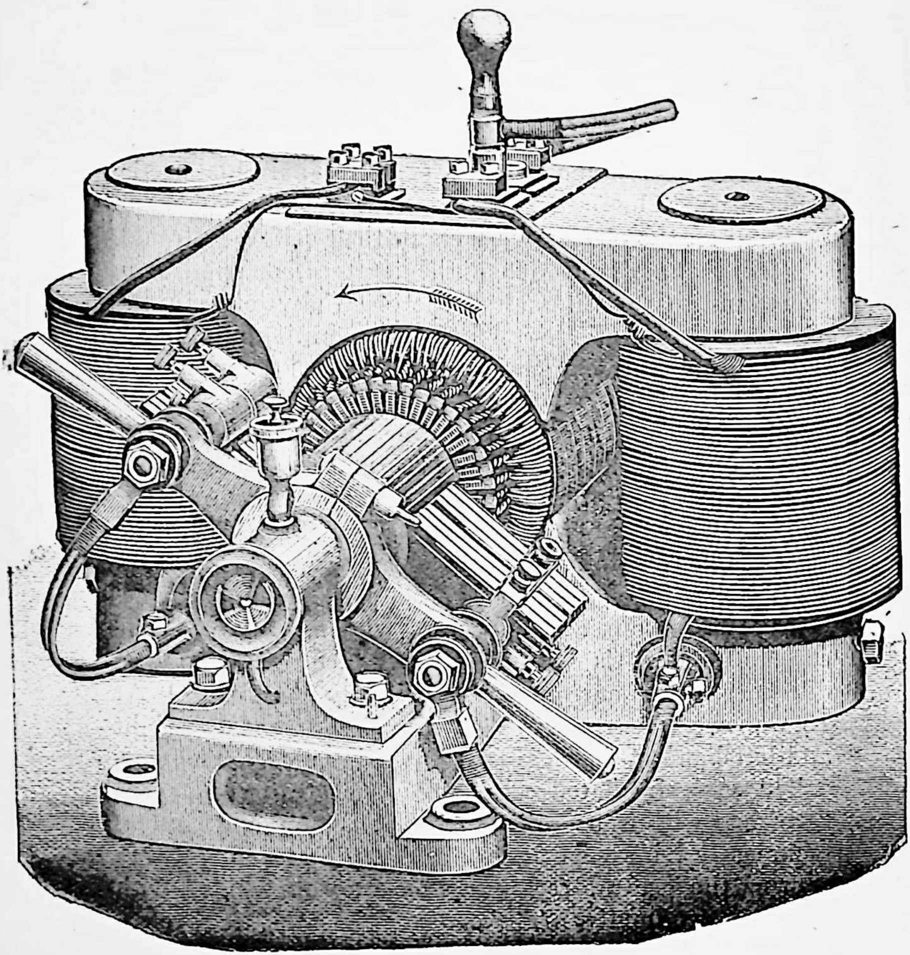


Fig. 99.

trically connected to the smaller cylinder, which constitutes the commutator, and which is built up of a number of copper bars insulated from each other. On either side of this commutator are metallic springs or brushes which serve to collect the current set up by the armature and led to the commutator bars, and convey it, after having in part, or entirely, passed through the coils surrounding the electro-magnets, to the terminals at the top of the machine, whence it can be conveyed to the outer circuit for use as desired. The observant reader will have noticed that the two electro-magnets in this machine are connected together by the iron yokes, of which the pole pieces form part, both top and bottom; consequently, if the electro-magnets were magnetised as usual, that is, with dissimilar poles at the same ends, the entire carcase of the machine would evince no active magnetism; but by so coiling and connecting the coiled wires, as to produce two north poles above, and two south poles below, we are enabled to produce and maintain consecutive poles (§ 13, last few paragraphs) at the centre of the upper and lower pole pieces, and hence act powerfully on the rotating armature which they embrace.

§ 135. In our last sections we have considered the action of a magnet (whether permanent or temporary) in setting up a current in conductors in its vicinity when these conductors have motion imparted to them. We will now direct our attention to the converse action, namely, of motion produced by the passage of a current in a movable conductor placed in the vicinity of a magnet. If on a wooden stand, as shown at Fig. 100, we erect a magnet bent twice at right angles, with its poles turned upwards, as illustrated at S and N, which, for convenience of supporting the movable portion of the device, should be connected together by means of the brass cross-piece H, and poise on a central pillar, P, by means of a pointed

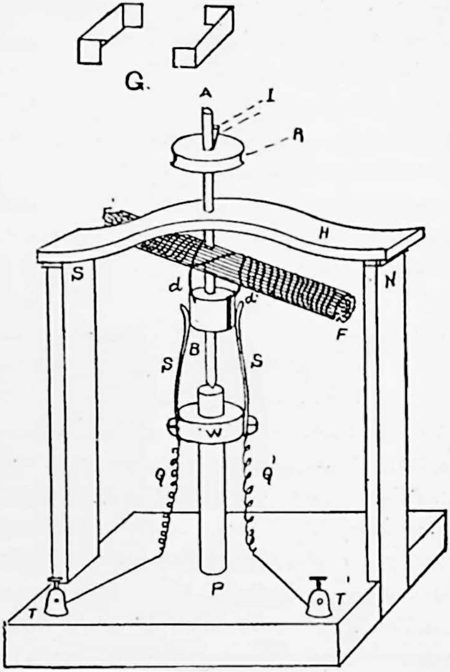


FIG. 100.

spindle, A, bearing at its upper extremity a helix of wire, or "solenoid" (§ 103), F F', the ends of which wire are connected respectively to the two halves of the split metal ring or commutator, *d d'*, we shall have an apparatus which will show well the relative effects of currents on magnets. There will only be needed a battery to supply current, the poles of which must be connected to the terminals, T T′, which in their turn convey the current along the coiled wires, *q q′*, to the springs or brushes, *s s*, which press lightly against the commutator, *d d′*. Let us suppose that having placed the solenoid with its extremities as shown in the figure, *not quite* facing the poles of the magnet, we couple up the positive pole of the battery (or, indeed, any other source of electricity) to the left-hand terminal, T, the negative being connected to T′. What takes place? According to our knowledge of the magnetic manifestation of a flowing current we shall find that the current passing along the wire, *q*, and entering the coil or solenoid at *d*, will convert it into a magnet having a North pole at F′ and a South pole at F. The consequence is that F′ is attracted towards the magnet pole S, while F is similarly attracted by N. Under the influence of this double attraction the solenoid (which we may conveniently designate as the movable electro-magnet or armature) is pulled round towards the poles of the magnet, carrying with it the spindle, A, and the commutator, B. When the solenoid or armature arrives with its extremities exactly facing the magnet's poles, S and N, *no current passes through the armature coils*, since the springs or "brushes," *s s′*, are now resting against the split, or non-conducting portions (see § 132, Fig. 98), hence it ceases to evince magnetic properties. And here it would stop, in this position, were it not for the fact that by the momentum gained during its travel from its original position it passes *a little beyond* the central line, in so doing carrying the slits of the commutator *a little past* the springs or brushes. Hence the spring, *s*, is actually resting against that section of the commutator which is attached to *d'*, while *s'* is resting against *d*. The result of this new position is that the current now enters the coils of the armature, F F', in the opposite direction to that which it did before, therefore the nearer extremities of the solenoid or armature are repelled by the poles of the magnet, N and S, and pushed on in the same direction until they stand *across* the said poles, when they enter into the sphere of attraction of the opposite poles, by which they are consequently attracted as in the first instance. Again, but with increased momentum, the armature flies to and past the attracting poles, breaking and renewing contact as before ; and this series of rapid magnetisations, demagnetisations, and reversals of magnetism continue as long as current is supplied.

We have here then a simple form of ELECTRO-MOTOR. It will be evident from the most cursory examination that this instrument is, in all essential particulars, the counterpart of Saxton's magneto-electric machine described at § 132 ; and, in fact, if the solenoid be furnished with an iron core,[1] and the spindle with a pulley, as shown at R, so as to drive it when necessary, or to convey motion from it when used as a motor, this little apparatus may be employed indifferently as a magneto-electric machine or as an electro-motor. Although this is by no means the best form which can be given to an electro-motor, since the bar-shaped armature churns the air very unnecessarily, while it is for a considerable portion of its travel at the least effective portion of the magnetic field,

[1] The presence of the iron core, by concentrating the lines of force, enhances the action, either as a motor or as a generator of electricity.

yet it embodies the principles which rule the construction of all electro-motors. From this it will be easily understood that any *dynamo* capable of setting up a current of electricity, if motion be applied to it, is equally capable of giving rise to motion if supplied with a current of electricity; in other words, the dynamo and the electromotor are convertible, which is yet another proof that

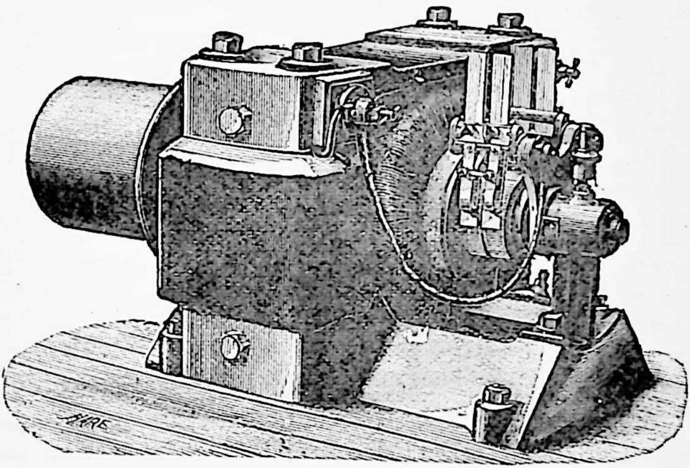


FIG. 101.

electricity is but a form of motion. At Fig. 101 we illustrate one of the best forms of modern electro-motors Here we have, as in the dynamo pictured at Fig. 99, the massive electro-magnets with their coils of wire, and pole pieces embracing the central movable armature, which consists of a cylindrical ring of iron over-wound with insulated copper wire. The arrangement of brushes commutator, etc., is precisely the same as in the dynamo previously figured. Motors of this class are coming into extensive use for driving tramcars, trains, cranes, and other machinery in situations where the employment of other motors would be inconvenient or impossible. It must be borne in mind, however, that the electro-motor is not a *producer* of power, but simply a converter of one form of energy, viz., *electricity*, into another, that is to say, motion. Hence the electro-motor is closely allied in its results to the band, the rope, or the shafting which conveys power from one part of a building, etc., to another. Thus, for instance, the power of a waterfall may be made to drive a dynamo near its banks, and the electricity thus evolved may be conveyed several miles from the spot where it was set up, by means of comparatively light wires, to the place where motive power is required, and here, by causing it to circulate around the coils of an electro-motor, the molecular motion electricity is reconverted into the desired mechanical motion at the spot where motive power is needed.[1]

§ 136. Passing over the numerous applications which have been made of the effects of currents upon each other, or upon masses of soft iron, such as the *needle telegraph*, in which the operator causes a magnetised needle at a distance to deflect at will to the right or left of a coil of wire surrounding it, according to the direction in which he sends the currents from the signalling end, and thus can transmit preconcerted signals to an observer at the receiving station ; or the Morse telegraph, in which an electro-magnet situate at the receiving station draws

[1] Full details as to the mode of making and using electro-motors will be found in the author's "Electro-Motors, How Made and How Used."

down an armature furnished with a pen or stylus upon a moving strip of paper, and thus imprints a dot or a dash at each time contact is made for a longer or shorter interval at the sending station, connected to the former by conducting wires or earth; or the electric bell, in which an electro-magnet, furnished with an armature carrying at one extremity a clapper, and provided with a make and break contact arrangement, as in the induction coil (§ 127), is made to actuate this armature and thus strike the gong in a continuous manner whenever a current of electricity is allowed to flow through its coils; we close by giving a brief description of the *telephone*, which combines at once the delicate vibratory motion which we call *sound*, with the polarized motion which we know as electricity.

§ 137. If any sound be made, if we speak, strike a drum, blow a whistle, or let off a cannon, the surrounding air is set into vibration, and the vibrations set up differ in amplitude, in rapidity, and in intensity, according to the causes which set them up. These vibrations striking against any elastic body throw it likewise into a state of motion. A singer with a powerful voice can break a wine-glass by singing near it, so well are the sound waves transmitted. So, if we suspend a thin sheet of iron by one of its extremities and speak or sing in front of it, the iron sheet will partake of the vibrations set up by the speaker or singer, and these vibrations will be faithfully copied in amplitude, in duration, in pitch, and in intensity. Now if behind such a sheet, near to it but not touching, we were to place a bar magnet, with one of its poles facing the sheet, it is evident that for every wave or undulatory motion imparted by the voice to the iron plate a corresponding disturbance would be set up in the magnetic (and therefore electrical) condition of the magnet. If around this magnet were coiled a few hundred feet of insulated wire, currents would be set up in this wire at every approach or recession of the sheet of iron (§ 130), and these currents would vary in intensity, and quantity, and direction, with the varying intensity, amplitude, and direction of the vibrations set up in the iron plate.

Now if we convey the currents thus set up, by means of prolongations of the ends of the coiled wire, to the ends of a precisely similar coil of wire arranged on another bar magnet facing a sheet of iron at a distant point, then, when these currents circulate around this second magnet, they will influence it either by strengthening it if the currents are travelling in such a direction as to increase its polarity; or by weakening it if they are travelling in an opposite direction; and these results will vary in intensity, amplitude, and in duration with the varying intensity, amplitude, and duration of the currents reaching this distant magnet's coils. Now the effect of this variation in this second magnet's power will evidently be to vary its pull or attractive force on the sheet of iron suspended in front of it, so that this second sheet of iron will itself be thrown into vibration, in correspondence with the sound vibrations originally imparted to the first iron plate or sheet. In its turn this second vibrating sheet will impart *its* vibrations to the air, so that a listener placed near it will hear reproduced the sounds originally set up before the first sheet. This then is the principle of the Bell telephone of which we present an illustration, Fig. 102. (In practice two precisely similar instruments are employed, one at the receiving end the

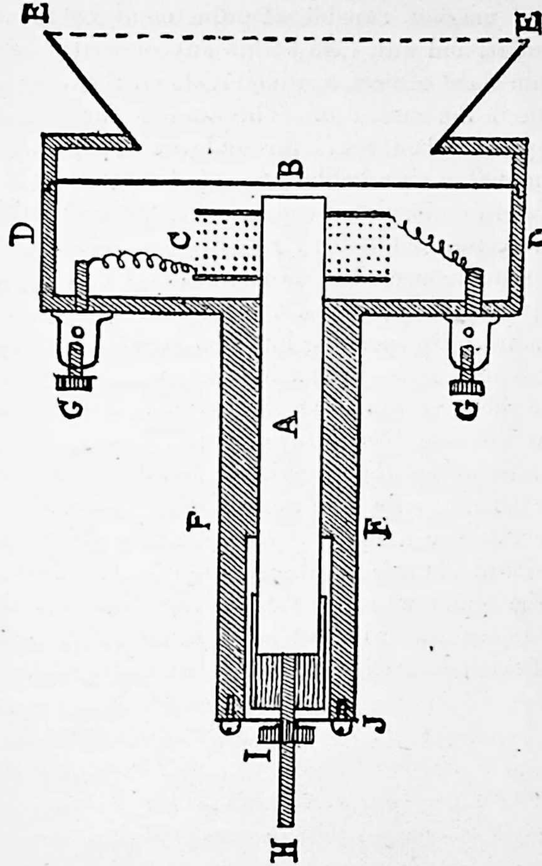


FIG. 102.

other at the transmitting end ; and either may be used indifferently as transmitter or receiver.) At A is a cylindrical magnet, capable of adjustment by means of the screw, H, and nut, I, to within any desired proximity of the thin sheet of iron, B, which rests on the inner edges of a ledge in the case, D D. This case is furnished with a mouthpiece or bell, E E. Around the upper extremity of the magnet, A, is a bobbin, C, coiled with several hundred feet of fine insulated copper wire, the extremities of which are connected to the terminals, G G. In use these terminals are connected by two wires to the corresponding terminals of a precisely similar instrument at, say, several miles distant. On speaking into the receiving instrument the diaphragm, B, is thrown into vibration, currents are set up in the C surrounding the magnet, A, these travel along to G G, and thence through the line wires to the similar terminals of the receiving instrument. There they disturb the magnetic condition of the magnet in that instrument, and consequently set up corresponding vibrations in its diaphragm, as already explained. The result is that the sound, whatever it be, is reproduced at the receiving instrument with all its characteristics of pitch, tone, inflexion, interruption, timbre, or amplitude.

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