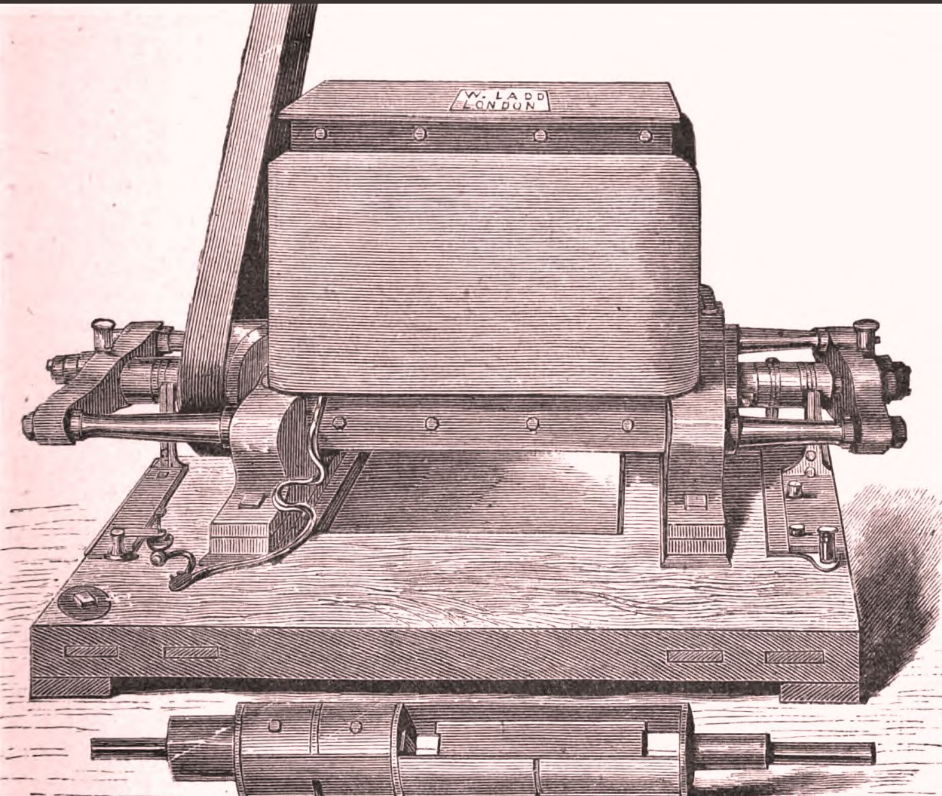

Magnetism: embracing electro-magnetism, ...

John Henry Pepper

MAGNETISM.

EMBRACING

ELECTRO-MAGNETISM, MAGNETO-ELECTRICITY, THERMO-ELECTRICITY—DIA-MAGNETISM—WHEATSTONE'S TELEGRAPHS.

BY

J. H. PEPPER,

Late Professor of Chemistry and Honorary Director of the Royal Polytechnic Institution; Author of various Works for Youth, &c.

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CONTENTS.

The Shepherd discovering the Magnetic Stone on Mount Ida with the Iron of his Crook.

MAGNETISM.

The magnetic or black oxide of iron, $Fe_3 O_4$, sometimes called the *lead*-stone or loadstone, is estimated as one of the most valuable ores of iron, because it enjoys the property, when freely suspended, of pointing to the north; and it does this by virtue of an inherent property which belongs to it, called magnetism.

The loadstone occurs native, and crystallizes in cubes, and is said to have been discovered by a shepherd on Mount Ida, who first noticed that the iron of his crook was attracted by it.

The magnet was not only called *magnes*, but "lapis Heracleus," from Heraclea, a city of Magnesia, a part of ancient Lydia, in Greece. It is also called *lapis nauticus*, because of its use in navigation; and *siderites* because the mineral attracts iron, which the Greeks called σιδερος.

"The earliest mention in English records of the primitive mariner's compass is that by Alexander Neckham, who describes the same in his 'Treatise on Things pertaining to Ships.' Neckham was born at St. Albans in 1157. A translation of his works, from the Latin, was published in 1866. In the reign of Edward III., the magnet was known by the name of the *sail-stone* or *adamant*, and the compass was called the sailing-needle or dial, though is long after this period before we find the word compass. A ship, called tl 'Plenty,' sailed from Hull in 1338, and we find that she was steered by tl sailing-stone. In 1345, another entry occurs of one of the king's ships, calle the 'George,' bringing over sixteen horologies from Sluys, in Normandy that money had been paid at the same placı twelve stones, called adamants or sail-stones repairing divers instruments pertaining to a shi

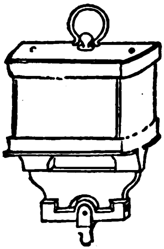


FIG. 1.
A mounted Loadstone.

Fine large pieces of loadstone are usually mou in handsome brass or silver boxes, and were hi prized in the reign of King Charles II., when Royal Society of England began to exert itseh the acquisition of scientific knowledge.

When examined with a magnetic needle, mineral is found to have two points where the ma netic virtue exists in the greatest intensity: these called poles, and are connected with the pieces soft iron which protrude from the case containi the loadstone; they take off the friction and we and tear of the mineral, whilst all cutting of tl stone, in order to obtain a hollow space between tl two poles, as in an ordinary horse-shoe magnet, is avoided. The magnetisı from the loadstone is easily conferred upon and retained by hardened steel.

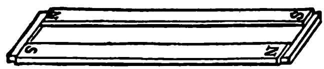


FIG. 2.—*Two Bars of Steel,*
Each marked N and S at their opposite extremities, and connected by pieces of soft iron, called "feeders."

It is only necessary to rub the steel or drag the loadstone round in one direction, taking care to put the pole N of the latter on the end of the steel bar marked S. An assemblage of steel plates in the form of an elongated horse-shoe, when carefully magnetised and fixed together, constitutes a kind of magnetic battery having greatly increased powers. (Fig. 3.)

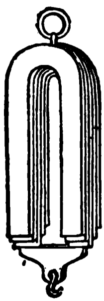


FIG. 3.

This would be called a compound horse-shoe magazine or battery, composed of an odd number of horse-shoe bars of different lengths. The union of unequal bars produces a step-like arrangement at the poles, the largest bar being in the centre, with the pair of bars next largest on each side, and so on progressively. This peculiar arrangement, with all other magnetic instruments, may be obtained from Elliott, Charing Cross, and possesses several advantages, especially when used to confer magnetism on other pieces of steel.

The magnets (Fig. 4) bearing the name of Scoresby are composed of many magnetized, laminated-steel plates, combined together so as to act uniformly as one bar, by which means a powerful magnetic arrangement is obtained. A piece

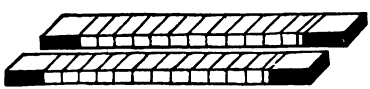


FIG. 4.—*Scoresby's Magnets.*

of steel, usually called a needle, when carefully balanced and suspended on a sharp point with a central hard metal cap, and then magnetized, is called a magnetic steel needle.

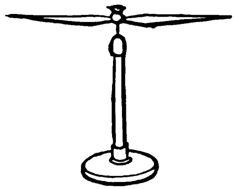


FIG. 5.

It is extremely useful for showing the influence of the magnetism of the earth as regards the horizontal-directive force, and is absolutely necessary in showing a repetition of the facts already explained in the article on "Static Electricity" (page 6), viz., that just as similar electricities repel, and opposite ones attract, so a north pole of a magnet repels the north pole of the magnetic needle, and the south behaves in a like manner with the south pole of the needle. Dissimilar magnetisms attract, therefore, the north pole of a bar magnet; one of those, shown at Fig. 2, will attract the south pole of the needle, and *vice versâ*.

At Elliott's may be obtained magnetic needles suspended in a beautiful manner, so that the needle moves either in a horizontal or in a vertical plane. When the needle moves in the horizontal plane, it is an ordinary mariner's compass; but when it is free to move in a perpendicular plane, it—however carefully balanced before magnetizing—dips downwards, and points to the earth like a finger-post, directing the eyes of the student to the terrestrial power of magnetism which causes the "dip."

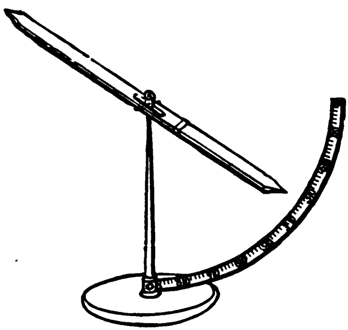


FIG. 6.—*Needle suspended, and dipping towards the Earth.*

The direction of the horizontal magnetized needle not only varies daily, called "diurnal variations," but it has changed during various periods of years. The magnetic needle does not point due north and south, but in a plane or direction peculiar to itself, called the magnetic meridian, to distinguish it fr the true or terrestrial meridian. Magnetic meridian lines are planes pass through the centre of the earth in the direction of the magnetic needle. terrestrial meridian is the plane passing through the same place on the axi the earth.

The angle made by these two planes is called the *declination of the nee* It is determined by measuring the angle which the direction of the nee makes with the meridian line. The declination was eastward at the beg ning of the 17th century; it was zero, or 0, in 1660, *i.e.*, the needle pointed d north and south. The declination now changed to the westward, and h increased to 24° 30′ in the year 1818, since which period it has steadily retr graded, and about ten years ago had reached 21° 48′ in London.

It would appear from the observations set on foot many years ago General Sabine, that the sun and moon are magnetic, and do affect the need in its diurnal movements.

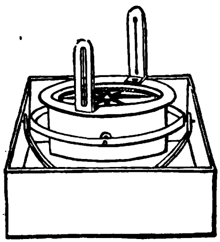


FIG. 7.

The marine compass only differs from the ordinary one in being suspended in such a manner that the motion of the vessel shall not disturb its horizontal position. The marine azimuth compass (Fig. 7) is a more elaborate mariner's compass, having within the circumference of the inner box sights for determining the angular distances of objects from the magnetic meridian, and being hung in detached gimbals.

The dipping needle or inclination compass is also found to vary as the dip increases, as might be expected, the nearer we approach to the north pole. At a point in 70° 5′ of north latitude and 96° 46′ west longitude on the west coast of Boothia Felix, a place was discovered by Captain Parry (the north magnetic pole) where the dipping needle became vertical, and the horizontal compass ceased to move right or left, or traverse. Captain James Ross discovered the other end of the great terrestrial magnetic power, the south magnetic pole, to be about latitude 73° south and longitude 130° east.

The student may realise such movements of the dipping needle by laying one of the bar magnets (Fig. 2) in the centre of a sheet of cardboard on which a circle has been described.

On moving the dipping needle round the circle, it will be found to take the vertical position at the poles A A, whilst it becomes horizontal at the equatorial position B B, *i.e.* midway between the north and south pole.

The inclination or dip varies like the horizontal declination. At London, it was 70° 27′ in 1720, 69° 2′ in 1833, and 68° 51′ in 1849; at the present time it is about 68° 30′.

The earth being virtually an enormous magnet, whose north pòle is in the southern hemisphere, and *vice versâ*, must affect all ferruginous matter on the earth by induction.

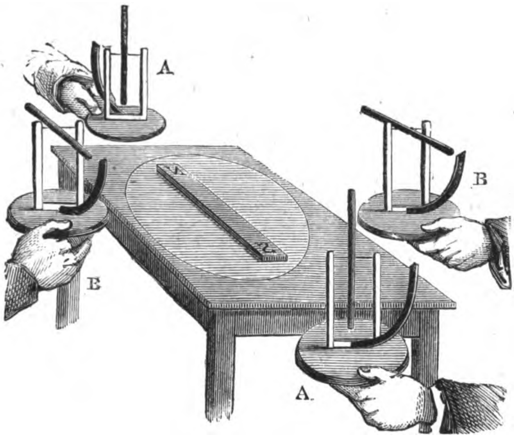


FIG. 8.

It was stated, in the article on Electricity, that the term induction would have to be used again; and the student is reminded that this is defined to be the magnetic influence set up by the mere neighbourhood or proximity of a body—the earth, or the loadstone, or a magnetized steel bar—having or possessing the magnetic virtue or force.

By placing variously shaped pieces of soft iron near a powerful magnet, they are supported or attracted so long as the magnet is kept sufficiently near them; but, as the distance is increased, they drop off one by one.

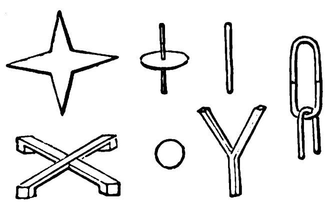


FIG. 9.—*Variously shaped pieces of soft Iron for showing Induced Magnetism.*

The magnetic power so quickly conferred on soft iron is as rapidly lost when it is removed from the disturbing cause, reminding one of conductors of electricity, which cannot maintain polarity; whereas steel, which acquires magnetic power more slowly, retains it with a tighter grasp, and, like non-conductors of electricity, glass, wax, &c., can maintain magnetic polarity.

On the supposition that all terrestrial magnetism has an electrical origin and is produced by currents of electric force which circulate around the globe, a very pretty piece of apparatus is constructed, consisting of a distribution of wires, covered with silk, over a terrestrial globe in parallel lines of latitude.

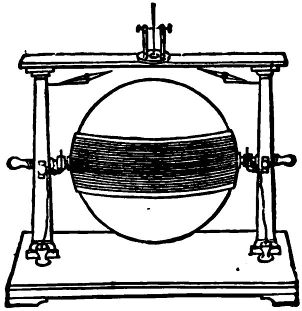


FIG. 10.—*Model made by Elliott*,
Showing that electrical currents circulating around a globe produce magnetic currents.

The dipping needle and horizontal needle held in different positions on the surface of the globe, whilst the wires are connected with the voltaic battery, give the student a very good notion of the natural directive power of the magnetism that exists over the surface of the earth on which we live, and also illustrates again the "*inductive*" power of magnetic force.

The force which rules the position of the magnetic needle is neither attractive nor repulsive, but simply directive. A magnetic needle floating on a cork neither advances nor moves backward; it simply takes a position nearly north and south, and places itself in the magnetic meridian.

The engraving, Fig. 12, is a correct copy of the photographic curves of the self-registering "Declination Magnetograph," as used at the Magnetic Observatory at Stonyhurst College, near Blackburn.

This is one of a series of magnetic instruments which are self-registering night and day; and it is interesting to notice in the photographic curves the amount of disturbance shown between the 8th and 10th of August, 1868. The instruments are under the charge of the Rev. S. G. Perry, who has most kindly furnished the following drawing and description of the Magnetic Observatory at Stonyhurst:

"An idea of the disposition of the instruments may be formed from the drawing (Fig. 11), and a very brief description will make it still more clear.

"The instruments record the oscillations of three magnets suspended under the glass shades; and we thus get completely all the changes, both as to direction and intensity, in the earth's magnetism. The magnet which is to the right in the sketch is suspended by a silk thread in the magnetic meridian, and, by the aid of a mirror attached to it, describes on a cylinder, which is put in motion by the clock on the centre pier, all the variations in the magnetic declination. The other two magnets give the two components of the total magnetic force of the earth. That which records the variations of the vertical

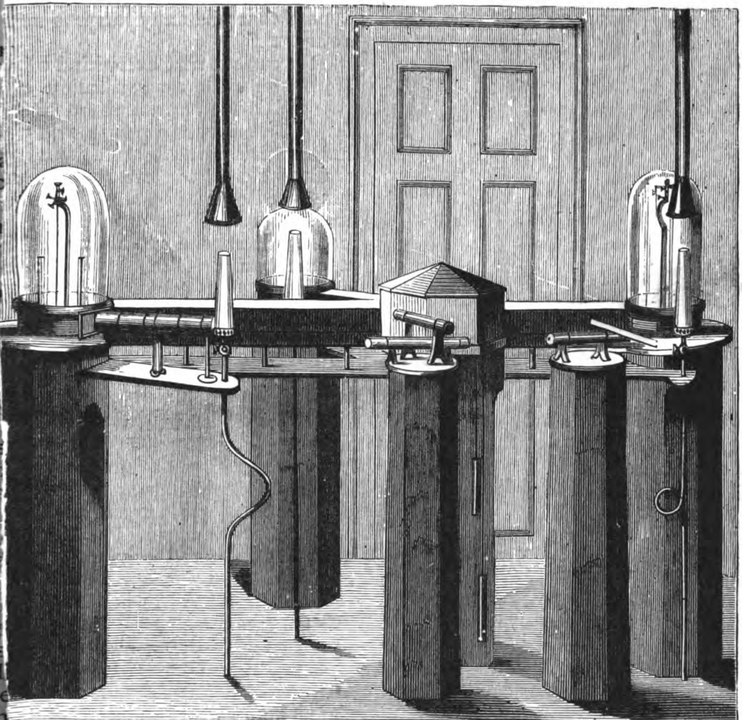


FIG. 11.—*The Magnetic Observatory at Stonyhurst College.*

nponent rests, under the shade near the doorway, on two agate edges; ilst the horizontal-component magnet is suspended by a double steel thread, ler the shade to the left of the picture, and is held nearly at right angles to magnetic meridian by the torsion of the thread.

'Under the clock-box, which stands in the centre, are the three cylinders vered with sensitive paper. To each magnet is attached a semicircular rror, which sends the rays from a jet of gas to one of the cylinders in the ck-box, and thus describes, by a curved line, all the oscillations of the gnet. A second semicircular mirror is fastened to the pier on which the trument stands, and, describing always a straight line on the cylinder which opposite to it, gives the zero line for the curve.

'These magnetographs were constructed by Mr. Adie, and are similar in rly every respect to those made for the Kew Observatory, under the direc- n of Mr. Welch.

The magnetic room is built underground to prevent sudden changes of

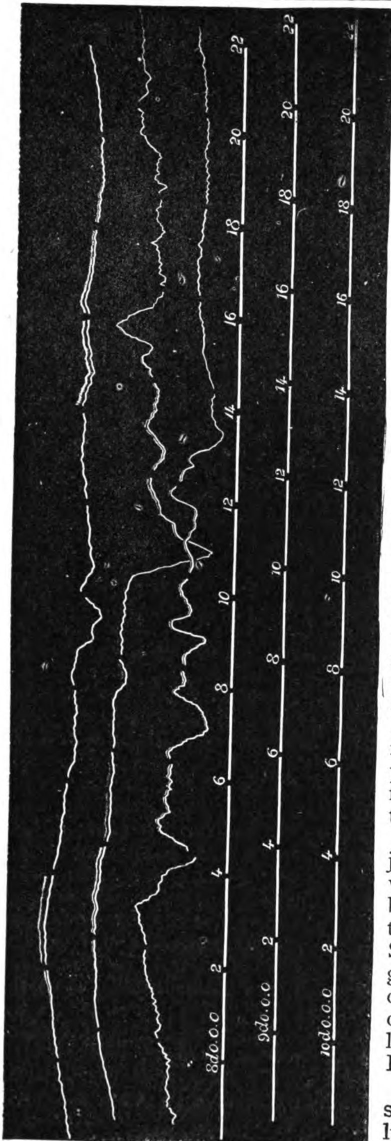


FIG. 12.

temperature, and we have been s tunate that the daily range is sca over 0·2°."

It is curious that every kind of v tion assists the magnetization of or steel by terrestrial magnetism half-a-dozen iron wires, 12 or 15 length, are twisted strongly tog whilst held in the direction of a ping needle, viz. 68°, they become magnetic, and, having now dis poles, will affect a magnetic needle a steel-bar magnet. Iron colu guns, the plating of ships of war, goes of iron or steel, all acquire r netic power; and, until this fact understood and provided for, m disastrous shipwrecks were caused the compass pointing in the wrong rection, and thus conducting the fortunate ship to the rocks, instea keeping her in mid-ocean. Mr. Bar has devised certain means by which compasses of ships may be correc and the influence of local magn attraction, due to the guns, or shot other iron or steel cargo, neutralized that the "*directive*" force of terrest magnetism alone shall guide the s over the pathless ocean. A late lamented friend of the writer (Mr. E Hopkins) tried a vast number of ex riments, and wrote an interesting p phlet on terrestrial magnetism, with ference to the compasses of iron sh their deviation and remedies.

It is impossible in our limits to justice to the arguments brought ward and discussed by Mr. Hopk but the remarks made at the term tion of the debate at the Royal Un Service Institution on his paper give the reader some notion of opinions entertained by the meet on the method of destroying the larity of iron ships, as proposed by Hopkins.

"Sir FREDERICK NICOLSON: subject has been treated in an emin ly practical way. In the abstrac Mr. Hopkins's papers, I find that t me statement which appears to me the most important, that is, Mr. Hopkins ys he is prepared to destroy the polarity of any given ship in ten minutes. e only question I wish to ask, because the gist of the paper lies in that sertion, is whether Mr. Hopkins has performed that operation upon any ship.

" Mr. HOPKINS: No, not in any ship as yet; but I have made experiments long bars and plates of iron, and I am quite satisfied that I can produce e same results on the iron plates of a ship. In reply to the observations ich have been made I will not detain you long, because I do not think the marks made require lengthy replies. First, with regard to Sir Edward elcher's remarks, he said that I stated that there was no magnetic pole. I d not state that there was no magnetic pole; on the contrary, I have endea-ured to explain that *the entire areas bounded by the antarctic and the arctic rcles are the great magnetic poles of the earth*, towards which all the magne-c meridians converge. I do not mean to say for one moment but that a ipping needle at the north latitude of 70° approached nearly 90°, observed y Sir James Ross, and probably over a great number of square miles in that egion; but I have seen dipping needles approaching 90° near the equator. here are many places in the islands of Scotland, also in Norway, Sweden, nd Russia, where the dipping needle will not only approach 90°, but remain t 90°. Therefore I repeat that the dip of the dipping needle does not neces-arily depend on the action of the terrestrial pole, but on local attraction. Besides, neither experiments, analogy, nor observations on the magnetic meridians support the notion of the magnetic pole being merely a mathema-ical point near Boothia Gulf. We have only to prolong the observed magnetic meridians to the circle of 70° of latitude to show the fallacy of the Boothian pole. We must be guided by the *meridians* of the needles to determine the position of the active polar areas. Go to Norway; go to Sweden; where do the needles point? Do they point to Boothia Felix? No; they do not. They point towards the arctic region, and not to any special *point*. With regard to the other point that Sir Edward stated with reference to the com-pass, I do not believe there is a possibility for the compass to point correctly unless it be left entirely under the control of the great terrestrial force: any interference, whether by magnets or electric appliances, can only increase the confusion and danger, and therefore the compass should not be tampered with, but left to act freely and under the sole influence of terrestrial magnetism. With regard to what Captain Selwyn stated about the steering compass. He said, 'Never mind that; I believe you do not care much for the steering com-pass; you go by the standard compass.' Well, there is now always a difference between the standard and the steering compasses. We know that in iron ships that difference constantly varies. You do not know what the variation is that is constantly going on. Were you certain of the exact amount of variation, it would be like the watch and chronometer spoken of by Captain Selwyn; but you cannot compare the case of your watch and chronometer with those of the standard and steering compasses when you have an iron vessel, and where you have a perpetual change going on in the action of the polarity of the iron vessel. With regard to the reflector, I see Captain Selwyn apprehends difficulty. I see none, and the appliance is already appreciated by several experienced captains. I do not think there would be much diffi-culty in seeing a compass, with a good strong light, with a 12-inch card at a distance of even 30 feet. However, I leave that to others. There is one thing Sir Edward Belcher mentioned with regard to the needles. I am perfectly familiar with all the needles they use in high latitudes. They are utterly worthless in *directive* power. As to the dipping needles, they have no directive power whatever, and, as justly observed by Captain Fishbourne, have no lateral directive power at all, and cannot therefore serve as guides to determine questions connected with *meridian lines*. The *curved* magnetic needle will act where neither the straight nor the dipping needles can be rendered serviceable in high latitudes. It only remains for me, in conclusion, to thank you for the patience and kindness with which you have listened to the observations I have made.

"The CHAIRMAN: I am sure there will be but one opinion among you as to a vote of thanks to Mr. Hopkins for the very interesting paper he has read. He has brought forward some of the old ideas relating to magnetism, which many here were not acquainted with, and he has given us some new ideas. I must say that his idea with respect to the bent needle is one which I think is deserving of a trial. I must also say I should like to see that dissipation of the polarity of a ship tried, although I am afraid that the soft iron of the ship would become magnetised by some other extraneous cause at present unknown. I really believe this, although we are very thankful to him for what he has told us, that we shall still find it positively necessary to have recourse to observation. I hope what you have heard to-night will strengthen your confidence in the compass as a means of steering. There is another remark about the pole. As I have passed within 70 miles of it, and the dip was 89° 47″, I must say that I can only look upon the pole as capable of being defined, not perhaps exactly as a point, but very nearly as a point, because as I passed up, I changed from 89° 47″ north dip to 89° 46″ south dip. With respect to the deviation of the compass, it has been an old thing with us who have been in high latitudes. We know perfectly well that we suffer the same inconvenience which is experienced now in iron ships. In Behring's Straits, in going about there, the deviation of the ship amounted to six points of the compass; and I can say, which I have no doubt Captain Maguire will corroborate me in, that we should have had the greatest difficulty in the world to take our ships up into the position we did, if it was not for the admirable charts of Admiral Beechey, and in which expedition Sir Edward Belcher served. There is only one other point. I will say that I have listened to this paper with a great deal of gratification and pleasure, because, during the course of my service in the Arctic regions, it so happened that for two years I was not able to use a compass at all; therefore, I am able to appreciate anything that will increase the value of it."

The sequel is soon told, for Mr. Hopkins caught a violent cold whilst engaged in attempting to depolarise one of the iron-clads; and, although he partially recovered, his system received a shock which ended in death. His kind and enthusiastic spirit was spared the disheartening report of the non-success of his method, subsequently brought before the Royal Society.

Mr. Barlow corrects the local magnetic power of the iron of the ship by placing a piece of soft iron in a particular position, so as to compensate for the derangement of the compass produced by the anchors, chains, guns, &c., of the vessel.

Amongst the latest practical applications of magnetism to useful purposes is that of Mr. Saxby, who proposes to test the iron of guns by magnetic power. Mr. Paget, C.E., in a very able paper in "The Engineer," thus reports on the process or method of Mr. Saxby for testing iron:

"It is well known to engineers that it is a most difficult and often impossible thing to find out the existence of a false weld in a forging, or of a blowhole or honeycomb in an iron or steel casting. The only safe way of doing this is by carefully measuring the elongation of the piece under a given load, as with a false weld all the work is thrown on the diminished area at the defective weld, and the thicker parts are scarcely extended by the force which is perhaps rupturing the bar at the flawed spot. It need scarcely be said that there are many important cases where this process, or the equivalent but dangerous one of trying the effects of an impulsive force, could neither be mechanically nor commercially practicable. Every one knows that a simple method by which internal flaws and solutions of continuity in constructive details could be easily detected would be of enormous value to the world. Such a method has undoubtedly been discovered by Mr. S. M. Saxby, R.N., who has very judiciously been allowed by the Admiralty, during the course of this year, to experiment with it in the royal dockyards. Though comparatively new, and not yet completely worked out, the process will possibly have a yet more extended application than finding out only mechanical flaws in iron, and possibly in cast iron and steel.

"The principle upon which Mr. Saxby's method is founded is so simple that it certainly seems strange that it had previously escaped notice. It has been known for nearly a century and a half that when a bar or any mass of soft iron is placed in the position of the dipping needle, it is at once sensibly magnetic, the lower extremity being a north pole in our latitudes, and the upper extremity a south pole. In the southern hemisphere the poles are of course reversed. The same action, only weakened, takes place in a bar hanging in a vertical or any other position; only the effect is weaker the more the position of the longitudinal axis of, for instance, a long bar departs from that of the magnetic dipping needle.

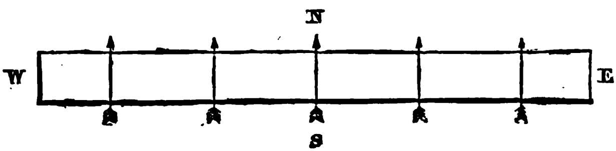


FIG. 13.

"When, therefore, as in Fig. 13, a small compass needle is slowly passed in front of a bar of very good iron, placed in an east and west direction, the needle will not be disturbed from its proper direction, which is of course at right angles to this, or north and south.

"All this refers to regularly homogeneous bars of best quality—to bars without any mechanical solutions of continuity. With internal flaws or interruptions of continuity the bar is no longer regularly magnetic. It has long been known that a good compass needle, or a good permanent magnet, must be homogeneous and without flaws in order to take and retain its maximum amount of magnetism. In a word, *any mechanical solution of continuity is accompanied with a polar solution of continuity*, and the given bar or mass with flaws—whether permanently magnetized or temporarily so by the induc-

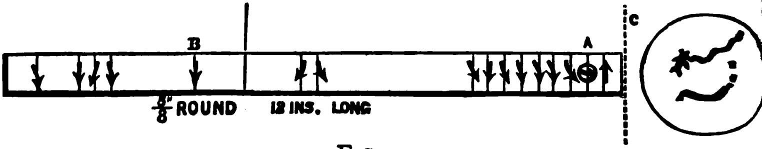


FIG. 14.

tive action of the earth—is no longer one regular magnet, but several differen
magnets, with the different magnetisms separated from each other. Th
delicately-poised magnet of a compass can thus be made to tell the presenc
of such solutions of continuity. The above drawing (Fig. 14), showing th
actual results of the test with a $\frac{5}{8}$ in. bar, 12 in. long, will illustrate the manne
in which the compass magnet is affected by the presence of cracks, of solution
of continuity, in the bar, which is supposed to be lying in the equatoria
magnetic plane, or east and west.

"By the enlightened permission of the Admiralty Board, Mr. Saxby, as stated, has already been allowed to test his method in various ways in the royal dockyards of Sheerness and Chatham, and we will describe some of the practical results of these experiments. Amongst these were a number of very remarkable trials conducted in the presence of the master smiths, the foremen of the testing-houses, and several of the chief engineers of the royal navy.

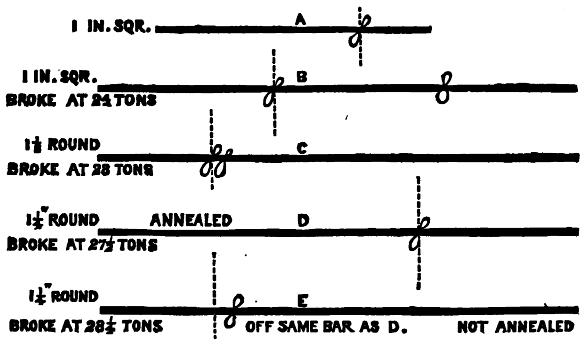


FIG. 15.

Mr. Saxby, for instance, was requested to find out the weakest spots in a number of bars, and to tie a string or make a chalk mark on each spot. Immediately afterwards all these bars were put into the testing machine and broken. Their history is given above, in the annexed cuts (Fig. 15), the prediction having in every case been verified. The bars are shown by lines to scale, and a scroll is placed where the weakest part was found out by the needle. The vertical dotted lines indicate the spots where the several bars broke.

"The smiths of the royal dockyards seem to have properly tried Mr. Saxby's powers in almost every possible way, and most ingenious devices were sometimes resorted to for the purpose. As examples out of many, in the centre of a bar (Fig. 16) of 1 in. square forged iron was welded a piece of unmagnetized steel about 5 in. long. The needle detected a fault at about the centre of the piece of steel.

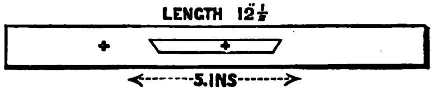


FIG. 16.

"Now Mr. Saxby's method can detect the presence, and negatively of course the absence, of small or large solutions of continuity. It can detect false welds, smaller flaws caused by bad workmanship or wear, and, we believe, what is commonly termed 'crystallization,' which will, probably, at once be generally acknowledged to consist in a disruption or parting of the facets of the amorphously arranged crystals of which iron is built up. It can, of course, only detect the results of the chemical constitution of iron, as evidenced in the less perfect cohesion of the crystals when alloyed, in relatively considerable quantities, with foreign bodies. There is little doubt that the magnetic method is a test of the homogeneous character of the iron and of its freedom from fissures and cracks, and so far it undoubtedly forms a test of quality. It will appear scarcely credible that a common pocket-compass needle should be able—almost like the divining rod said to be used for finding out springs of water—to discover important defects in large iron bars. A mere statement of the fact does sound almost incredible until the simple means actually employed are explained."

Amongst the influences which open the pores of the steel, as it were, to receive a full charge of magnetic force is that of heat, and it is found that when steel is made red hot, and allowed to cool in the direction of the magnetic dip, it acquires more quickly and largely the magnetic charge.

It was contended by Mrs. Somerville that unmagnetized needles were magnetized if exposed to the violet ray of the spectrum; but Riess and Moser have shown that these effects only take place when the needle is perpendicular to the magnetic meridian, facilitated by the heating of the needle, first by exposure to the violet rays, and secondly and more especially by the subsequent cooling.

A powerful steel magnet, heated to a white heat, loses its magnetic power. Red-hot iron is no longer rendered magnetic by induction.

Nickel, raised to the temperature of boiling oil, loses its magnetic virtue.

It ought to be mentioned here, that certain metals, nickel and cobalt, have distinct magnetic powers; and Sir Charles Wheatstone has given a very ingenious and elegant method of detecting minute quantities of magnetic force. He says—

"If a short sewing needle, A (Fig. 17), the eye end being broken off, rest upon its point on the polar surface of a powerful bar magnet, it will generally take a position inclined to the surface; but a locality may generally be found in which the needle will stand nearly vertical; this point may be ascertained by placing a piece of unglazed paper, D, between the needle and the magnet, and moving it about until the vertical position of the needle is obtained.

"If we elevate the paper and needle above the magnet to the greatest distance at which the needle will remain vertical, it becomes to the last degree sensitive of magnetic force; so that by bringing specimens of nickel or cobalt, which have the least magnetic power, or any impure metal, such as a specimen of metallic manganese, which Faraday thought he had proved (when entirely free from iron) does not indicate the slightest magnetic power,* or rhodium, iridium, or hammered brass, if the latter metals contain any iron, they will affect Wheatstone's test needle, but not otherwise."

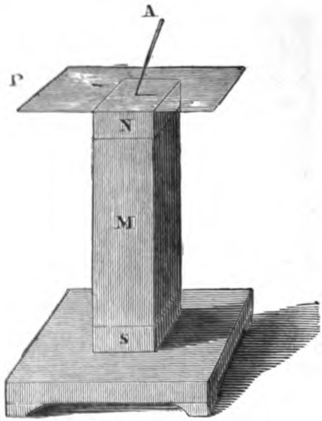


FIG. 17.

There are other influences that may affect the magnetic needle. When a plate of copper is rotated quickly (say 800 revolutions per minute) beneath a suspended magnet, the latter also is thrown into rapid rotation.

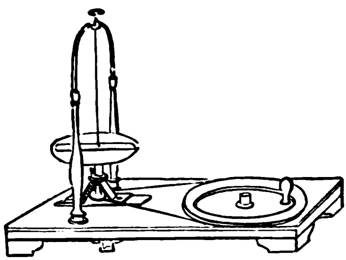


FIG. 18.

It might be thought that this was brought about by the motion of the air; but the same effect occurs even when the copper plate rotates in a vacuum, or is wholly screened by glass from the magnetic needle.

* See Dia-magnetism, for further information.

The apparatus (Fig. 19) exhibits this curious property of metallic plates in motion, and is usually made by Elliott with a variety of metallic plates, all of which, when spun round rapidly, first cause the magnetic needle to deviate from its natural position, and then finally to assume rotation.

When the experiment is reversed, and a compound bent magnet is caused to revolve with great velocity about its axis of symmetry, and below the metallic plate, which is carefully suspended, then the latter commences revolving in the same direction.

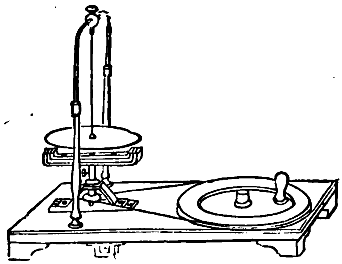


FIG. 19.

All these experiments have arisen from the original one performed by Arago, who first tried the effect of a ring of copper upon the oscillation of a delicate magnetic needle which it enclosed. In free space the magnet performed 420 oscillations before it reached an arc of 10°, whereas, when surrounded with a copper ring, they were reduced to fourteen oscillations; under the same circumstances in a ring of wood, the oscillations were reduced from 420 to about 300.

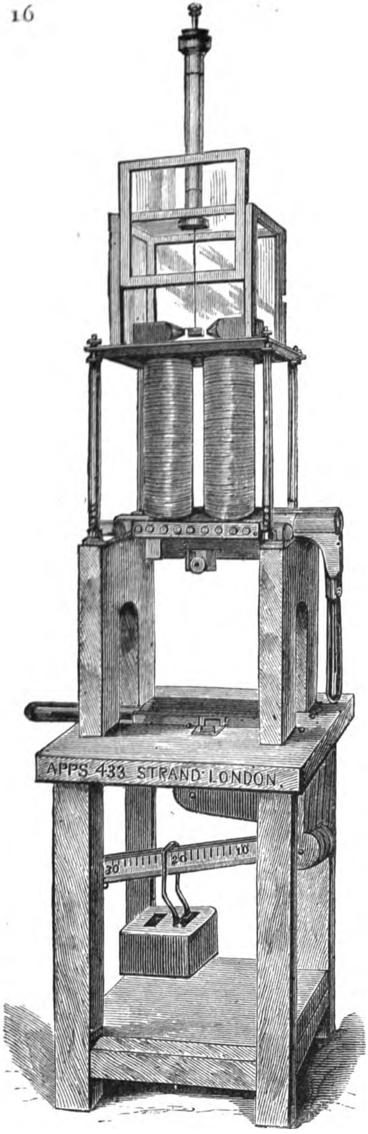


FIG. 20.
Apparatus made by Mr. Apps,
Which may be used either for dia-magnetic experiments or to show the enormous weight which can be supported by a powerful electro-magnet.

DIA-MAGNETISM.

In the preceding chapter, it has been pointed out that the loadstone, iron and steel, cobalt and nickel, possess ordinary magnetic powers, and can attract or repel a magnetic needle. We have now in the beautiful experiments first made by Faraday to consider the magnetic powers of other substances, and shall discover that a vast number of bodies are affected by magnetism when produced by and circulating from pole to pole of a very powerful electro-magnet, such as that depicted at Fig. 20.

The dia-magnetic apparatus is specially designed to illustrate Faraday's celebrated experiments on the dia-magnetism or para-magnetism of bodies, and the effect on light in the rotation of the plane of the polarized ray, &c.

Besides these very extensive and varied applications, the actual lifting power of the electro-magnet is easily found by turning the poles downwards, when they face the armature connected with the compound-lever arrangement. The power obtained with a single cell of Bünsen's, of very small size, will lift 5 cwt., and with twenty Grove's cells this magnificent apparatus will lift 3 tons. It was exhibited before the Royal Society, April, 1868.

In the experiments, which will presently be detailed, there are certain positions constantly referred to, *i.e.*, the positions which various bodies may assume between the poles of the electro-magnet (Fig. 20). Thus the space between the two poles is called the magnetic field, and a straight line drawn from pole to pole, like the poles of the earth, is called the axial line, similar to the imaginary line around which the earth rotates, called its axis. Any body subjected to the action of the magnetic current is said to place itself *axially* when it takes the above direction. If, however, the body under experiment takes a position at right angles to this direction, it is said to point *equatorially*. Thus, in Fig. 21, the poles are represented by pieces of soft iron bevelled

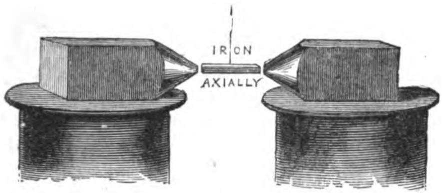


FIG. 21.

off to a rough point; and if a rod of iron is suspended between them and the electro-magnet connected with the battery, the rod takes up an axial position, whilst a similar rod of bismuth, also suspended by a filament of silk, places itself at right angles to that position, as is shown at Fig. 22.

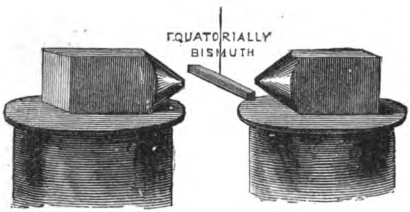


FIG. 22.

In all these experiments the poles of the magnet, with their soft-iron armatures, are surrounded with a glass box, like the lantern of a balance, to prevent the action of currents of air. Faraday discovered that when the crystals or solutions of salts of metals that are magnetic, such as ferrous sulphate, are placed in a glass tube which is not magnetic, they do, as a general rule, place themselves axially. Cobaltous and nickelous sulphate behave in the same manner; and this axial position is always maintained, provided the metal enter into the *basyl* of the salt.

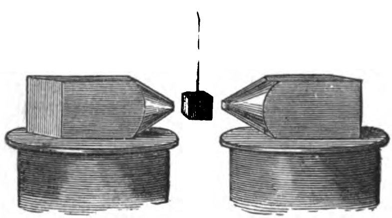


FIG. 23.—*The Cube of Bismuth taking the Equatorial position.*

When a single pole of the electro-magnet is used, repulsion takes place with very many bodies, and, of course, if the substance is repelled by both poles when placed in the magnetic field, it will take a place at right angles to the magnetic current, or the equatorial position.

Phosphorus, bismuth, and antimony—the first a non-conductor of electricity, and the second and third metals therefore conductors—are each and all repelled from a single pole, or place themselves in the equatorial position between the two poles.

It is most amusing to twirl a suspended halfpenny between the poles of the electro-magnet (Fig. 24). Of course this may be done as often or as long as the experimenter pleases; but if, whilst the coin is rotating, the electro-magnet is connected with the battery, the halfpenny stops dead, and instantly places itself in the equatorial position.

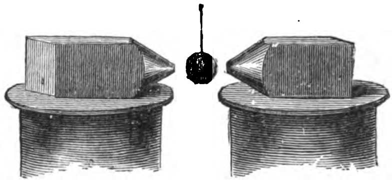


FIG. 24.—*The Halfpenny twirled, then stopped by the magnetic force.*

The preceding experiments show that those bodies which are not magnetic will exhibit dia-magnetic properties, *i.e.*, they are substances through which the lines of magnetic force (represented by the beautiful curves assumed by iron filings when sprinkled on a sheet of cardboard held over the poles of a powerful magnet or, still better, an electro-magnet) pass without affecting them like iron, cobalt, or nickel.

This mode of experimenting is more delicate as a test for magnetism than the use of the needle, already alluded to at page 14. FIG. 17.

And it was by taking solutions of pure salts of manganese and chromium, and placing them in the magnetic field, that they were discovered to be magnetic, whilst as metals it was so difficult, if not almost impossible, to obtain them in the pure state and free from iron. (Fig. 25.)

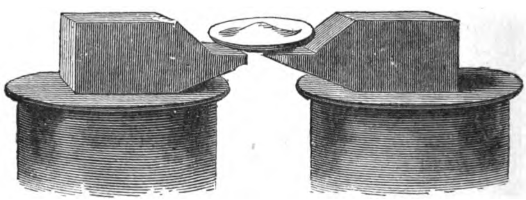


FIG. 25.

Faraday, always so exact and orderly in his classification and nomenclature, proposes to include all the phenomena under one general title, viz., that of magnetism, and to subdivide this into para-magnetic and dia-magnetic phenomena. A very long list, originating with Faraday, has therefore been framed on this principle.

Para-Magnetic, usually called Magnetic. Axial.	Dia-Magnetic. Equatorial.
Manganese	Lead
Nickel	Cadmium
Cobalt	Sodium
Iron	Mercury
Titanium	Zinc
Palladium	Tin
Cerium	Bismuth
Chromium	Antimony
Platinum	Arsenic
Osmium	Silver
Paper	Gold
Sealing-wax	Copper
Berlin porcelain	Tungsten
China ink	Uranium
Plumbago	Rhodium
Peroxide of iron	Iridium
Fluor spar	Alum
Asbetos	Glass
Silkworm gut	Rock crystal
Red lead	The mineral acids

Para-Magnetic, usually called Magnetic. Axial.	Dia-Magnetic. Equatorial.
Sulphate of zinc	Litharge
Shellac	Phosphorus
All sorts of iron, where the latter is basic	Common salt
	Nitre
	Sulphur
Vermilion	Resin
Tourmaline	Spermaceti
Charcoal	Iceland spar
Oxygen, which stands alone as a para-magnetic gas	Tartaric acid
	Citric acid
	Water
	Alcohol
Salts of chromium	Ether
Salts of manganese	Sugar
	Starch
Oxide of titanium	Gum arabic
Oxide of chromium	Wood
	&c., &c.
Chromic acid.	

Nitrogen.

Nitrogen is like a vacuum—it is neither para-magnetic nor dia-magnetic; it is, in strict reason, like space, with reference to these experiments; it is a zero, or a starting-point.

The magnetic or dia-magnetic property of a body, curious to say, varies according to the medium in which it is placed: thus, a glass rod, suspended horizontally in water, which we find, with glass, in the dia-magnetic column, points axially, like any ordinary magnetic body; but if the same glass rod is suspended in a solution of ferrous sulphate, a magnetic body, it points equatorially.

The magnetic-field test discovers whether a metallic salt has the metal in the basyl, the basic, or electro-positive state; or whether the metal is simply a part or constituent of the acid or electro-negative compound. Iron is basyl in ferrous sulphate, and sets axially, and is para-magnetic; but in potassic ferrocyanide it forms part of the ferrocyanic acid, and therefore the crystal sets equatorially, and is dia-magnetic.*

The reader will find all the apparent exceptions and peculiarities attending their structure in Tyndall and Knoblauch's paper (Phil. Mag., 1850, vol. xxxvi., p. 178, and xxxvii., p. 1). The same gentlemen have discovered that dia-magnetic repulsion is as the square of the intensity of the current; and Reich, Weber, and Tyndall seemed to have proved that which foiled Faraday, viz., that bodies under dia-magnetic influence exhibit polar characters. The polarity is the reverse of all other polarities, electrical or magnetic: the feeble polarity of a dia-magnetic substance is the *same* as the pole of the magnet in its neigh-

* The same test will discover, for instance, in a roll of paper, whether it contains iron or not: if it contains the metal, or is coloured blue with cobalt, it will set axially, because iron and cobalt are magnetic, or, to use Faraday's phraseology, para-magnetic.

bourhood; whereas we have learnt that north induces south magnetism in a piece of iron, and vitreous electricity induces negative in the body to which it is approached.

The dia-magnetism of gases was first shown by Father Bancalari, of Genoa, who discovered that flame, such as the flame of a candle, was influenced by the poles of a powerful electro-magnet.

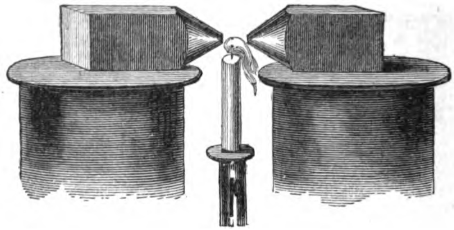


FIG. 26.—*Effect of the Poles on Flame.*

Faraday tried Bancalari's experiment, and found that when the axial line of the magnet was horizontal, and the flame of a taper held near it, and on one side or the other, with about one-third of the flame rising above the level of the upper surface of the poles, the flame seemed to be repelled away from the axial line, moving equatorially until it took an inclined position, as if a gentle wind was acting upon it, and causing its deflection from the perpendicular line.

It was the flame experiments which led to the discovery of the magnetic property of oxygen, and of the dia-magnetic properties of atmospheric air, nitrogen, hydrogen, coal gas, olefiant gas, &c.

Faraday showed that soap-bubbles, filled with various gases and blown from the end of a capillary tube, were either attracted or *repelled* according as the gas was magnetic or dia-magnetic.

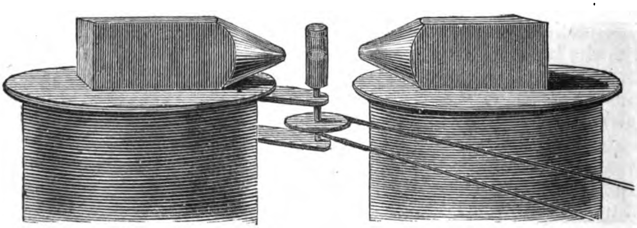


FIG. 27.—*Melting Fusible Metal between the Poles of the great Electro-Magnet.*

One of the most curious experiments which may be performed with the dia-magnetic apparatus is that of overcoming the equatorial or para-magnetic force by physical power. The twirled penny-piece brought to rest between the poles, if forcibly turned round, will by the motion generate heat, and may be made very hot.

If a brass tube, containing some solid fusible metal, composed of two parts by weight of bismuth, one of lead, and one of tin, with a few drops of mercury, is rotated very fast by a whirling-table wheel between the poles of the powerful magnet, no effect is produced until contact is made with the battery, and then the rotation or motion is speedily converted into heat, and the fusible metal is melted as if it had been held over the fire. Here again is a perfect *conservation of force.* The heat which melted the alloy is the exact equivalent of the chemical power of the battery used, although it acts by an intermediate force, viz., magnetism; but the chemical action produced the electricity, the current electricity produced the magnetism, and, the magnetic force which tends to keep the bismuth in the alloy in the equatorial position being overcome and resisted by physical force, the muscles of the arm acting on the whirling table eliminate heat.

Faraday thought he had proved, by using heavy glass and permitting a ray of polarized light to pass through it, that the ray was affected by the powerful magnetic force eliminated from the great electro-magnet. Faraday's glass consists of a mixture of silicate and borate of lead, and is much denser than ordinary glass. If a ray of polarized light is allowed to pass through it, and is then examined in the ordinary manner with an analyzing plate or a bundle of plates of glass, or by a tourmaline or a Nicol's prism, the light, of course, disappears, as already explained in the article on Light, when the plane of reflection from the analyzing plate is at right angles to the plane of polarization. (Fig. 28.)

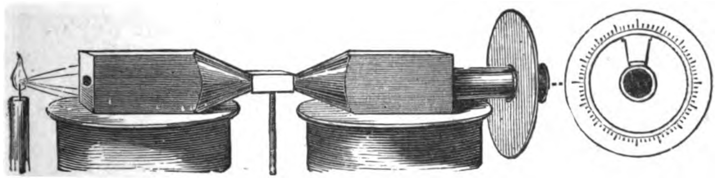


FIG. 28.

If now the battery is connected with the electro-magnet, between the poles of which the bar or cube of Faraday's dense glass is placed, the light re-appears instantly, again disappearing when contact is broken with the battery.

Matteuchi found that the effect was increased by increasing the temperature of the cube of heavy glass to 600° Fahrenheit; and he also ascertained that by subjecting the heavy glass to pressure he could change the direction of the ray of polarized light, as Faraday had done. So that, in fact, Faraday was wrong; the magnetic force did not act upon the ray of polarized light, but on the molecules or particles of the glass, which were under a strain during the time they were subjected to the action of the powerful electro-magnetic force.

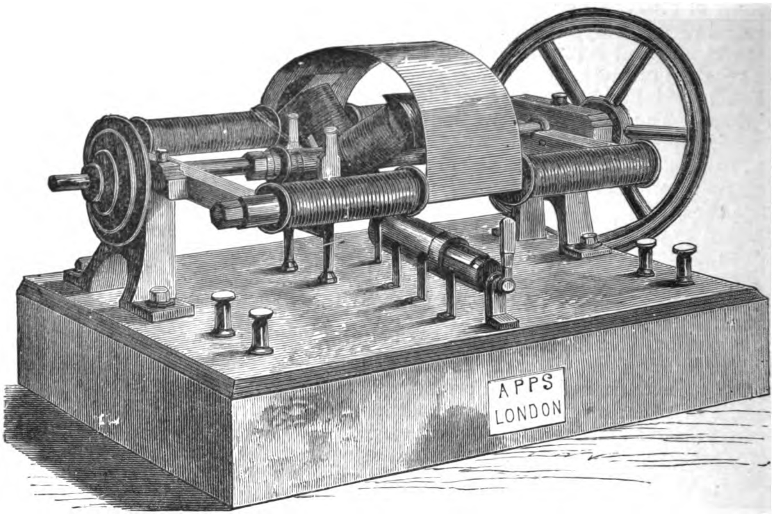


FIG. 29.—*Apps's half-horse power Electro-Magnetic Engine.*

ELECTRO-MAGNETISM, MAGNETO-ELECTRICITY, THERMO-ELECTRICITY.

In 1820, Œrsted, a Danish scientific man, discovered the connection between electricity and magnetism. It was not found where philosophers sought for it. They thought to imitate Nature; and as some steel knives were found to be powerfully magnetic after a discharge of lightning had passed through a box containing them, they subjected other pieces of steel to the discharge of powerful Leyden batteries without producing the effect they expected.

Œrsted found that the electricity must be in motion, or in a dynamical state, such as it would be in when evolved from the voltaic battery.

Static electricity will, under certain arrangements to be hereafter described, magnetize steel; but the mere fact of allowing a wire charged with statical electricity (the force from the electrical machine) to approach a magnetic needle does not affect the needle like the same wire conveying a current from a single voltaic circuit or, still better, a battery.

M. Ampère, who took up the subject directly after Œrsted had published his discoveries, laid the foundation of the science of electro-dynamics. He discovered that every part of the whole circuit—the wires, the terminals or poles, the battery, in fact, all parts—exercised a magnetic power upon the magnetic needle. He also proved that the force was in an eminent degree one of *circulation.* Ampère made himself fully understood by asking his readers to conceive a man lying down in the circuit, so that the wire lies along his face and body. We are now to suppose that the current enters the wire at his feet and goes out at his head, and that his upturned face and eyes are directed to a magnetic needle suspended parallel with and over the wire conveying the electric current, so that the north pole of the needle points to his face. Directly the current passes, the needle is deflected to his left hand; and by reversing the direction of the current, and causing it to flow into the wire at his head and out from his feet, the needle will now move to his right hand.

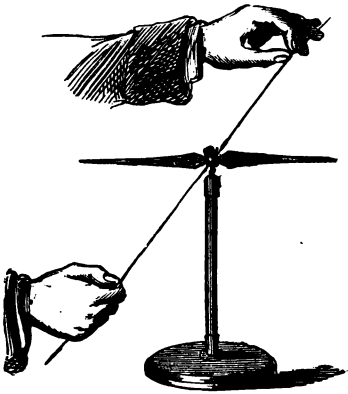


FIG. 30.—*Wire conveying a Current of Electricity affecting the Magnetic Needle.*

Thus every possible variation may be imagined as long as we maintain the same relative positions of the wire and the human body; and it was further ascertained that the intensity of the electro-magnetic force is in the inverse ratio to the simple distance of the magnetic needle from the current; or, in other words, that the elementary action of a simple section of the current upon the needle is in the inverse ratio to the square of the distance.

If a single wire can affect a magnetic needle, it is evident that by doubling and trebling the wire, or winding it round in a helix, the effect must be enormously increased, provided the coils of wire do not touch each other, or are covered with some non-conducting material, such as silk or cotton; hence it is that coils of wire are constructed so that a piece of soft iron placed

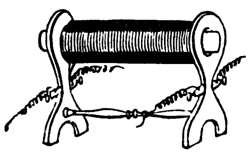


FIG. 31.

inside the core becomes a most powerful magnet directly contact is made with the battery. When the immense power of the electro-magnet was ascertained, great anticipations were formed of the application of this force as a motive power. It is not surprising that this should have been the first conclusion. Thus the great electro-magnet, made by Mr. Apps, that heads the chapter on Dia-magnetism, will lift five hundredweight with a single quarter-pint Grove's cell, and three tons with twenty cells. This conveniently arranged magnet, after being used for dia-magnetic experiments, may be employed for showing the attractive force of the great electro-magnet. It is attached to a lever, which turns it over; and, when suspended with the poles downwards, it is connected with a compound-lever arrangement, on the same principle as railway weighing-machines, and the weights used are one quarter, one half, and one hundredweight.

The writer well remembers the late Prince Consort, on the occasion of one of his private visits to the Polytechnic, putting a question to him as to the rate at which the electro-magnetic power increased or decreased with the distance from the great electro-magnet belonging to the Polytechnic. The attractive force diminishes enormously. Thus, in a paper read by Mr. Robert Hunt before the Institution of Civil Engineers, the following instructive diagram was exhibited:

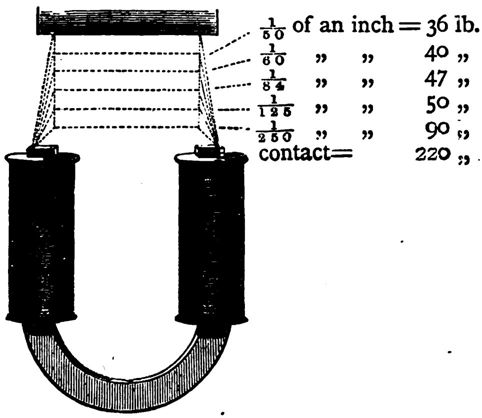


FIG. 32.

It is shown that, whilst *contact* gave a power of 220 lb., at a distance of $\frac{1}{50}$ of an inch the attractive force diminished to 36 lb.

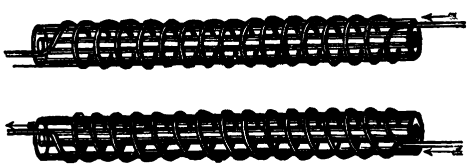


FIG. 33.—*A Dextrorsal and a Sinistrorsal Helix.*

When a wire, traversed by an electric current, is held in iron filings, they adhere to it as long as the current passes. If the wire is coiled upwards round a glass tube from left to right, it is called a dextrorsal helix; and if coiled downwards, and in the same direction, it is termed a sinistrorsal helix.

A piece of steel placed inside such a helix, conveying the voltaic current, is soon magnetized. If the same coil is used to convey the charge from a Leyden battery of 6 ft. surface, a piece of steel is instantly magnetized. Electricians had missed this form of the experiment until Œrsted's discovery.

If a bar magnet be held so that it is horizontal, and the north pole directed to the vertical portion of the rectangular wire, so supported that whilst conveying the electric current it moves freely round in a circle (Fig. 34), it will be found

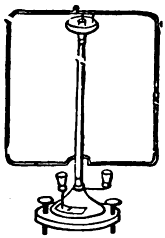


FIG. 34.—*The Rectangular Wire freely suspended on a vertical Standard.*

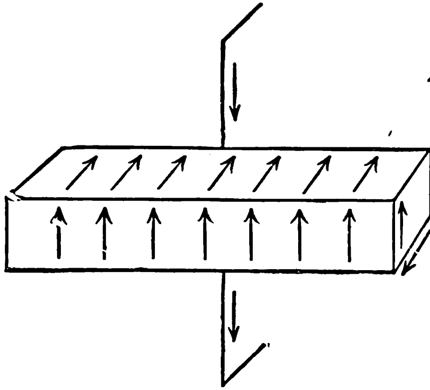


FIG. 35.

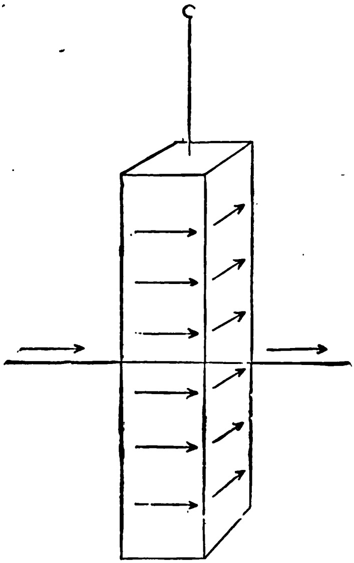
that, if the upright portion of the wire is conveying the current from below upwards, it is repelled, but attracted if the south pole is substituted; and thus, by the dexterous substitution of one pole for another in presenting the bar magnet to the rectangular wire, it may be caused to rotate.

Polarity is shown by the sides of the wire, whereas in steel magnets it is discoverable at the ends.

The same attraction and repulsion occurs if another electrified wire is brought towards the suspended rectangular wire whilst conveying the electrical current.

Fig. 35 is a good illustration of the direction of the current circulating around each section of a magnet everywhere in the same direction, viz., from top to bottom in the face that is turned towards the moving wire, and from bottom to top in that which is opposite to it. The sum of these directions amounts to a current.

A similar result is obtained when a horizontal wire is directed to a magnet suspended vertically. The magnetic currents circulating around the magnet are again shown by arrows. A magnet may, therefore, says De la Rive, be considered as formed by an association of electric currents, all circulating in the same direction around its surface, and all situated in planes parallel to each other, and perpendicular to the axis of the magnet. It is this hypothesis of Ampère of the constitution of magnets, shown in Figs. 35 and 36 and which



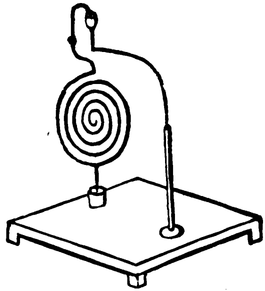


FIG. 37.

FIG. 36.—*Magnet suspended in a perpendicular line, the Current flowing horizontally.*

explains Œrsted's original experiment, and also all those that relate to the deviation. In order to confirm the hypothesis to which he had been led, of the nature of magnetism, Ampère endeavoured to arrange electric currents in the same manner as he had conceived they were naturally arranged in a magnet.

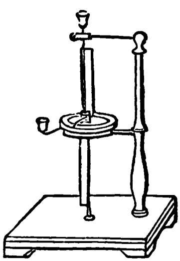


FIG. 38.—*Magnet revolving around Wire conveying the Current.*

Thus a flat spiral coil of wire (Fig. 37), nicely supported and resting on points, and perfectly mobile, takes a position perpendicular to the magnetic meridian. By reversing the experiment, and causing the wire to be fixed, and the magnet to revolve around it (Fig. 38), further proof was obtained by Faraday of the mutual relations between magnets and wires conveying the voltaic current. In this case we have the revolution of one pole of a magnet about a vertical wire transmitting a rectilinear current. The direction of rotation is reversed each time the direction of the current is reversed.

Or the experiment may be again modified and reversed by supporting (as with the apparatus made so nicely by Messrs. Elliott) two helices or coils of copper which are made to convey the voltaic current, and rotate in opposite directions around the poles of the horse-shoe magnet, as shown in Fig. 39.

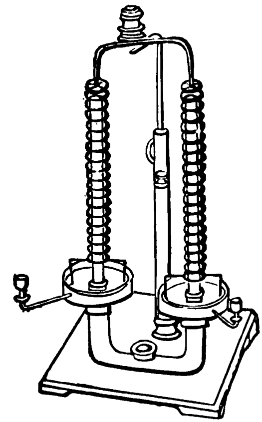


FIG. 39.—*Contrary Rotation of two helical Coiled Wires around the Poles of a Magnet.*

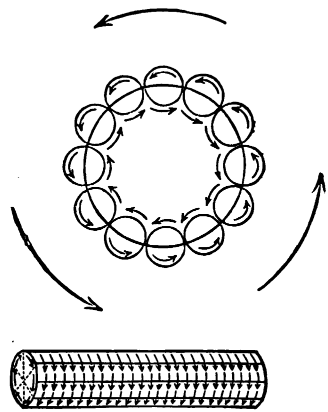


FIG. 40.

This apparatus is usually called Ritchie's spirals. De la Rive says Ampère succeeded in overcoming all objections to his theory, and established it on such a solid basis that it is at the present time generally admitted. He set out from the principle that the electric currents to which, according to his view, magnets owe their properties are molecular, that is, that they circulate around each particle. These electric currents pre-exist in all magnetic bodies even although they have not been magnetized, only they are arranged in an irregular manner, so that they neutralize each other. Magnetization is the operation by which a common direction is impressed upon them; whence it follows that the series of the exterior portion of the molecular currents, which are all moving in the same direction, constitutes a finished current around the magnet, whilst the interior portions are neutralized by the exterior ones, moving in the contrary direction, of the following molecular stratum.

Fig. 40 represents the section of a cylinder magnet and the magnet itself. The direction impressed upon the currents by magnetization is maintained in bodies that are endued will coercitive force, and ceases in others, such as soft iron, as soon as the force that determined it ceases, because then all the molecular currents, being free to obey their mutual action, take the relative position that produces equilibrium, or the neutralization of every exterior effect.

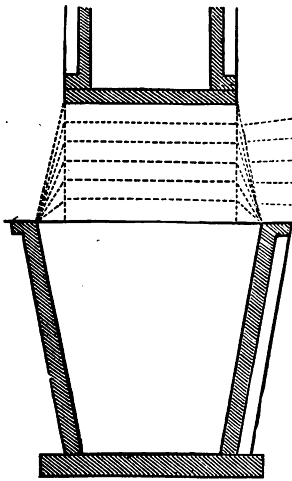
To Faraday is due the credit of realising the idea that the mutual reaction of magnets or wires conveying electrical currents, and *vice versâ*, should produce rotation; and he was the first to cause a wire conveying a current to revolve around a magnet, and the latter to rotate about a wire through which the voltaic current is passing.

These original and philosophical experiments have been extended to larger apparatus, and various attempts have been made to use the electro-magnetic rotation successfully: Dal Negro, 1832; Professor Botto and Professor Jacobi in 1835; Mr. Thomas Davenport, of the United States, in 1837; and Mr. Taylor in 1839.

Davidson, in 1837, placed an electro-magnetic locomotive on the Edinburgh and Glasgow Railway. The carriage was 16 ft. long and 6 ft. broad, and weighed about 5 tons, with all the arrangements; but, when put in motion, a speed of only 4 miles per hour could be obtained.

Professor Page constructed an electro-magnetic engine which created much interest at the time, and he calculated that the consumption of 3 lb. of zinc per diem was equal to one horse power. Page's engine was followed by those of Talbot and Wheatstone.

Mr. Hjörth exhibited in London an engine which found many admirers. The attractive force of Hjörth's machine is thus given by Mr. Hart, from whose valuable paper the above historical details are taken:



5 inches	72 lb.
4 "	80 "
3 "	88 "
$2\frac{1}{4}$ "	124 "
$1\frac{1}{2}$ "	140 "
1 "	160 "

FIG. 41.—*Hjörth's Principle.*

but, like the rest, it was abandoned.

Dr. Botto states that 45 lb. of zinc consumed in a Grove's battery are sufficient to work a one-horse power electro-magnetic engine for twenty-four hours.

Mr. J. P. Joule calculates that the same result would have been obtained by the consumption of 75 lb. of zinc in a Daniell's battery. Mr. Joule and Dr. Scoresby thus sum up a series of experimental results:—"Upon the whole, we feel ourselves justified in fixing the maximum available duty of an electro-magnetic engine, worked by a Daniell's battery, at 8c lb. raised one foot high for each grain of zinc consumed. This is about one-half of the theoretical maximum duty. In the Cornish engines doing the best duty, one grain of coal raised 143 lb. one foot high. Zinc i. worth about £35 per ton, and engine coal is worth less than £1 per ton, delivered in London. Comment upon this is unnecessary.

The fact is, an electro-magnetic engine is a very pretty toy, and can be used, like Mr. Apps's half-horse power engine (Fig. 29, p. 22), to turn a small lathe, or propel a small boat, or turn whirling tables or other apparatus on the lecture-table, *i.e.*, where the cost of zinc and acids from the battery is of no consequence. Mr. Apps furnishes the following particulars of the above named electro-magnetic engine:

"Weight 80 lb. When driven to 400 revolutions per minute by 20 cells Grove (platina 6 in. × 3 in.), a half-horse power is obtained. It will drive with equal facility in either direction, or, on reversing the current by the double commutator, the magnetic power produced is opposite to the momentum previously acquired (acting like a friction-brake); the direction of rotation is reversed, and in about three seconds the former rate of speed is acquired.

"A very important point is gained in this machine. The current being gradually broken, the spark usually produced at the breaking of the contact is avoided. Besides this great advantage, the residual magnetism is destroyed, which alone in the old machines diminished their power by at least one quarter. The machine is well adapted to drive a lathe or the screw propeller of a small boat."

MAGNETO-ELECTRICITY.

INDUCTION BY CURRENT ELECTRICITY.

It has been noticed that a current of electricity elicits magnetism, and therefore it is not surprising that the effect should be reversible; but, simple as this may appear in theory, it was a long time before Faraday succeeded in overcoming the difficulties he encountered, and was enabled to relate his success in the "Philosophical Magazine, 1832, page 125.

The extremities of a helix or large hollow bobbin of wire were connected with the galvanometer needle, care being taken that the galvanometer should not be near enough to be affected by the magnet which Faraday used.

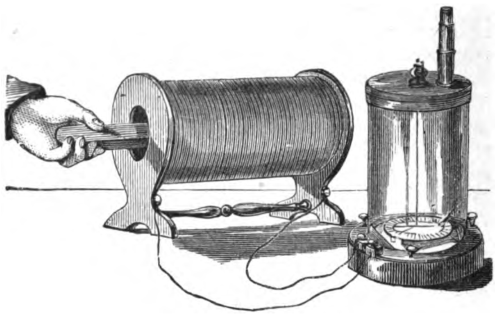


FIG. 42.—*Faraday's first Experiment.*

The movement of the bar magnet across the coils produced a current which affected the needle, and still better when, as in Fig. 42, the magnet was intruded into the axis or hollow of the bobbin or helix. Not only is the needle deflected when the magnet is insulated, but it is also moved in an opposite direction when the magnet is removed.

When two concentric helices, of course of insulated or covered wire, are arranged, the inner one being of thicker wire than the outer, and wound round an axis or core of soft iron, a very powerful secondary current is obtained in the outer coil when the inner core is magnetized. Such currents are called induced currents, and are always more powerful when soft iron forms the axis or core, because the iron, in acquiring or losing magnetism, produces a secondary current which occurs in the same direction as that induced by the inner coil or helix.

Here, then, is a distinct excitation or elimination of electricity by magnetism alone, and is called magnetic electric induction to distinguish it from volta-electric induction, also investigated by Faraday, and brought before the Royal

Society in 1831. In the latter experiments, two great coils of wires were wound together, metallic contact, of course, being prevented. One coil was connected with the galvanometer, and the other with the voltaic battery. The induced electricity in the second coil was suddenly produced like a wave, presenting a marked difference to the magneto-electric induction, which was much slower in its production. Here, then, are two modes of induction:

1. VOLTA-ELECTRIC INDUCTION;
2. MAGNETO-ELECTRIC INDUCTION.

The magneto-electric induction has been applied to the production of currents of electricity by Pixii—the first in Paris, 1832, followed by Saxton and E. M. Clarke.

Such instruments, in which a powerful compound-magnet, having rotating in front of its poles an armature or bobbin of fine wire (which may be varied to produce either quantity or intensity effects), elicits a current that can be made to illustrate physiological, mechanical, chemical, and ordinary electrical effects, are so fully described in every book on electricity that the writer prefers to pass to newer and more perfect arrangements.

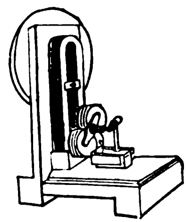


FIG. 43.

Magneto-electricity was applied and exhibited by Mr. Holmes in the Great Exhibition of 1862, and obtained from a machine of novel construction. At the same Exhibition, and also in Paris, 1867, the writer saw Nollet's machine as improved by Mr. van Malderen, who took great pains to show the writer the construction of his magneto-electric machine for light-giving purposes; and it was understood that, at a cost of £300, one of these machines, turned by a steam-engine, might supply the Polytechnic with the electric light at any time it was set in motion. The current passed to a Serrin's lamp, and certainly produced a most brilliant light.

In the article on the Telegraph, it will be noticed that Sir Charles Wheatstone uses a magneto-electrical machine of improved construction, instead of the voltaic battery. Wheatstone's exploder for military purposes generates its electricity in the same manner. There are many other modifications of induced currents, such as the experiments of Faraday, "On the Induction of a Current on itself," read before the Royal Society, 1835; and Dr. Henry's (College of New Jersey, Princeton) experiments (described in 1833) with flat coils of insulated copper ribbon and helices of fine covered copper wire, by which induced currents of the third, fourth, and fifth order could be obtained, by alternately arranging the insulated copper ribbons and the helices of fine wire.

In the "Proceedings of the Royal Society," No. 90, 1867, Sir Charles Wheatstone describes a most interesting series of experiments "On the Augmentation of the Power of a Magnet by the reaction thereon of Currents induced by the Magnet itself," as follows:

"The magneto-electric machines which have been hitherto described are actuated either by a permanent magnet or by an electro-magnet deriving its power from a rheomotor placed in the circuit of its coil. In the present note, I intend to show that an electro-magnet, if it possess at the commencement the slightest polarity, may become a powerful magnet by the gradually augmenting currents which itself originates.

"The following is a description of the form and dimensions of the electro-magnet I have employed. The construction, it will be seen, is the same as that of the electro-magnetic part of Mr. Wilde's machine.

"The core of the electro-magnet is formed of a plate of soft iron, 15 in. in length and $\frac{1}{2}$ an inch in breadth, bent at the middle of its length into a horse-shoe form. Round it is coiled, in the direction of its breadth, 640 ft. of insulated copper wire $\frac{1}{12}$ of an inch in diameter. The armature, which is according to Siemens's ingenious construction, consists of a rotating cylinder of soft iron, $8\frac{1}{2}$ in. in length, grooved at two opposite sides so as to allow the wire to be coiled upon it longitudinally; the length of the wire thus coiled is 80 ft., and its diameter is the same as that of the electro-magnet coil.

"When this electro-magnet is excited by any rheomotor the current from which is in a constant direction, during the rotation of the armature, currents are generated in its cell during each semi-revolution, which are alternately in opposite directions; these alternate currents may be transmitted unchanged to another part of the circuit, or by means of a rheotrope be converted to the same direction.

"If now, while the circuit of the armature remains completed, the rheomotor be removed from the electro-magnet, on causing the armature to revolve, however rapidly, it will be found by the interposition of a galvanometer, or any other test, that but very slight effects take place. Though these effects become stronger in proportion to the residual magnetism left in the electro-magnet from the previous action of a current, they never attain any considerable amount.

"But if the wires of the two circuits be so joined as to form a single circuit, in which the currents generated by the armature, after being changed to the same direction, act so as to increase the existing polarity of the electro-magnet, very different results will be obtained. The force required to move the machine will be far greater, showing a great increase of magnetic power in the horse-shoe; and the existence of an energetic current in the wire is shown by its action on a galvanometer, by its heating 4 in. of platinum wire ·0067 in diameter, by its making a powerful electro-magnet, by its decomposing water, and by other tests.

"The explanation of these effects is as follows:—The electro-magnet always retains a slight residual magnetism, and is therefore in the condition of a weak permanent magnet; the motion of the armature occasions feeble currents in alternate directions in the coils thereof, which, after being reduced to the same direction, pass into the coil of the electro-magnet in such manner as to increase the magnetism of the iron core; the magnet, having thus received an accession of strength, produces in its turn more energetic currents in the coil of the armature; and these alternate actions continue until a maximum is attained, depending on the rapidity of the motion and the capacity of the electro-magnet.

"If the two coils be connected in such manner that the rectified current from the coil of the armature passes into the coil of the electro-magnet in the direction which would impart a contrary magnetism to the iron core, no current is produced, and consequently there is no augmentation of magnetism.

"It is easy to prove that the residual magnetism of the electro-magnet is the determining cause of these powerful effects. For this purpose it is sufficient to pass a current from a voltaic battery, a magneto-electric machine, or any other rheomotor, into the coil of the electro-magnet in either direction, and it will invariably be found that the direction of the current, however powerful it may eventually become, is in accordance with the polarity of the magnetism impressed on the iron core.

"If, instead of the currents in the coil of the rotating armature being reduced to the same uniform direction, they retain their alternations, no effects, or at most very small differential ones, are produced, as no accumulation of magnetism then takes place.

"I will now call attention to the fact that stronger effects are produced at the first moment of completing the combined circuit than afterwards. The machine having been put in motion, at the first moment of completing the circuit 4 in. of platina wire were made red hot; but immediately afterwards the glow disappeared, and only about one inch of the wire could be permanently kept at a red heat. This diminution of effect was accompanied by a great increase of the resistance of the machine. The cause of the momentary strong effect was, that the machine from its acquired momentum continued its motion for a few seconds, though it required a stronger force than could be applied to maintain that motion. Each time the circuit is broken and re-completed, the same effect recurs.

"On bringing the primary coil of an inductorium (Ruhmkorff's coil) into the circuit formed by connecting the coils of the electro-magnet and rotating armature, no spark occurs in the secondary coil. On account of the great resistance of the circuit, which now also includes the primary coil of the inductorium, the current is not in sufficient quantity to produce any noticeable inductive effect.

"A very remarkable increase of all the effects, accompanied by a diminution in the resistance of the machine, is observed when a cross wire is placed so as to divert a great portion of the current from the electro-magnet. The four inches of platinum wire, instead of flashing into redness and then disappearing, remains permanently ignited. The inductorium, which before gave no spark, now gave one a quarter of an inch in length; water was more abundantly decomposed; and all the other effects were similarly increased.

"I account for this augmentation of the effects in the following way:

"Though so much of the current is diverted from the electro-magnet by the cross wire, the magnetic effect still continues to accumulate, though not to so high a degree; but the current generated by the armature, passing through the short circuit formed by the armature branch and cross wire, experiences a far less resistance than if it had passed through the armature and electric-magnet branches; and though the electromotive force is less, the resistance having been rendered less in a much greater proportion, the resultant effect is greater.

"I must observe that a certain amount of resistance in the cross wire is necessary to produce the maximum effect. If the resistance be too small, the electro-magnet does not acquire sufficient magnetism; and if it be too great, though the magnetism becomes stronger, the increase of resistance more than counterbalances its effect.

"But the effects already described are far inferior to those obtained by causing them to take place in the cross wire itself. With the same application of force, 7 in. of platinum wire were made red hot, and sparks were elicited in the inductorium $2\frac{1}{2}$ in. in length.

"The force of two men was employed in these, as well as in the other experiments. When the interrupter of the primary coil was fixed, the machine was much easier to move than when it acted. For when the interrupter acted, at each moment of interruption the cross wire being, as it were, removed, the whole of the current passed through the electro-magnet, and consequently a greater amount of magnetic energy was excited, while in the intervals during which the cross wire was complete the current passed mainly through the primary coil.

"The effects are much less influenced by a resistance in the electro-magnet branch than in either of the other branches.

"To reduce the length of the spark in the inductorium (the primary coil of which was placed in the cross wire) to $\frac{3}{4}$ of an inch, it required the resistance of $5\frac{1}{4}$ in. of the fine platinum wire in the cross wire, 5 in. in the armature branch, and 4 ft. in the electro-magnet branch.

"When there was no extra-resistance in either of the branches, the length of the cross wire being only about a few feet, the intensity of the current in the electro-magnet branch, compared with that in the cross wire, was as 1 : 60; and when the resistance of the primary coil of the inductorium was interposed in the cross wire, the relative intensities were as 1 : 42.

"In conclusion, I will mention that there is an evident analogy between the augmentation of the power of a weak magnet by means of an inductive action produced by itself, and that accumulation of power shown in the static electric machines of Holtz and others, which have recently excited considerable attention, in which a very small quantity of electricity directly excited is, by a series of inductive actions, augmented so as to equal, and even exceed, the effects of the most powerful machines of the ordinary construction."

Mr. Wilde's machine has been fully described in all the illustrated scientific papers, such as "The Engineer" and "The Mechanic's Magazine." The writer, therefore, proposes to give drawings of Mr. Ladd's improved magneto-electric machine, which he thus describes in the "Transactions of the Royal Society," No. 91, 1867:

"In June, 1864, I received from Mr. Wilde a small magneto-electric machine, consisting of a Siemens's armature and six magnets. This I endeavoured to improve upon, my object being to get a cheap machine for blasting with Abel's fusees. This was done by making one of circular magnets, and a Siemens's armature revolving directly between the poles, the armature forming part of the circle; with this I could send a very considerable power into an electro-magnet, &c. It was then suggested to me, by my assistant, that if the armature had two wires instead of one, the current from one being sent through a wire surrounding the magnets, their power would be augmented, and a considerable current might be obtained from the other wire available for external work; or there might be two armatures—one to exalt the power of the magnets, and the other made available for blasting or other purposes. Want of time prevented me carrying this out until now; but since the interesting papers of C. W. Siemens, F.R.S., and Professor Wheatstone, F.R.S., were read last month, I have carried out the idea as follows:—Two bars of soft iron, measuring $7\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in., are each wound, round the centre portions, with about thirty yards of No. 10 copper wire; and shoes of soft iron are so attached at each end, that when the bars are placed one above the other there will be a space left between the opposite shoes, in which a Siemens's armature can rotate: on each of the armatures is wound about ten yards of No. 14 copper wire, cotton-covered. The current generated in one of the armatures is always in connexion with the electro-magnets; and the current from the second armature, being perfectly free, can be used for any purpose for which it may be required. The machine is altogether rudely constructed, and is only intended to illustrate the principle; but with this small machine three inches of platinum wire ·01 can be made incandescent."

Mr. Ladd now calls his improved machine, which it is hoped may be permanently erected some day at the Polytechnic as a convenient source of electricity for all purposes, the "Dynamo-Magnetic Machine" (Fig. 44).

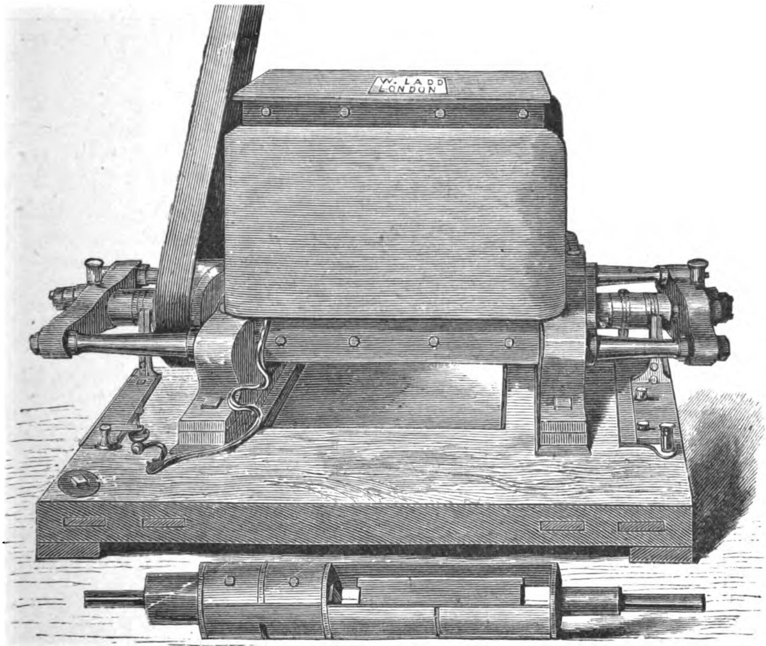


FIG. 44.

This machine was awarded a silver medal at the Paris Exhibition, 1867. Another form of the apparatus (Fig. 45), also constructed by Mr. Ladd, is that in which the two armatures are combined in one, and the coils are wound at right angles to each other.

The results obtained are simply regulated by the amount of mechanical force used to rotate the armatures; and thus indirectly coal, used as a means of exciting electricity, is made to generate steam, which produces force in the steam engine, and this ultimately turns the dynamo-magnetic machine; and thus *indirectly* coal generates an electric current, by which the electric light is obtained.

A convenient little magneto-electrical machine is made by Mr. Browning, for the purpose of giving shocks and for medical use. (Fig. 46.)

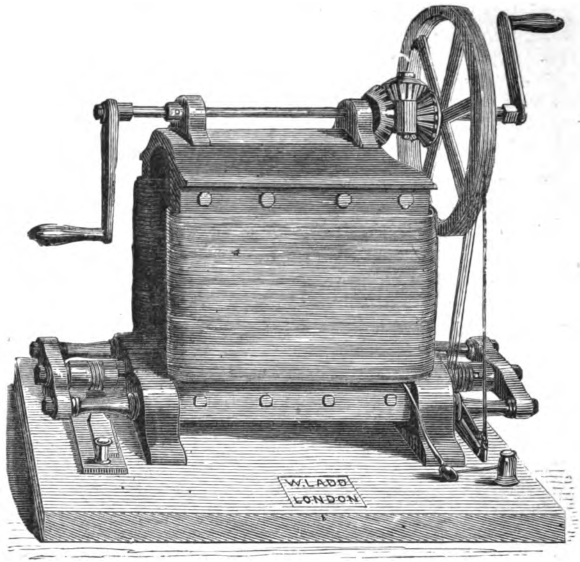


FIG. 45.

Directions for using the Instrument.—Take the hollow conductors A B off from the large studs on which they are placed; uncoil their metallic cords which are wound upon them, and insert the pins which are attached to the ends of these cords into the small holes which will be found in two upright brass studs at the back of the stand of the machine, marked C D in the diagram; then upon holding the hollow conductors, one in each hand, and turning the handle of the machine quickly, a strong electrical current will be felt.

A horizontal stud in front of the machine, projecting beyond the frame, serves to move an iron feeder before the ends of the large circular magnet. By shifting this feeder, the strength of the current given out by the machine can be regulated within any desirable limit. When the feeder is lifted up in front of the magnet, the current will be very feeble; when it is withdrawn ouite below the magnet, it will be very intense.

Two brass springs project from the brass studs C D; these springs should rest on the edge of a small wheel of ebonite and brass, known as a commutator. It sometimes happens that, from rough usage in carriage, these springs are bent, so that they no longer touch the edge of the wheel; in this case the current becomes greatly weakened, or altogether ceases; but the machine can be easily set right by carefully bending down the springs so that they again rest upon the edge of the wheel.

We now come to the last of the induction machines, sometimes called the induction coil, the inductorium, &c. In 1851, M. Ruhmkorff, a most clever instrument maker in Paris, made a coil which produced in the scientific world

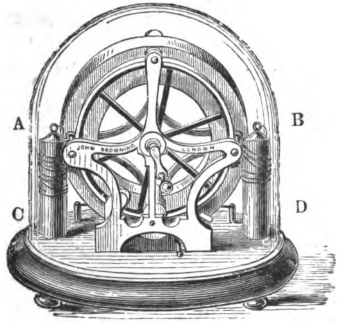


FIG. 46.—*Browning's Magneto-Electrical Machine.*

of Paris and London a profound sensation of surprise and delight at the beautiful light-effects obtainable.

Mr. Hearder, of Plymouth, and Mr. Bentley subsequently made coils of great power; but to Mr. Ladd is due the merit of constructing a serviceable apparatus which would always produce the most reliable results. A very large coil, having a secondary coil of seven miles of wire, has long been used at the Polytechnic. It consists of the usual primary coil, wound round a faggot of iron wires; around this is the secondary coil, of the required number of miles in length. The condenser, composed of alternate sheets of tinfoil and well dried and varnished paper, is placed under the coil, and, by making and breaking contact with the primary by a convenient "contact-breaker," an enormous current is induced in the secondary, which produces the most brilliant results.

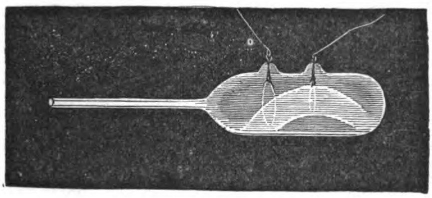


FIG. 47.—*Plücker's Tube.*

A Leyden jar or Leyden plate may be incessantly charged and discharged with a continuous roar. Paper is immediately set on fire when held between the poles. Tubes of glass are filled with various gases or liquids, or rather not filled according to the ordinary acceptation of the term, because they are *vacua*, the last gas which has been permitted to enter the tube alone representing the attenuated atmosphere through which the electric current passes.

The reader is referred to Dr. Noad's little book, entitled "The Inductorium," and published by Churchill for Mr. Ladd, for all the minute details connected with the primary coil, the secondary, the condenser, and the thousand-and-one experiments which, like the "Arabian Nights' Entertainments," crowd upon the student, but which may all be performed with the apparatus described.

Amongst the most interesting experiments, that of Plücker deserves especial notice.

"Two aluminium rings are hermetically sealed into a glass tube, 4 or 5 in. long and about 1½ in. in diameter; the air in the tube is then exhausted as perfectly as possible. On passing the discharge from the induction coil between the two rings, the tube becomes filled with a beautiful pale blue light.

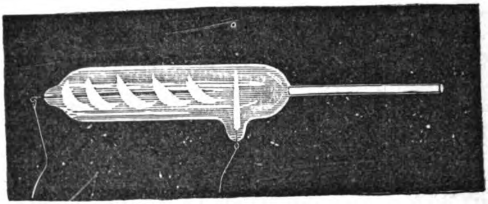


FIG. 48.—*Plücker's Tube with Aluminium Wires.*

"If the small ring be made negative, and the tube placed between the poles of an electro-magnet, the moment the latter is excited the light arranges itself in the form of a broad arc between the rings.

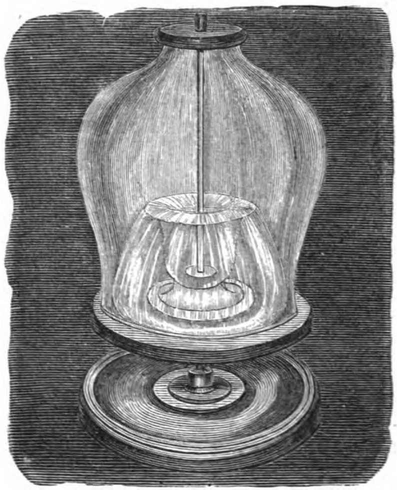


FIG. 49.—*Gassiot's Cascade,*

The current passing into and out of a glass vessel placed in a vacuum.

"On rendering the electro-magnet passive, the arc disappears, the light in the tube re-assuming its different character; but, on re-exciting the magnet, the arc re-appears. If, instead of two rings, the terminals in the tube are two aluminium wires, as shown in Fig. 48, the long wire being made positive and the short wire negative, the arc produced is very broad and brilliant."

It must be apparent from the preceding figures that the stratification noticeable in all experiments of this type is a special object of interest, to which M. Gassiot, the generous and large-hearted friend of science, has paid particular attention.

Speaking of Geissler's (of Bonn) tubes,—one of the prettiest arrangements the writer has seen is that of Mr. Apps, and shown in the next figure.

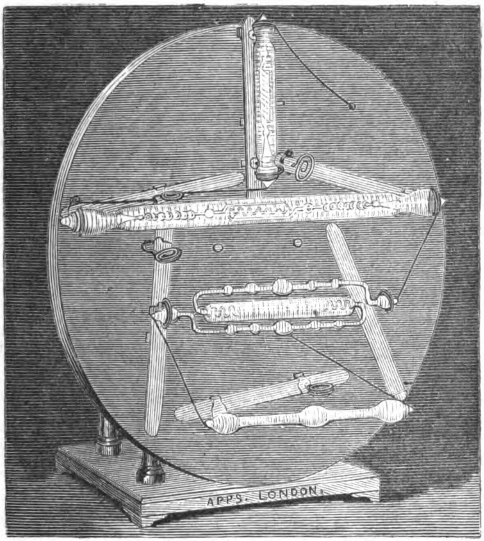


FIG. 50.—*Front View of Geissler's Tubes, arranged on a disc of blackened Mahogany.*

The back view exhibits the use of the electro-magnetic engine for rotating or reversing the disc. (Fig. 51.)

The electro-magnetic engine, in a convenient and handsome form, well adapted to rotate the vacuum tubes, is attached to the black polished disc, and arranged so as to turn in either direction: the speed can be easily regulated. The discharge from the coil passes through the entire series of tubes.

Amongst the remarkable effects produced by the induction coil, there are none more interesting than the generation of ozone by the "ozone tube," which is thus described by Dr. Noad, and made by Mr. Ladd. (Fig. 52.)

It consists of a glass tube, about the size of an ordinary test tube, coated with tinfoil or, still better, silvered, and enclosed in an outer tube lined outside with tinfoil. The two tubes are sealed together at the neck of the outer

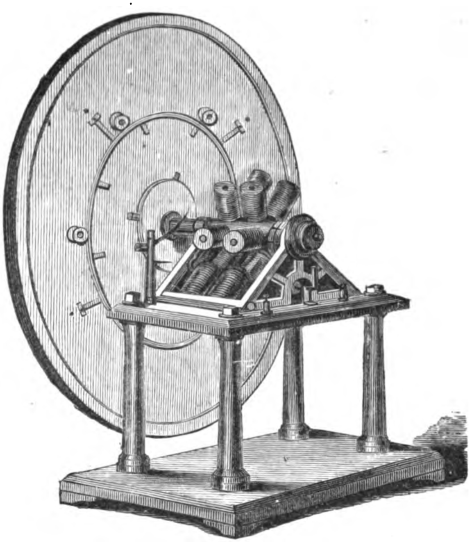


FIG. 51.

one, and so adjusted that the space between them shall be as narrow as possible.

At the projecting end of the inner tube is a brass button, which is connected by a spring with one of the binding-screws on the frame of the apparatus, which screw is to be connected with one of the terminals of the secondary coil of an inductorium, and the other with another binding-screw in metallic communication with the coating of the exterior tube.

The apparatus is, in fact, a sort of slit Leyden jar; and air or oxygen, admitted through the lateral tube, becomes during its passage through the apparatus powerfully ozonized.

The air may be driven through by means of a bladder or india-rubber bag, or drawn through with an aspirator.

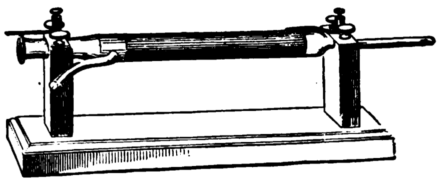


FIG. 52.—*The Ozone-Tube.*

Mr. Edward Beanes, who has already done so much in improving certain processes required in the manufacture of sugar, has patented the application of apparatus for generating ozone and bleaching syrup, and, although there appears to be some difficulty in obtaining enough ozone for this purpose, the experiments hitherto tried are very promising.

The writer abstains from saying anything about a new gigantic coil, building for the Polytechnic by Mr. Apps. Like David with his armour, he has not proved it: had he done so, this article would have contained an account of the Mammoth Induction Coil.

THERMO-ELECTRICITY.

Electricity produces magnetism, heat, light, mechanical and chemical effects. It is not opposed to the harmony of created forces that heat should produce electricity.

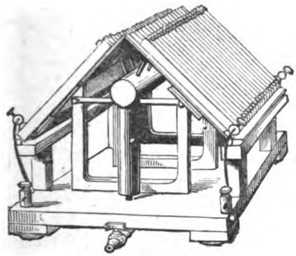


FIG. 53.—*Marcus's Thermo-Electric Battery, made by Mr. Ladd.*

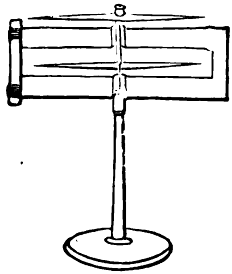


FIG. 54.

The above battery (Fig. 53), consists of thirty-six elements; the negative bars, which are 6 in. long, being composed of 12 parts of antimony, 5 of zinc, and 1 of bismuth; and the positive bars, which are 7 in. long, of copper 10 parts, zinc 6 parts, and nickel 6 parts. The bars are ranged on a frame in the slanting position shown in the figure, and were facetiously referred to by a writer in "Punch" as a "chestnut roaster," the positive bar of the first pair being metallically connected with the negative of the second, and the two extreme bars connected with binding-screws which form the terminals of the battery. The upper ends of the bars are heated by a series of Bunsen's burners, the flames of which can be easily regulated.

This battery at the Polytechnic, under the charge of Mr. J. L. King, decomposed water, of course very feebly; it gave small sparks between iron points without the assistance of a coil, and enabled an electro-magnet to support a considerable weight, and, when connected with an induction coil, gave sparks which were very marked in their character and length.

We have now to ask how this apparatus, in which heat takes the place of friction, chemical action, or magnetism, elicits electric force.

Seebeck's apparatus, a rectangular figure, made of bismuth and antimony, with an astatic magnetic needle supported inside, well exhibits the thermo-electric action; and, directly one of the angles is gently heated by a spirit flame, the needle, like that of the galvanometer with the voltaic circuit, is deflected. (Fig. 54.)

Pouillet's thermo-electric apparatus (made by Elliott), and already figured in Wheatstone's paper on the Rheostat (p. 127), consisting of a short cylindrical bar of bismuth, bent twice at right angles, with soldered copper wires attached to the ends, communicating with an ingenious contrivance on the stand for

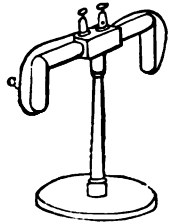


FIG. 55.—*Pouillet Thermo-Electric Circle.*

completing the electric circuit in any direction, is another and most perfect arrangement for showing currents of electricity obtainable by the exciter, "heat." (Fig. 55.)

On the second or third page of this work, in the article on Light, Melloni's small and compact composite "thermo-electric pile" is specially alluded to.

When the writer was a student, thirty years ago, he well remembers trying experiments with this beautiful contrivance for showing minute disturbances of heat; and, at that time, it had the reputation of being delicate enough to show the heat of the body of a "fly or a blue-bottle." Exaggeration apart, its

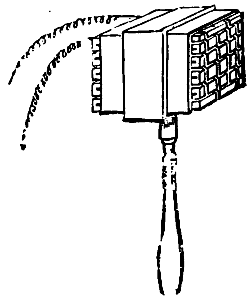


FIG. 56.—*Melloni's Thermo-Electric Pile or Battery.*

power to show the slightest heat-wave disturbance has never been equalled bv any other apparatus. It consists of a series of pairs of very slender bars of antimony and bismuth soldered alternatelv together, and arranged parallel side by side, so that all the soldered pairs are at one end, and all the solders not pairs at the other. This apparatus, mounted in a brass tube and placed on a stand, is now the special attendant at all lectures in which the dynamical theory of heat is taught. (Fig. 56.)

The late Mr. Francis Watkins, the predecessor of the Messrs. Elliott, paid particular attention to this subject, and constructed a "Thermo-Electric Combinator." Eighteen pairs of bismuth and antimony, united alternately by

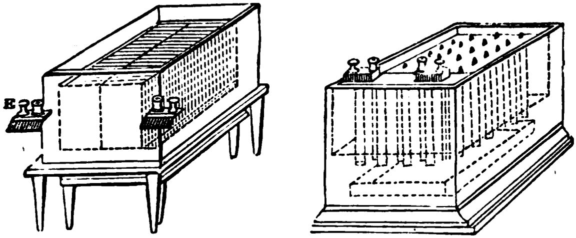


FIG. 57.—*Van der Voort's Thermo-Electric Battery.*

solder top and bottom, and fixed in a mahogany box by plaster of paris, leave the two extremities to be acted upon, the one by heat and heated iron or boiling oil, and the other by cold—some ice or a freezing mixture. All the common effects of an electric current, such as the spark, &c., can be shown with this contrivance.

Thus the corelation of forces is complete, and Light, Heat, Electricity, and Magnetism resolve themselves into each other, and represent probably a series of waves, every one of which is different from the other in the phases of its vibrations and resultant form.

Portrait and Autograph of Sir Charles Wheatstone.

WHEATSTONE'S TELEGRAPHS.

The limits of this article will not permit of any lengthened history of all the clever inventions either proposed or carried out by the various scientific men who have contributed to our knowledge of the science of telegraphy.

Whatever amount of credit may be accorded to others, there can be but one opinion respecting the merits of a living philosopher, whose portrait graces the head of this chapter. Foreigners are usually very frank and honest in their expression of the amount of merit due to their contemporaries in other countries. The jury of the French Exhibition of 1855 thus report upon Wheatstone:

"La transmission de l'électricité entre les pays séparés par la mer n'a pu s'effectuer qu'au moyen de cables particuliers unissant entre élles les stations télégraphiques. Mais combien de travaux n'a-t-il pas fallu pour atteindre ce but; et même maintenant que la question est résolue, on ne peut sans admiration penser que la transmission des dépêches télégraphiques est aussi facile à l'aide des cables sous-marins qu'au moyen des fils isolés et tendus dans l'air. C'est par l'emploi de ces cables que l'on a pu mettre en relation télégraphique la France et l'Angleterre, la Crimée et les provinces Danubiennes, les pays enfin dans lesquels ces principes ont été appliqués, et peut-être bientôt l'Europe et l'Amérique. Le Jury a voté une mention très-honorable pour M. Wheatstone (Royaume Uni), membre du Jury de la IX^e classe, pour avoir conçu l'idée première et pour avoir proposé, en 1840, un moyen de résoudre la question; il accorde la même distinction à M. Brett (Royaume Uni), sous la direction duquel a été placé un conducteur au travers de la Manche, entre Douvres et Calais, et qui a montré ainsi que le succès était possible. Le Jury décerne également une mention très-honorable à M. Crampton (Royaume Uni), membre du Jury de la V^e classe, auquel revient l'honneur d'avoir réalisé cette immense application, en unissant définitivement, en 1851, par un cable sous-marin, la France et l'Angleterre."

Another very distinguished foreigner, A. De la Rive, thus speaks of Wheatstone in his "Treatise on Electricity:"

"The philosopher who was the first to contribute by his labours, as ingenious as they were persevering, in giving to electric telegraphy the practical character that it now possesses is, without any doubt, Mr. Wheatstone. This illustrious philosopher was led to this beautiful result by the researches that he had made in 1834 upon the velocity of electricity—researches in which he had employed insulated wires of several miles in length, and which had demonstrated to him the possibility of making voltaic and magneto-electric currents to pass through circuits of this length."

The following is the order of the inventions made by Sir Charles Wheatstone:

The 5-needle telegraph, 1837.
The alphabet-dial telegraph, 1840.
The type-printing telegraph, 1841.
The new magnetic alphabetic-dial telegraph, 1858-60.
The fast-speed automatic telegraph, 1858—1867.

Sir Charles Wheatstone, in addition to the other honours he has lately received, has just been elected to replace Faraday as one of the twelve corresponding members of the "Società Italiana delle Scienze, detta dei XL.," and has also received their first gold medal, instituted during the present year by the late Minister of Public Instruction, Signor Matteucci, to honour the most important discoveries in physical science.

The president, in his address, says:

"I will not here pass in review the various memoirs in physics which you have published in the 'Philosophical Transactions,' since all carry the impression of the inventive genius which ever distinguishes all that you have done. I cannot, however, refrain from calling to mind that to you we owe the discovery of the method, as ingenious as it is original, for measuring the velocity of electric currents and the duration of the spark.

"The applications of the principle of the rotating mirror are so important and so various that this discovery must be considered as one of those which have most contributed in these latter times to the progress of experimental physics.

"Not less ingenious was the invention of the stereoscope and of the modes by which binocular vision is effected, which enable us to obtain the perception of relief from the simultaneous observation of two plane images.

"Also the memoir on the measure of electric currents, and on all the questions which relate thereto and to the laws of Ohm, has powerfully contributed to spread among physicists the knowledge of those facts and the mode of measuring them with an accuracy and simplicity which before we did not possess.

"All physicists know how many researches have since been undertaken with your rheostat (see p. 126, and with the so-called Wheatstone's bridge, and how usefully these instruments have been applied to the measure of electric currents, of the resistance of circuits, and of electro-motive forces.

"And here it would be impossible to leave out of view that to you we principally owe the practical invention and the true realization of the electric telegraph.

"Finally, I would call to mind your recent researches on the augmentation of the force of a magnet by the reaction which its own induced currents exert upon it.

"All these great acquisitions, procured by you, to physical science render you well worthy of this distinction from the Italian Society of Sciences.

"Preserve yourself in health and activity, and your country and all your admirers and friends are certain to find, in the discoveries still to be added while you continue to work, some compensation for that immense and irreparable loss which natural philosophy has received by the death of Faraday."

In addition to the memoirs by Sir Charles Wheatstone, alluded to by Signor Matteucci, the following may be specially noticed:

"On the Acoustic Figures of Vibrating Surfaces," published in the "Philosophical Transactions" for 1832. In this memoir, which gained for Sir Charles his admission into the Royal Society, the author gave for the first time the laws of formation of the varied and beautiful figures discovered by Chladni. Attention has recently been revived to this subject by König and others on the Continent.

"On the Transmission of Sound through Solid Conductors" ("Journal of the Royal Institution," 1828). This memoir describes the means discovered by the author of transmitting musical performances to distant places.

"On the Prismatic Analysis of Electric Light" (British Association, 1832). By these experiments Sir Charles proved for the first time that the spectrum of the electric spark from different metals presented each a definite series of lines differing in colour and position from each other, and that these appearances afforded the means of distinguishing the smallest fragment of one metal from that of another. This investigation was one of the earliest starting-points of an entire new branch of physical science, in which there are now many distinguished workers.

"On the Polar Clock" (British Association, 1849). This is an optical instrument which indicates the time by means of the changes in the plane of polarization of the blue light of the sky in the direction of the pole. It is founded on the discoveries of Arago and Quetelet; and Arago states that "l'honneur de la construction de l'horloge polaire, je la reconnais avec empressement et sans réserve, revient exclusivement à M. Wheatstone."

It would carry us beyond our limits to enumerate the various inventions relating to the electric telegraph and other applications of electricity which have emanated from Sir Charles. We will mention two only.

We owe to him, in addition to his former inventions relating to the electric telegraph, the alphabetical-dial telegraph, working without any clockwork power, and in which a magneto-electric machine supplies the place of a voltaic battery. These instruments were first introduced on the Paris and Versailles Railway in 1846, and, with the improvements which the inventor has since made, have been employed to a great extent throughout the kingdom by the Universal Private Telegraph Company in furnishing telegraphic communication between public offices and private establishments, to which purposes, from their facility of manipulation and constancy of action, they are admirably adapted.

A more recent invention is his fast-speed telegraph, in which the messages, previously prepared on strips of paper by manipulations as easy as those for sending an ordinary message, are, by passing through a very small machine constructed on somewhat the principle of a Jacquard loom, made to print the messages at the remote station in the ordinary telegraphic characters, with a rapidity and distinctness unattainable by the hand of an operator. The invention of these instruments dates from 1858; but they have only, with recent improvements, been practically introduced, by the Electric Telegraph Company, during the last year. Since June last these instruments have been in constant action for the ordinary business of the establishment between London and Newcastle, printing from sixty to a hundred and ten words per minute. The result has been so successful that the company have just resolved to adopt them on other leading lines of communication.

In the report of the Paris Exhibition of 1855, honourable mention was awarded to Sir Charles, he being *hors de concours*, for having been the first to conceive the idea, and for having proposed, in 1840, a means of resolving the question, of a submarine telegraph between Dover and Calais.

It may be mentioned in reference to an eminent philosopher, Sir David Brewster (whose loss we have had to deplore), that one of the last acts of his life was to nominate Wheatstone for election as an honorary member of the Royal Society of Edinburgh, thus falsifying the couplet of Dryden, who says,

> "Forgiveness to the injured does belong;
> But they ne'er pardon who have done the wrong."

In 1868 Wheatstone received the honour of knighthood at the hands of his gracious sovereign, and this same year of grace the Royal Society have awarded to him their highest distinction, viz., the Copley medal.

> "This is the state of man: to-day he puts forth
> The tender leaves of hope; to-morrow, blossoms
> And bears his blushing honours thick upon him."

In concluding this brief notice of the laborious and useful life of Wheatstone, we may, in common with all his friends and admirers, be permitted to hope that he may pass the evening of his days in peace and in the enjoyment of health, and that he will give to the world, in the calmness of matured age, a monograph of the "Labours of his Life."

In every book devoted to the consideration of electric telegraph instruments we find illustrations and descriptions of Cooke and Wheatstone's earlier inventions of the single and double needle telegraph. We will, therefore, commence at the year 1840, when he constructed the alphabet-dial telegraph, which the writer has always found to be one of the best forms for teaching and demonstrating the broad principles upon which motion is developed by a current thrown alternately from one electro-magnet to another. Such is the construction of the telegraph, the dial of which is shown at Fig. 58.

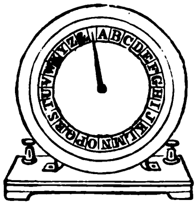


FIG. 58.—*Wheatstone's first Alphabet-Dial Telegraph* (1840).

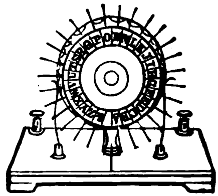


FIG. 59.—*Wheatstone's Communicator* (1840).

It consists of a circular dial, on which the letters of the alphabet are painted in black letters on a white ground. The mechanism is very simple. Two electro-magnets, with feeders and long arms, strike alternately the pallets; these take up at each blow one tooth of a wheel or escapement, and every time a tooth is taken up the hand on the dial moves forward one letter. To make the letters on the dial coincide with the letters of the sender of the message, another instrument is required, called the "communicator." (Fig. 59.)

This consists of a wheel, upon the circumference of which are thirty alternations of brass and ivory corresponding to the letters of the alphabet, &c., with which also this instrument is provided. There are two springs, one on each side, which communicate alternately with the communicator and through that to the battery and wires of the dial telegraph. When the communicator is turned round one letter, the hand or the dial moves one letter; and, if the instruments are very carefully made, they answer remarkably well.

Wheatstone, however, found that they sometimes missed a tooth in the escapement, and, of course, one letter being gone, the message afterwards might be very chaotic, particularly when a number of words in rapid succession had to be forwarded. This system was, however, at the time adopted on some of the continental lines.

Passing by the type-printing telegraph of 1841, we now come to the new magnetic alphabetic-dial telegraph of 1858 and 1860.

The reader will be able to understand the construction better by reading and examining the annexed description and diagrams than if a minute description of the above instrument (Fig. 60) were given at once. It is, perhaps, unnecessary to remark that these instruments are in daily use by the Universal Private Telegraph Company.

Instructions for connecting-up the Instruments.—The instruments (communicator, indicator, and alarum) at each station should first be placed in short circuit in the following manner (Fig. 61):

Place short wires upon the two upper terminals, *a b*, at the back of the indi-

FIG. 60.—*Wheatstone's new Magnetic Alphabetic-Dial Telegraph.*

cator, and connect them with *c* and *d* respectively, the switch, *x*, being turned to point to the letter T—Telegraph. The handle, *z*, of the communicator is then to be turned steadily at a rate of about a hundred and twenty revolutions per minute, and the index or pointer passed from + to + on the dial by

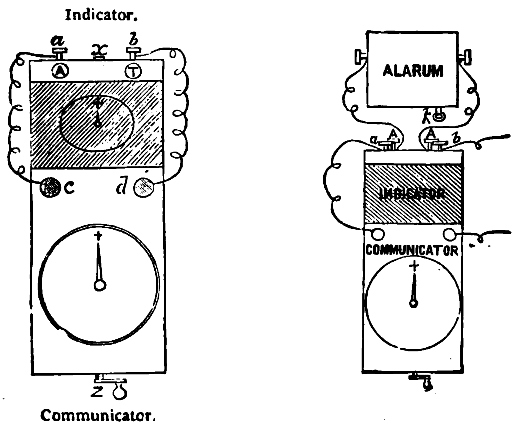


FIG. 61.

depressing the finger-key opposite the full stop (.) and the key opposite the + immediately afterwards. If the index of both communicator and indicator correspond, the connections will be right; but should the hand of the indicator be either in advance or behind the + one space, the connecting wires must be reversed.

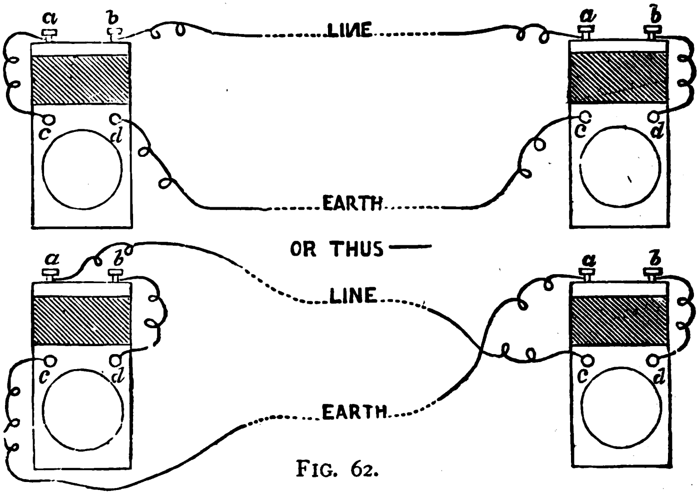


FIG. 62.

a being now joined up to *d*, and *b* to *c*, the instruments will be found to correspond in the revolution of their pointers round the dials. The line wire may now be connected to the instruments by removing one of the short wires at each station, and substituting the line wire and earth wire, as shown at *a b* and *c d*. The same signal of passing the pointer from + to + is now to be sent from station to station, and if the index at the other station falls either one in advance or behind, the position of the line and earth wires at one station only must be reversed.

The hand of the indicator may be reset by gently moving the small button under the face backward and forward between the thumb and finger.

When more than two stations require to be connected up in the same circuit, the above rules are to be observed with reference to the signals from + to + at each successive station, the connections appearing thus (Fig. 63)—

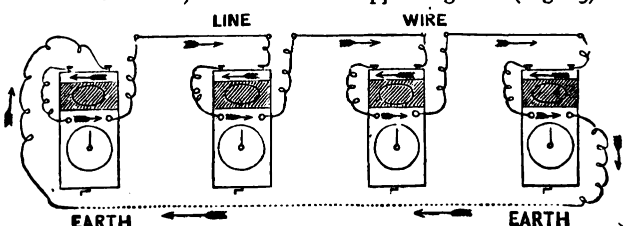


FIG. 63.

When several stations are in the same circuit, it will often be found convenient to introduce the switch, enabling the operator to send up and down the line in either direction, without interrupting the communication of those stations situated in an opposite direction to that in which he is speaking. The

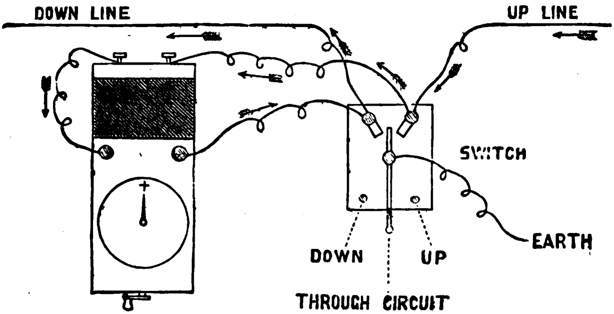


FIG. 64.

manner of connection will be seen by reference to the drawing. This arrangement will enable several stations to communicate with each other at the same time.

a——*b*——*c*——*d*——*e*——*f*——*g*——*h*

For instance, while *a* is speaking to *b*, *c* can talk to *d*, *e* with *f*, and so on. This system requires that each station has its own signal or preface for calling attention, and that when no station is called either up or down the line, the handle of the switch remains on the *through circuit*, as shown in the diagram. The switch is generally adapted to the peculiar requirements of the line.

When alarums or bells are used to call attention, they must be placed in circuit by connecting their binding-screws to the two lower binding-screws at the back of the indicator. The alarum may be placed at any distance from the instrument, in the most convenient position for calling attention. The switch, *x*, of the indicator should point to A, alarum, when no messages are being sent, but be turned to T when operations begin.

Instructions for working the Telegraphs.—The following summary of rules for working the telegraph may be advantageously introduced here:

1. The handle in front of the instrument (Fig. 60), which causes the armature of the magnet to rotate, must be kept in *continuous* motion by one hand, while the fingers of the other are employed to manipulate the stops or keys. Care must be taken not to intermit the motion until the end of the message.

2. A key need not be continuously pressed down; it will suffice merely to touch it; but another key must not be pressed down until the index or pointer has arrived at the letter previously indicated.

3. The same key cannot be pressed twice down in succession; to repeat a letter it is necessary to touch the preceding key, and, without waiting for the arrival of the index, to touch again the proper key.

4. Before commencing to send a message, the index of all the instruments must point to +. To bring the telegraph to this position when out, the small

pin or button on the face of the telegraph must be moved alternately backwards and forwards between the finger and thumb until the index stands at +.

5. If by inadvertence the index of the communicator has been left at a letter, it must be brought to the cross before the telegraph is adjusted.

6. The pointer of the alarum must invariably, when the instrument is not in use, be turned to the letter A.

7. To call attention for the purpose of sending a message, first turn your own alarum off, then rotate the handle of the communicator and let the needle pass from + to +. This will ring the bell at the other end. Wait an interval of time sufficient to allow of reply. If no reply, continue to call in the same manner.

8. Receiver will notify his attention by repeating the signal.

9. The receiver will then turn off his alarum, by passing the pointer from letter A to T.

10. A short time must be allowed the receiver before sending, to enable him to put his indicator in accord with his transmitter, if it be wrong.

11. At the end of each word the needle to be brought to the +.

12. Should the receiver not understand, he will send the letter R for repeat, prior to giving +. The sender will then repeat the last word.

13. Every initial letter or part of a word used for abbreviation must be followed by the full stop, and the full stop must be given at the end of each sentence.

14. At the end of message, needle to be turned from + to + twice.

15. Receiver to repeat this double revolution.

16. If by accident the needle of the indicator becomes misplaced, so as to render a message unintelligible, the receiver must break in by pressing down several keys in succession. The sender will immediately stay sending. Both receiver and sender will then set needles at +, and receiver will give repeat, R.

17. To signify figures, use the semicolon, and then the +, before and after them.

Instructions for keeping the Instruments in order.—When the telegraph is in operation, the handle of the communicator should be turned at a uniform rate of 120 revolutions per minute, and the finger-keys should not be depressed when the handle is at rest.

The working parts and bearings of the communicator will require occasionally to be oiled with good watch-oil, procured from any respectable watchmaker. If the oil is good, and the telegraph moderately used, the instrument will work eight or ten months without touching; but, when in constant use, it is desirable to apply a little oil regularly every two months. Access for this purpose may be obtained to the interior of the communicator by unscrewing the bottom of the communicator. The various parts to be oiled are shown in the annexed diagram at *a*, *b*, *c*, *d;* and by dipping the point of a penknife into the oil, it may be neatly applied in small quantities where desired.

If the centre, *b*, has become worn by constant revolution, and causing the armature, *e*, to touch the iron prolongations of the magnet, the handle will work stiffly or stop altogether. This may be remedied by tightening slightly the screw, *g* (Fig. 65), with a pair of small pliers, or other means sufficient to free the armature from contact with the poles of the magnet.

After long use, the watch-chain, which runs round the rollers on the lower plate, for the purpose of mechanically raising each key, after it has been depressed by the hand, may become too slack; this is remedied by slightly

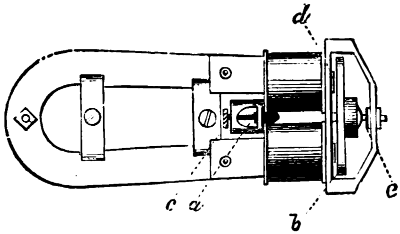


FIG. 65.

tightening the screw, A, attached to a lever carrying an extra roller, care being taken to leave sufficient slack in the chain to allow of one key always remaining depressed, as shown at B (Fig. 66).

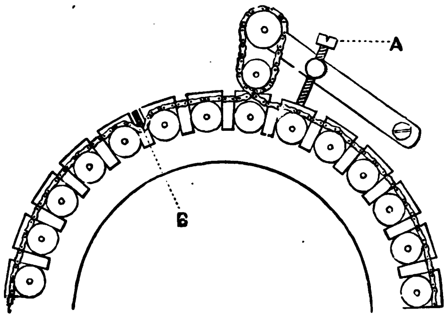


FIG. 66.

If it becomes necessary to take the communicator to pieces (this operation had always better be performed by a clock or watch maker, or other experienced person), the bottom of the case must be taken off first, and the little ivory number-plate in front of the instrument pushed out from the inside. This will enable the position of the wheel and pinion to be marked through the hole of the number-plate, by making a scratch (Fig. 67), as at x, across both, care being taken in putting together that the marked parts of the wheels are placed as before. The magnet may then be taken out, having previously unscrewed the wires leading from the coils. The brass casing which covers the upper portion of the mechanism is now to be unscrewed, and the ring with the glass, which is only sprung on, removed; then the dial card and plate. Unscrew the four pillars below, and, after the whole frame has been taken off the wooden case, all may be taken to pieces. It will be necessary to mark the

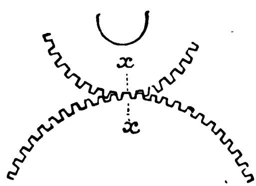


FIG. 67.

position of the two wheels, *h* and *i*, by a scratch across both, before taking that portion asunder. Oil must be put to the teeth of the wheel *k*, and also to *n*, *m*, *o*, and *p* (Fig. 68.)

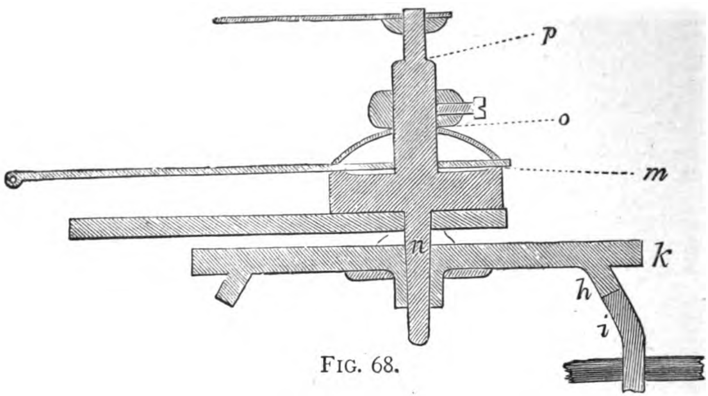


FIG. 68.

The operation of putting together is as follows:—First put the centre arbor and all upon it in the frame, and secure the same by the four pillar screws. Then place the finger-keys, the dial-plate, the springs for the keys, the dial, the index, and the glass together, and fix the whole on the wooden case. Lastly, place the magnet in its proper position, and, when all is ascertained to be correct, screw on the brass casing and the wooden bottom of the instrument.

The indicator and alarum may be taken to pieces, when necessary, and put together again, by marking the proper position of the several parts. In the indicator, pivots only require to be oiled, and that in very small quantities. The indicator, when good oil has been used, will work without attention for two or three years.

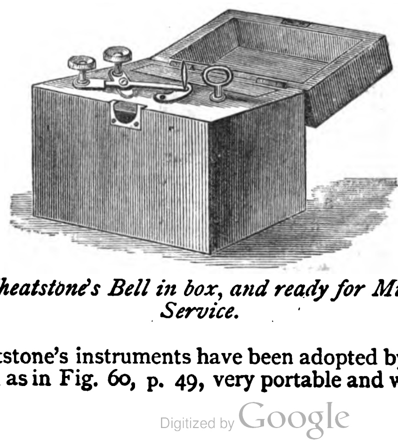


FIG. 69.—*Wheatstone's Bell in box, and ready for Military or other Service.*

Professor Wheatstone's instruments have been adopted by the army authorities, and are made, as in Fig. 60, p. 49, very portable and wholly independent

of all battery power, the trouble of putting batteries togethe
acids, breakage, and all the trouble that would be multiplie
hurry of the battle-field. These instruments, as already descr
current developed by magnetism and by the use of steel ma
made very strong and substantial, and are well calculated t
and tear of military operations conducted in the field.

The bell is rung, as nearly all other electric bells are rung
wound up, but stopped by a "detainer." Directly the detent
the current, the bell rings.

The same instruments, connected with enlarged dials, are
the iron-clads. We show an enlarged dial, and can easily u
quickly the commander's orders could be conveyed to the eng

FIG. 70.—*Wheatstone's enlarged Dials, such as are used in rooms of Ships of War.*

The dials, of course, would have special orders printed on th
given constantly in the navigation of these immense vessels.

In a very short time, similar dials will be placed in the vario
pied by members in the House of Commons, and the dials
business is in progress and what has been done. The busin
acted, being printed in a circular form, is laid upon the dial
points to that in progress, whilst all behind it is over.

The steering of the iron-clads is also to be conducted with t
similar dials.

One of the most useful of Sir Charles Wheatstone's elegan
inventions is the instrument he has supplied to the editor of
newspaper to record the number of copies printed and printin

reads in his own room the progress of that great undertaking, the daily printing of "The Times."

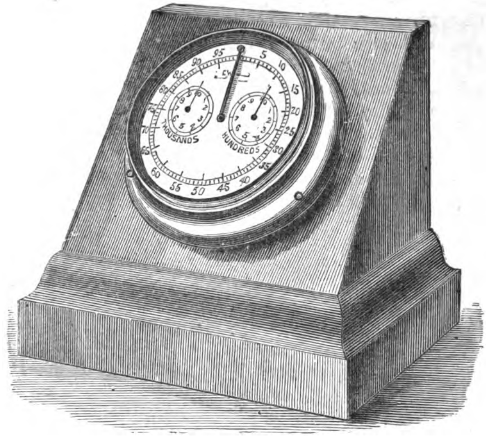


FIG. 71.—*Wheatstone's Recording Instrument for Newspaper Offices or Public Buildings.*

This instrument will record from ten thousand to one million copies. The same contrivance the writer hopes to be able to adopt at the Polytechnic, so that, without moving from his office, he will be able to know the number of persons in the building.

These instruments culminate to their highest degree of perfection in the inventions of 1858 and 1867, viz., Wheatstone's Fast-speed Automatic Telegraph, of which the inventor gives the following particulars:

"My invention consists of a new combination of mechanism for the purpose of transmitting through a telegraphic circuit messages previously prepared, and causing them to be recorded or printed at a distant station. Long strips or ribbons of paper are perforated, by a machine constructed for the purpose, with apertures grouped to represent the letters of the alphabet and other signs. A strip thus prepared is placed in an instrument, associated with a rheomotor (or source of electric power), which on being set in motion moves it along, and causes it to act on two pins in such manner that, when one of them is elevated, the current is transmitted to the telegraphic circuit in one direction, and when the other is elevated, it is transmitted in the opposite direction; the elevations and depressions of the pins are governed by the apertures and intervening intervals. These currents, following each other indifferently in the two opposite directions, act upon a printing or writing instrument at a distant station, in such manner as to produce corresponding marks on a ribbon of paper moved by appropriate mechanism.

"I will proceed to describe more particularly the several parts of this telegraphic system, observing, however, that each part has its independent originality, and may be associated with other apparatus already known.

"The first improvement consists of an instrument for perforating the slips of paper with the apertures in the order required to form the message. The slip of paper passes through a guiding groove, at the bottom of which an opening is made sufficiently large to admit of the to-and-fro motion of the upper end of a frame containing three punches, the extremities of which are in the same transverse line. Each of these punches is capable of being separately elevated by an appropriate finger-key. By the pressure of either finger-key, besides the elevation of its corresponding punch in order to perforate the paper, two different movements are successively effected—first, the raising of a clip, which holds the paper firmly in its place, and, secondly, the advancing motion of the frame containing the three punches, by which the punch which is raised carries the ribbon of paper forward the proper distance during the reaction of the key consequent on the removal of the pressure; the clip first fastens the paper, and then the frame falls back to its normal position. The two external keys and punches are employed to make the holes which, grouped together, represent letters and other characters, and the middle punch to make holes which mark the intervals between the letters. The perforations in the slip of paper appear thus:

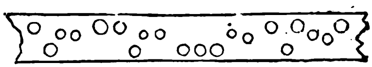


FIG. 72.

"The second improvement consists of an apparatus which may be called the transmitter, the object of which is to receive the slips of paper prepared by the previously described instrument or perforator, and to transmit the currents produced by a voltaic battery or other rheomotor in the order and direction corresponding to holes perforated in the slip; this it effects by mechanism somewhat similar to that by which the perforator performs its functions. An eccentric produces and regulates the occurrence of three distinct movements: 1st, the to-and-fro motion of a small frame, which contains a groove fitted to receive a slip of paper, and to carry it forward by its advancing motion; 2nd, the elevation and depression of a spring clip, which holds the slip of paper firmly during the receding motion, but allows it to move freely during the advancing motion; 3rd, the simultaneous elevation of three wires placed parallel to each other, resting at one of their ends on the axis of the excentric, and their free ends entering corresponding holes in the grooved frame; these three wires are not fixed to the axis of the excentric, but each of them rests against it by the upward action of a spring, so that when a light pressure is exerted on the free ends of either of them, it is capable of being separately depressed. When the slip of paper is not inserted, and the excentric is in action, a pin attached to each of the external wires passes, during each advancing and receding motion of the frame, from contact with one spring into contact with another spring, and an arrangement is adopted, by means of insulations and contacts properly applied, by which, while one of the wires is depressed and the other remains elevated, the current passes from the voltaic battery to the telegraphic circuit in one direction, and passes in the other direction when the wire before elevated is depressed, and *vice versâ;* but while both wires are simultaneously elevated or depressed, the passage of the current is interrupted. When the prepared slip of paper is inserted in the groove, and moved onwards, whenever the end of one of the wires enters an aperture in its corresponding row, the current passes in one direction, and when the end of the other wire enters an aperture of the other row, it passes in the other direction; by this means the currents are made to succeed each other automatically in the proper order and direction to give the requisite variety of signals. The middle wire only acts as a guide to the paper during the cessation of the currents.

"The wheel which drives the excentric may be turned by hand or by the application of any motive power. Instead of a voltaic battery, a magneto-electric or an electro-magnetic machine may be employed as the source of electric power. In this case the transmitter and the magneto-electric or electro-magnetic machine form a single apparatus moved by the same power, and they are so adapted to each other, that the shocks or currents are produced at the moments the pins of the transmitter enter the apertures of the perforated paper.

"The transmitters just mentioned require only a single wire of communication, and currents in both directions are available for printing the signals; but in some cases it may be advantageous to employ two telegraphic wires, and to use the inversions of current to bring back the pens or markers without the aid of reacting springs. In this case the only modification of the apparatus required is in the disposition of the insulations and contacts necessary to transmit in their proper order the currents from the rheomotor into the two wires.

"The third improvement is in the recording or printing apparatus, which prints or impresses legible marks on a strip of paper, corresponding in their arrangement with the apertures in the perforated paper. The pens or styles are depressed and elevated by their connection with the moving parts of the electro-magnets; they are entirely independent of each other in their action, and are so arranged that, when the current passes through the coils of the electro-magnets in one direction, one of the pens is depressed, and when it passes in the contrary direction the other pen is depressed; when the currents cease, light springs restore the pens to their usual elevated positions. The mode of supplying the pens with ink is as follows:—A reservoir, about an eighth of an inch deep, and of any convenient length and breadth, is made in a piece of metal, the interior of which may be gilt, in order to avoid the corrosive action of the ink placed in it. At the bottom of this reservoir are two holes, sufficiently small to prevent by capillary attraction the ink from flowing through them. The ends of the pens are placed immediately above these small apertures, which they enter when the electro-magnets act upon them, carrying with them a sufficient charge of ink to make a legible mark on the strip of paper passing beneath them. The motion of the paper ribbon is produced and regulated by apparatus similar to those employed in other register or printing telegraphs.

"Instead of reacting springs for restoring the position of the pens, the attractive or repelling force of small permanent magnets may be employed. All the essential parts of my new recording or printing telegraph are included in the previously mentioned three improvements. The following improvements are either auxiliary or substitutions for parts already mentioned.

"The fourth improvement is an instrument which I call a translator; its object is to translate the telegraphic signs, consisting of successions of points or marks, adopted in this system, into the ordinary alphabetic characters. In the system I have adopted, limiting the number of points in succession to four, thirty distinct characters are represented.

"The instrument presents externally nine finger-stops, eight of which are arranged in two parallel rows, four in each, and the remaining one is placed separately.

"The principal part of the mechanism within is a wheel, on the circumference of which thirty types are placed at equal distances, representing the letters of the alphabet and other characters; other mechanism is so disposed and connected thereto, that when the keys of the upper row are respectively depressed, the wheel is caused to advance 1, 2, 4, or 8 steps or letters, and when those of the lower row are in like manner depressed, the wheel advances respectively 2, 4, 8, or 16 steps. By this disposition, when the stops are touched successively in the order in which the points are printed on the paper—touching the first stop for one point, the first and second for two points, &c., and selecting the stops of the upper or lower row, according as the point is in the upper or lower row of the printed ribbon—the type wheel will be brought into the proper position for placing the letter corresponding to the succession of points over a ribbon of paper. The ninth stop, when it is pressed down, acts to impress the type on the paper, to cause the advance of the paper, in order to bring a fresh place beneath the type-wheel, and subsequently to restore the type-wheel to its initial position.

"The fifth improvement is a modification of the electro-magnets of the instrument of the third improvement, which enables the pens to go back to their normal positions when the currents in the telegraphic circuit cease, without the aid of reacting springs or permanent magnets. An extra coil of wire is wound round each of the electro-magnetic bars, which act on one side of each of the double magnetic needles appropriated to the two pens. These coils are entirely insulated from those connected with the telegraphic circuit, and form together a short local circuit, in which a feeble voltaic current continually circulates, in consequence of the interposition of a small rheomotor; by this current the needles are held, when no current exists in the telegraphic circuit, constantly attracted towards these electro-magnets. When, however, the current transmitted through the telegraphic circuit acts on the coils, besides its direct action to cause the deflection of one of the double needles and the detention of the other, it neutralizes the current of the local battery in that electro-magnet where its effect for the time would be disadvantageous.

"The sixth improvement consists in the application of ribbons of paper prepared by the perforator, and passed through the transmitter as heretofore described, to produce the successive motions of a magnetic needle or needles corresponding to the signals required, whether separately employed for this purpose or in conjunction with the printing apparatus already mentioned."

Even these beautiful instruments were not considered perfect by the indefatigable inventor, and we again find him, after a most severe illness, recording, in 1867, further great improvements in the mechanism of all their parts.

IMPROVEMENTS IN ELECTRIC TELEGRAPHS, AND IN APPARATUS CONNECTED THEREWITH.

"My present invention (1867) consists in certain improvements in the various instruments constituting the electric telegraph system described in the specification of the patent granted to me on the second day of June, A.D. 1858, No. 1239.

"This system comprises three distinct apparatuses: first, a perforating machine for preparing the messages to be sent on the strips of paper or other suitable material;

"Second, a transmitter, or apparatus for receiving the strips of paper so prepared, and for transmitting the currents produced by a voltaic battery, magneto-electric machine, or other rheomotor, in the order corresponding to the holes perforated in the strip, the direction and sequence of these currents being governed by pins, or other suitable apparatus, disposed so as to enter the perforations, and operating in a manner analogous to that in the mechanism of a Jacquard loom, and the strip being advanced intermittingly by the action of pins or other apparatus appropriated for that purpose;

"And, third, of a recording or printing apparatus adapted to print or impress marks on a strip of paper, such marks corresponding in their arrangement with the currents transmitted to the telegraphic line and with the apertures in the perforated paper.

"Having separately described each system of recording telegraphs, with the improvements which form the objects of the present specification, I proceed to designate those points which I specially claim as new.

"First, the modification of the perforator for the dot-printing telegraph, which enables it to prepare the strips of paper with an uninterrupted series of central apertures; this modification, described as the first improvement, consists of the mechanism being so arranged that when either of the keys corresponding with the outer apertures is depressed, besides acting on its own punch, it carries with it the punch which corresponds with the central apertures, while the latter is alone acted upon by means of another key causing the perforation only of a single aperture at a time.

"Second, the modification of the perforator, described as the fourth improvement, having five punches, and the mechanism so arranged that, when the first key is pressed, three of the punches in the order described are simultaneously acted upon; when a second key is depressed, four of the punches are in like manner simultaneously acted upon; and when a third key is depressed, the single punch only of the central line is acted upon. I claim also, in connection with this arrangement, the mechanism by which when either the first or third keys are pressed down the paper advances only a single space, and when the second key is depressed it advances two spaces; but be it understood that I do not claim the advance of the paper by unequal spaces, unless in connection with the arrangement of the punches described.

"Third, the additions of extra keys to the preceding modification of the perforator, with additional punches, described in the fifth improvement, which are so arranged that each additional key when depressed, while it punches simultaneously all the required apertures, shall advance the paper at once three, four, or more steps, so that all the perforations may be simultaneously made which are necessary to cause lines of the various required lengths to be marked or printed by the receiving instrument.

"Fourth, the modification of the transmitter, described as the second improvement, whether actuated by a magneto-electric machine or by a voltaic battery, in which the central needle alone has a to-and-fro motion for the purpose of propelling forward the strip of paper by means of the central apertures alone, and not also by means of the external apertures and outer pins, as described in the second improvement of the specification of my patent, No. 1239 (A.D. 1858).

"Fifth, the modification of the transmitter, described as the sixth improvement, which is adapted to send into the telegraphic circuit short currents at various intervals and alternately in opposite directions, so as to determine the occurrence of printed lines and intervals of various lengths in the receiving instrument: in this modification one current-governing needle has a to-and-fro motion simultaneously with the central needle, while the other has no such motion, the latter acting only while the paper is at rest, and the former while it is in motion.

"Sixth, the modification of the transmitter, described as the eighth improvement, which is suited to send into the telegraphic circuit currents of various lengths in one direction only in a different way to that described as the seventh improvement in my patent, No. 2462 (A.D. 1860). The characteristics of this new method are, first, that lines of any lengths can be produced, instead of lines of two different lengths only; second, that the short lines occupy a shorter space on the paper than the long lines do; and, third, that strips of paper prepared by the perforators of the third and fourth improvements may be employed to regulate the motions of the needles in order to produce the required effects.

"Seventh, the modification of the dot-printing receiving instrument, described as the third improvement, in which the pens or markers are acted upon by one set of electro-magnets and magnetic bars, instead of by two sets, as described in the specification of my patent, No. 1239 (A.D. 1858).

"Eighth, that modification of the printing apparatus of the receiving instruments of the second and third systems described as the eighth improvement, by means of which lines of various lengths are printed with great rapidity, certainty, and distinctness. The characteristic distinction of this mode of printing is, that the inking-disc and tracing-disc are both independently kept in motion by the maintaining power, and are not in actual contact with each other, and that the ink is retained on the circumference of the inking-disc by capillary attraction."

We now give the description of the three instruments:

I. The perforator.
II. The transmitter.
III. The recorder.

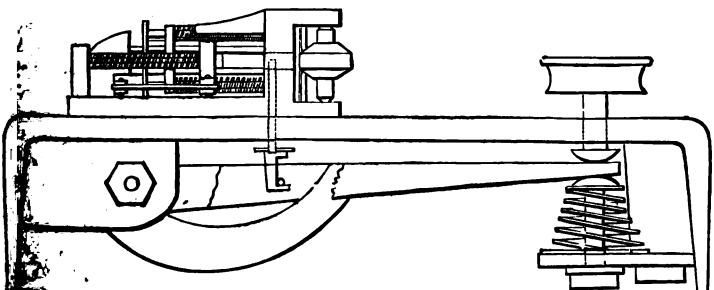


FIG. 73.—*The Perforator* (1867).

"The present improvement provides for the continuity of the middle perforations of the paper strip. The punching-plate carries three punches (Fig. 74), placed transversely to the path of the paper through the machine. Three lever finger-keys act upon the punches in such a manner that whenever either of the outer keys is depressed, it acts upon the punch which belongs to it, and at the

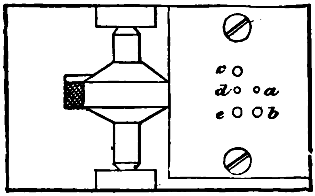


FIG. 74.

same time carries with it the middle punch by means of a collar which is fixed thereto, and simultaneously perforates the two apertures; but the depression of the middle key acts upon the middle punch alone, and perforates a middle aperture only, which is equivalent to a space in the receiving instrument. On the removal of pressure from any finger-key, the corresponding punch or punches is or are restored to its or their normal positions by means of a reacting spring or springs. A lever and link arrangement, moved by either of the three keys, draws back the paper-moving lever during the depression of a key; the release of a key permits a reacting spring to force the paper-moving lever forwards and to advance the paper one step, the said lever having a rough end next to the paper strip for that purpose: this mechanism propels the paper quite independently of the middle row of holes.

"Fig. 75 is a perspective view of a transmitter arranged to work with two line wires; in this instrument, besides the necessary change in the insulations and contacts, the mechanical arrangements are slightly varied, the construction shown being more convenient when two line wires are employed than that first described. *a* is a permanent magnet, and *b* is an armature mounted on an axis *c*, so as in revolving to pass in front of the poles of the magnet. On the axis *c* there is a toothed wheel, *d*, which drives the pinion *e* on the vertical axis *f*, so that this axis makes twice as many revolutions as the axis *c*; at the upper end of the axis *f* is a cam, *g*, arranged to act on the pin *h*, which is mounted on a rocking-frame similar to the rocking-frame of the transmitter already described. The pin *h* is kept in contact with its cam *g* by a spring *i*. The form of the cam is such that the forward motion of the frame is gradual, but its return motion takes place as rapidly as the spring *i* will react. *j* is another cam on the axis *f*; it comes in contact with a projection on the lever *k* just as the return motion of the rocking-frame is going to take place, and so causes this lever to draw down the three needles carried by this frame. At the same time the tail of the lever *k* presses on the end of another lever *l*, which is fixed to the spring-clip *m*, and so causes the clip, by turning slightly on its axis, to nip the paper under it. It will be seen that the two outside needles carried by the rocking-frame have projections from their lower ends, and when they are allowed to rise by the perforated paper, as before explained, their ends come in contact with the springs *n* and *o*, which are insulated from the rest of the instrument, and are in communication with the two line wires. On the

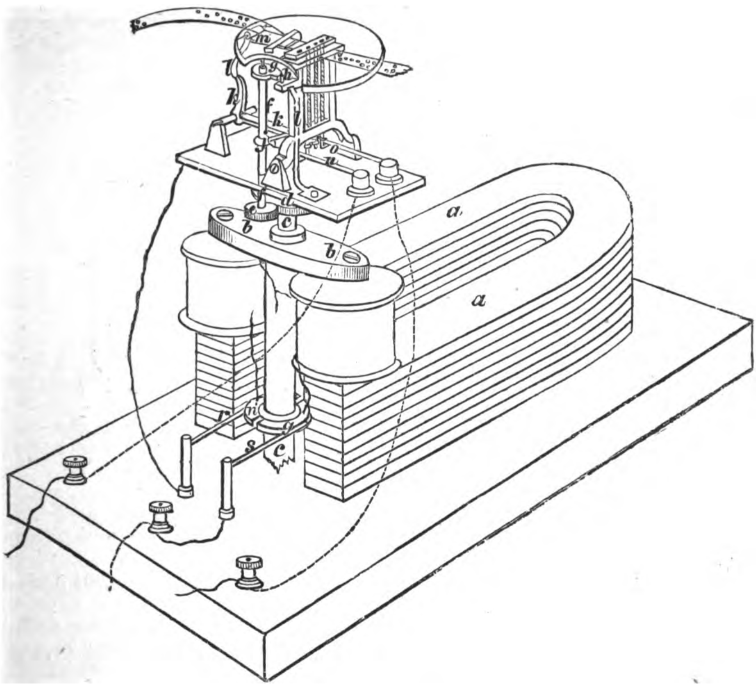


FIG. 75.—*The Transmitter* (1858).

axis *c* a metal disc is mounted; it is made in two parts, *p* and *q*, which are insulated from each other and from the axis. *r* and *s* are two springs, which press on the periphery of the disc as it revolves; the spring *r* is in metallic communication with the working parts of the instrument, and the spring *s* is insulated from these parts, but is put into metallic connection with the earth. When one of the needles of the rocking-frame comes into contact with its corresponding spring, *n* or *o*, it brings the line wire in connection with the spring into metallic communication with the working parts of the instrument, and any currents or shocks transmitted to these flow into the line wire. From the construction of the apparatus, the contact between the needles of the rocking-frame and their corresponding springs when established lasts during half a revolution of the axis *c*, and in this period two currents in opposite directions are transmitted into the line wire. The first current acts to bring one of the pens or markers of the receiving instrument into contact with the surface to be marked, and the second current to bring this pen or marker to its original position. It is evident that, if necessary, the instrument above described may be worked with one line wire only, without any change being made in the instrument; all that is necessary is that, in perforating the strfor the message, only one of the outside finger-keys of the perforator should be employed (the alphabet or signs employed being modified accordingly). Or the perforating instrument and the transmitting instrument may both be modified, if desired, so as to be suitable only for working with one line wire, by constructing the perforator with two in place of three finger-keys and punches, and the transmitter with two in place of three needles."

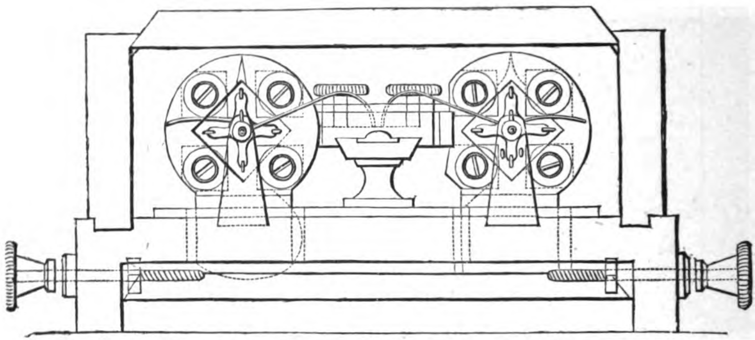


FIG. 76.—*The Recording or Printing Instrument* (1858).

Another improvement is in the recording or printing apparatus; but as the chief parts of this instrument have already been described with sufficient minuteness, it is only necessary to refer our readers to page 406 for the details of the beautiful mechanism which regulates the marking of the slips of paper and the supply of ink to the dotting apparatus.

The improved instruments are now working between London and Newcastle, Edinburgh, Manchester, and Glasgow; and they can send and print *messages from seventy to one hundred and twenty words per minute*, according to their exigences. They are also used in connection with the submarine cable extending from Newcastle to Denmark.

SIR CHARLES WHEATSTONE'S LAST AND MOST COMPLETE TELEGRAPHIC APPARATUS,

AND OTHER BEAUTIFUL APPLICATIONS OF ELECTRICITY—THE CHRONOSCOPE AND TELEGRAPH THERMOMETER FOR GREAT ALTITUDES.

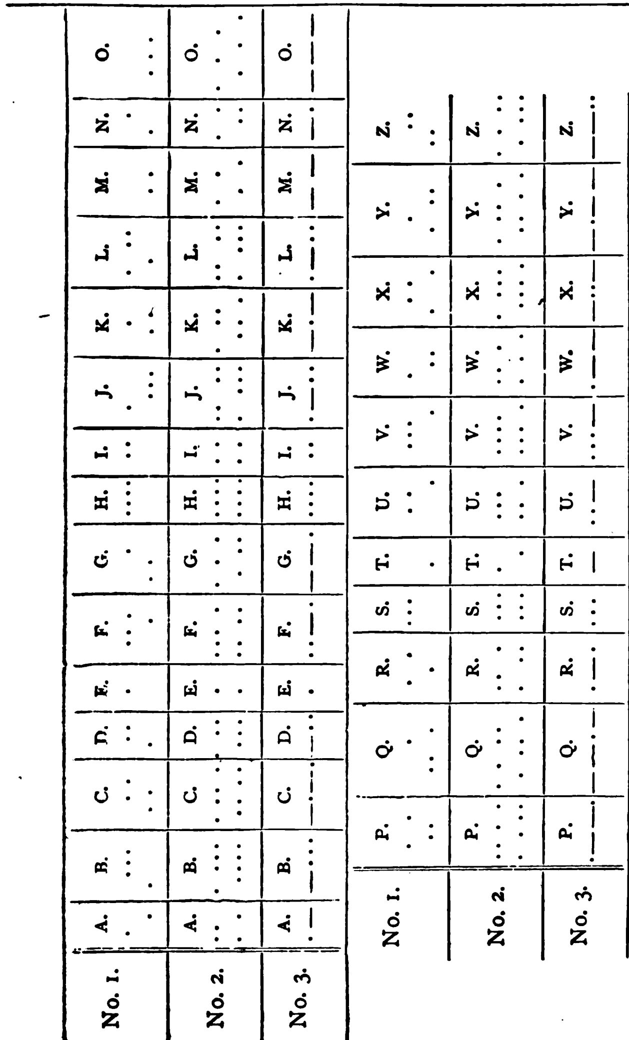


FIG. A.—*The various Telegraphic Alphabets.*

No. 1.—The Dot Printed Alphabet, and also the perforated slip for the same system, with the transmitting perforations omitted.
No. 2.—The Line or Morse Printing Perforated Slip, with the transmitting perforations omitted.
No. 3.—Line or Morse Printed Alphabet.

When Sir Charles Wheatstone turned his attention to fast-speed telegraphs, the result was the dot printing. He attained 700 letters per minute; but the telegraph companies objected to it, because it necessitated the clerks learning the new alphabet, the dots being in two lines (No. 1, Fig. A), the lower dot taking the place of the dash in the line or Morse alphabet. In addition to the above objections, it is not suited for submarine cables requiring reversals for rapid working; therefore, Sir Charles brought out a transmitter to work the inking Morse. But words could be transmitted quicker than the instrument would print; therefore, it remained for Sir Charles to bring out a rapid printer,

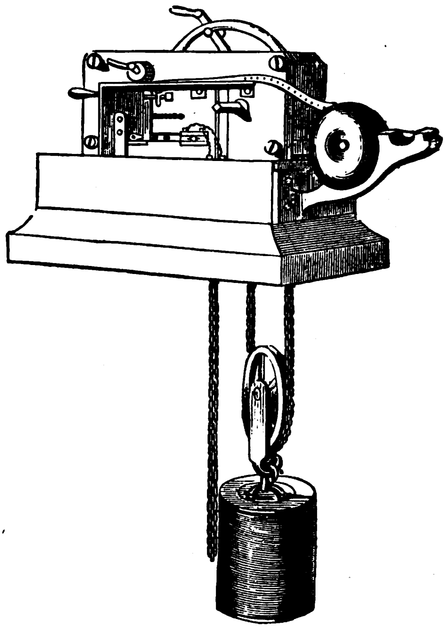


FIG. B.—*The Line-printing Transmitter.*

which he accomplished, and it is now known by the name of the "line-printer," printing the dot and dash alphabet (No. 3, Fig. A), such as is used by all telegraph companies, printing 600 letters per minute; the dot and line printing differing especially in this respect—the line currents always being inverted alternately; in the dot, three or four currents in the same direction sometimes follow each other.

THE LINE TRANSMITTER WITH MAINTAINING POWER (Fig. B), is a modification of the transmitter described as the sixth improvement for receiving the strip prepared by either of the perforators described as the fifth improvement, and transmitting voltaic currents along the telegraphic conductor to the receiving instrument at the distant station, in accordance with the arrangement of the perforations in the paper strip (motion being produced by a weight); the propulsion of the paper strip and the makings of the contacts with the batteries are accomplished by the same power; and, by means of levers, beam, eccentric, and springs, the upper ends of two vertically moving pins, being alternately pressed against the paper, are free to enter the perforations, if any present themselves; or, being prevented from entering the paper by the absence of apertures, they regulate the succession, frequency, and direction of the electric currents sent into the telegraphic circuit.

The action of the pins in conjunction with the paper strip is as follows: the

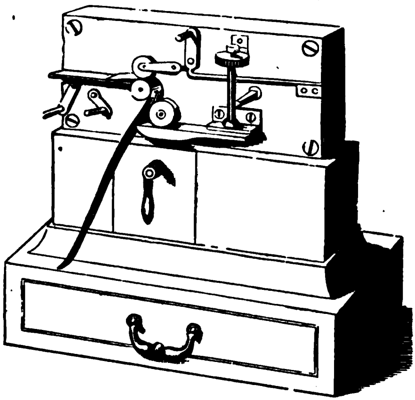


FIG. C.—*Line Printer or Receiver.*

only means of propulsion of the paper is by the pins of a star-wheel entering the middle perforations, and by its rotation moving the paper forward, the strip being held down by a broad-toothed wheel pressing it against the paper-ledge, the vertically moving pins entering the notches in the before-mentioned wheel, pass through an aperture in the paper, and are carried forward by it, thus not interfering with the duration of contact at the lower end of the pins; the reacting springs restore them to their normal position on their downward movement, effected by the levers to which they are attached receiving an up-and-down motion from an oscillating beam, connected with an eccentric driven by the maintaining power; and, on the arrival of an outer aperture on one side of the middle line of holes, the pin of that side will enter and transmit a current in one direction; and on the presentation of an aperture on the opposite side, the pin will also enter and transmit a current in an opposite direction, the apertures in the paper regulating the frequency, direction, and duration of the current sent into the telegraph line.

In the Line Printer or Receiver (Fig. C), the magnetic armatures are placed in a vertical position; the central axis is prolonged so as to carry the cross-piece, through an aperture in the extremity of which a horizontal rod passes; on this is mounted at one extremity the small, light tracing-disc, whilst the opposite end, which is loosely centred, so as to be capable of a slight lateral movement, carries a small toothed wheel; this wheel, gearing with the maintaining power of the instrument, imparts a rotatory motion to the tracer, at the same time that the axis is capable of receiving a to-and-fro motion in a horizontal plane from the movement of the armatures and arm.

In the same vertical plane, and immediately beneath the tracing-disc, is an inking-disc, caused to rotate, by appropriate gearing, with the maintaining power of the apparatus: this disc revolves in a reservoir containing ink or other suitable marking fluid. The periphery of the disc is slightly hollowed, and the edge of the tracing-disc just enters this hollow without contact or friction with the inking-disc; during the revolution of the disc, capillary attraction keeps the hollow full of ink, and a constant and uniform quantity will be supplied to the tracing-disc.

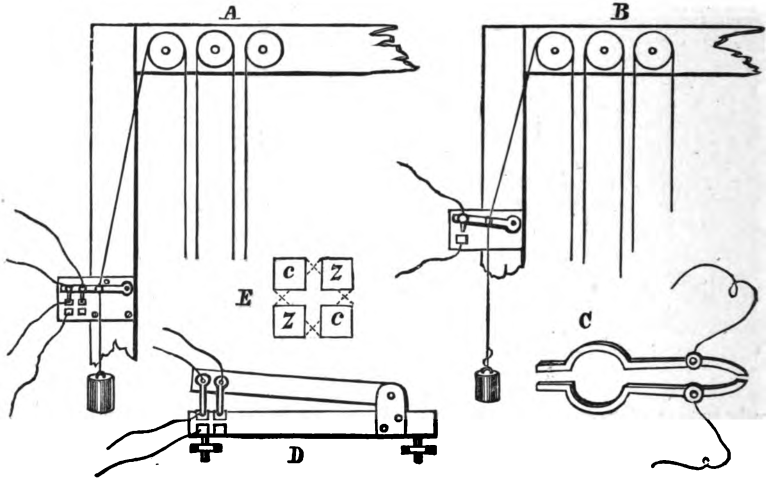


FIG. D.—*The various parts of Apparatus used with Wheatstone's Chronoscope.*

The paper intended to receive the marks is drawn forward at suitable speed over a roller in close proximity to one edge of the tracing-disc. It will be understood that a series of instantaneous alternate currents passing through the electro-magnet causes a to-and-fro motion of the tracing-disc, a current in one direction pressing the tracing-disc against the paper, where it will remain, by reason of the residual magnetism of the electro-magnets retaining the armatures in that position, until a current in the opposite direction withdraws the tracer from the paper. By this arrangement lines of more than two lengths can be printed with perfect accuracy in connection with the perforator with five keys described as the fifth improvement. Another remarkable instrument is

WHEATSTONE'S CHRONOSCOPE.—The various parts of this arrangement are shown at Fig. D, and employed to ascertain the velocity of projectiles. They will be readily understood when we describe the ball-holder and target used in the falling bodies experiments. A and B are enlarged parts of screens;

C is the ball-holder closed to receive the ball, each side being insulated. The electric circuit is not complete; but, at the moment of the release of the ball, the two sides will meet and complete the circuit, which, traversing in one direction, will start the chronoscope: this will continue running until the ball strikes the target, when it will reverse the current and stop it. The method of reversing is readily understood by E and D, Fig. D. Two springs are fixed to the target, which is hinged at one end, the other end falling when the ball strikes it. The springs slide over the reversing-piece, consisting of two poles of the battery, which are bridged over at the back, as indicated by the dotted lines, E.

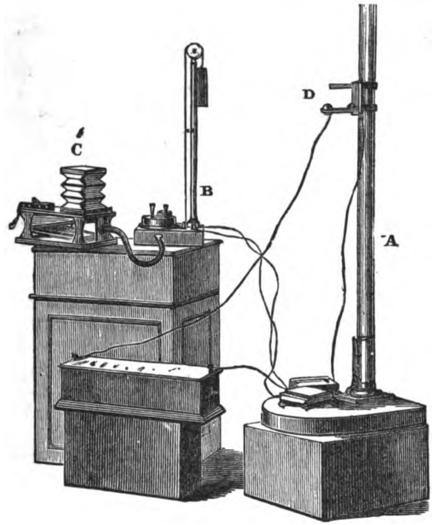


FIG. E.—*The Chronoscope in Elevation.*

Fig. E represents the chronoscope as arranged for indicating automatically the time occupied by falling bodies. A is a column, upon which the ball-holder slides, the target being placed at the base; B is the chronoscope, consisting of clockwork mechanism, with two dials, one divided into hundredths, and the other into thousandths, of a second, with hands like a watch, motion being communicated to it by a weight passing over a pulley, which is regulated by an escapement with a musical spring, tuned to a thousandth part of a second, caused to sound by the pressure of air from the bellows, C. The clockwork is in two distinct parts, the driving and the dial parts; they are made to gear by sensitive magnetic needles and an electro-magnet. One pole of the battery is connected with the ball-holder, the other with the target; two wires from the target connect it with the chronoscope, one wire connecting the ball-holder with the target. The poles of the battery are so arranged that on the release of the ball the electric circuit is completed, and the dials are brought into gear with the driving part; the current is reversed the instant the ball strikes the target, and

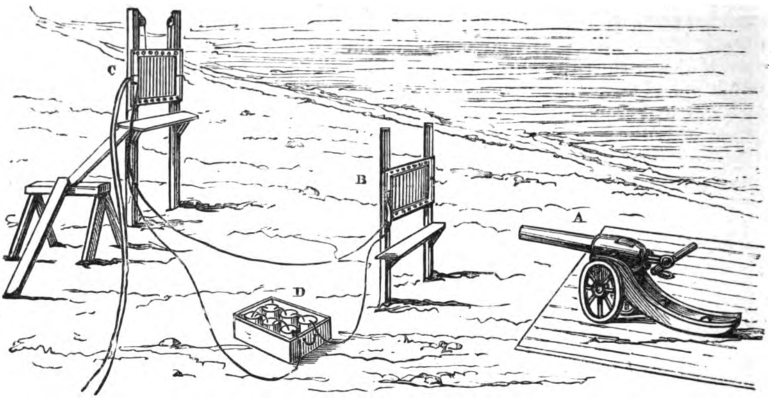


FIG. F.—*Wheatstone's Projectile Arrangement.*

The targets, B and C, connected with the battery, D, and Wheatstone's chronoscope, arranged to receive and indicate the velocity of the shot from the Armstrong gun, A.

the dials are disengaged, enabling the operator to read off the time by the hands, without the tedious calculation necessary by other means generally employed. The almost inexhaustible inventive faculty of Wheatstone, ever devising new or improving older inventions, is again displayed in his New Telegraph Thermometer (Fig. G).

This instrument was invented by Wheatstone to supply a scienific want, viz., the means of ascertaining, day or night, without making tedious ascents, the temperature of any lofty summit—such as that of Mont Blanc.

The cut (Fig. G) represents the general internal arrangement of the instruments requisite to ascertain the temperature at a distant point, two insulated wires connect them, the earth being used to form the third conductor.

The apparatus includes the thermometric arrangement, and also an electro-magnetic contrivance for converting the vibrations of magnetic needles between electro-magnets into a circular motion, for the purpose of altering the electric conduction from one circuit to another.

In order to indicate the temperature measured by the instrument above mentioned, there is an electro-magnetic arrangement, and also a permanent compound magnet with fixed coils, having an armature opposite to its poles, capable of being rotated by a handle, to produce a series of alternately inverted currents.

Fig. G, p. 71, represents the internal construction of both instruments; the dotted and other lines represent the wires necessary to conduct the electric currents. In the knob A, which is attached to the glass covering the dial, is contained a metallic thermometer, having a hand or pointer attached to its axis; and in the same line is an insulated axle, with arms, C and D, proceeding from it, a spiral spring tending to maintain the contact of the arm C with the hand B; under this axle is a toothed wheel, F, with a spring-catch, E, the said wheel gearing with the pinion G, connected by a spindle with the wheel H, mounted on an oscillating arm proceeding from the axle, carrying the magnetic needles placed between two coils (only one is shown in the drawing) analogous to the indicator of the alphabetical telegraph (Fig. A). O K is a similar arrangement; M N is a magnetic machine.

When an observation is about to be made, the dial of the indicator is adjusted to zero by means of the rim P, and the handle N rotated, producing a series of positive and negative currents, which may be imagined to take the course indicated by the arrows, coming from a coil, passing through wire 6 to

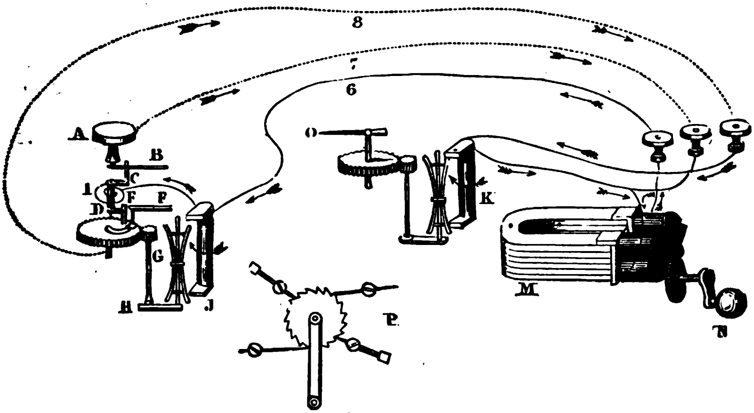


FIG. G.

the coils J, the short wire to the axle C D, to the hand B, and wire 7 to the coils of the magnets, thus completing the circuit, causing the needles between the coils J to oscillate by their alternate attraction and repulsion, communicating that motion by the arm H J to the wheel H, which, by its peculiar construction, will rotate, communicating that motion, by means of the pinion G, to the wheel F in the direction G E D; the pin E, pressing against the arm D, will draw away the arm C from the hand B; the piece D C will make a partial rotation on its axis, or describe an arc by the arms C D, the angle being the number of the degrees of temperature, thus breaking the circuit at C B, and completing it through D E; the wheel F, and wire 8, including the coils K, imparting motion to the hand or pointer O by the same means to those already described, which will continue until the catch F arrives at the pin L, corresponding to the zero in the scale of the instrument, when it will disengage the pin E from arm D, the spiral spring forcing arm C in contact with the hand B, thus restoring the circuits to their former condition.

When the circuit is complete through the wires 6 and 7, only the coils J come into action; but when the connections are made through wires 6 and 8, both coils are caused to act, moving the arm C in the thermometer from the highest point indicated on the dial to the zero, and in the indicator from the adjusted zero to the highest point, when the motion of the pointer will cease, indicating the state of the dial B A.

In a paper read by Sir Charles Wheatstone before the Academy of Sciences at Paris he thus sums up the advantages of his automatic printing telegraphic system:

"I will conclude by offering a few remarks on the advantages possessed by this system.

"Whatever practical dexterity may be acquired by a voluntary operator, the result arrived at will be far inferior to that obtained by the automatic process, which is only limited by the rapidity with which the recurring motions of the transmitter can be effected. By the present construction of the instrument, five times the quantity of signs at present used can be transmitted to moderate distances; though for very considerable distances this rapidity may be limited in conductors subjected to inductive influences by the tendency which rapidly recurring short currents have to coalesce.

"But even if there were no advantage in point of rapidity possessed by the automatic over the voluntary process of transmission, its other advantages would be incontestable. For the profitable working of a telegraphic line, it is necessary that the operator should manipulate as rapidly as is consistent with a correct transmission of the message: it requires great skill to become a proficient in such manipulations, even when the language in which the despatch is sent is quite familiar to the operator; but if he would send a despatch in a language unknown to him, or in cipher, he is obliged to proceed with caution and slowness. In my new system the prepared messages are transmitted with equal rapidity in whatever language or cipher they may be; and as the perforated bands may be prepared at leisure, and be subjected even to the revision of a corrector, guarantees of accuracy are obtained which cannot be afforded by the system of immediate voluntary transmission. Several clerks will be required to prepare messages for a single telegraphic line in constant activity; but, in an economical point of view, their time is of far less importance than the time occupied by the transmission of a message.

"Another advantage this new system possesses is that the same prepared message may be transmitted through any number of distinct lines, if not simultaneously, at least in such rapid succession as to be equivalent thereto; and besides, without any fresh labour, the same message may be retransmitted, if thought necessary; and service messages in constant use may be preserved for transmission whenever they may be required.

"Were this automatic system generally adopted, it might in many instances be more convenient to prepare the messages at the offices from which they are sent, the instrument for effecting this purpose being very portable and of small cost. The operations at the telegraph office would in these cases be limited to passing the perforated band through the transmitter at one station and receiving the printed message at the other, the translation as well as the preparation of the message devolving on the department of the administration to which it relates.

"In the present case it is not the question to substitute one kind of acquired skill for another kind equally difficult to attain, which would entail great labour on all the employés. The great practical dexterity at present required being dispensed with, and the principal and most laborious operation being entirely automatic, there is little to learn, though there may be something to forget."

THE ATLANTIC TELEGRAPH CABLE.

The resistance of a conductor of any given metal is *directly proportional to its length*, and *inversely proportional to its thickness* or cross section.

It was soon found to be necessary, in experiments with thousands of miles of cable or insulated wires, to adopt some standard or starting-point, in order to ascertain exactly the resistance of the whole.

The matter was put into the hands of a committee of the British Association, who determined that an English mile of pure copper wire, No. 16, should be the B. A. unit; they further constructed a wire of silver and platinum, because it was little affected by temperature, which they deposited as the standard of comparison, and this length of wire they estimated in figures to be 13·59 of the length of the copper wire. Bobbins upon which hundreds and thousands of miles of copper wire No. 16 would have to be wound would be too bulky and cumbersome to manage; it has, therefore, been arranged that German silver, an alloy of about 60 parts of copper with a fraction of lead, 25 zinc, and 15 nickel, should be employed, because it has about thirteen times less conducting power than the same-sized copper wire; consequently the standard unit would be represented as follows:

B. A. unit of German silver wire = 13·59 of an English mile.

The bobbins, having 13·59 of an English mile of German silver wire wound upon them, represent, therefore, a resistance equal to one mile.

The length of the great Atlantic cable, stretching between Valentia in Ireland and Newfoundland in America, a distance of 3,500 miles, is 1,858 knots, and each knot, equal to $7\frac{1}{2}$ nautical miles, has an electrical resistance, at a temperature of 75° Fahrenheit, equal to 4·272 of the above-named B. A. units. Consequently 1,858 knots, multiplied by 4·272, would give the resistance of the whole cable as 7,937 B. A. units; or, allowing for diminished resistance caused by the low temperature of the bed of the Atlantic, and deducting a certain number of units for that, we have, say, 7,500 B. A. units.

The resistance of the cable of 1865, according to Mr. Latimer Clark, is 7,604 B. A. units. The resistance of the last new cable, 1866, is 7,209 B. A. units. It is so much better, and the instruments are so vastly improved, that they can send from eighteen to twenty words per minute, instead of, as formerly, only two and a half. The new cable has three times more speaking power now it is immersed in the Atlantic than it had on board the Great Eastern.

At the commencement of the article on Electricity, great stress was laid upon the explanation of the phenomena of induction. The conducting wires of the Atlantic cable, formed of a strand of seven wires, each 0·048 inch in diameter, and together equal to a wire of 0·144 inch diameter, are surrounded with, and insulated by, gutta-percha.

Such being the case, it is easy to understand that, when conveying an electrical current, it must become charged like a Leyden jar. The wire is the inner metallic coating, the gutta-percha is equivalent to the glass, and the salt water outside the other metallic coating. This enormous Leyden jar measures in its inner coating about 425,000 square feet, and it was the charge maintained by the cable that seemed at first to negative and destroy all hope of sending messages quickly. This very property is now found to be most valuable, and

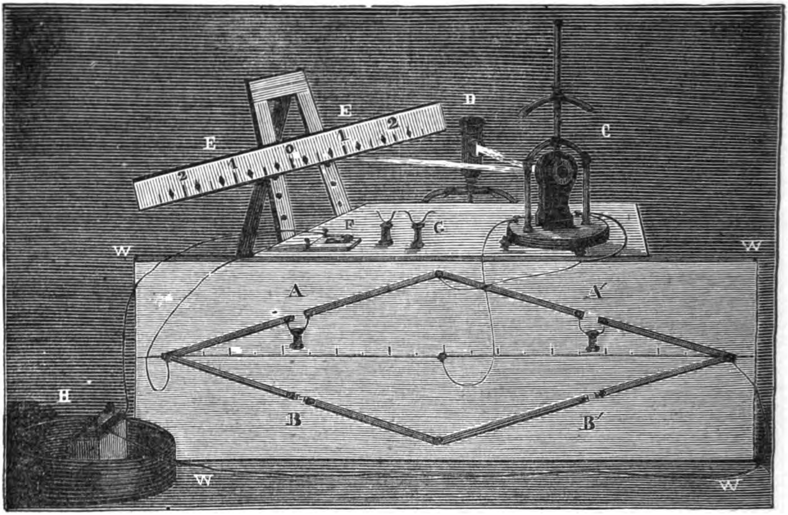


FIG. 77.—*Thompson's Reflecting Galvanometer Needle.*

C, The galvanometer; D, the oxy-hydrogen light; E E, the scale; W W W W, the Wheatstone bridge F, the key; G, extra-resistance coils; and H, the battery.

is made use of to expedite the sending of the signals, and in brief terms may be thus described:

The cable is first charged until, like a Leyden jar, it will bear no more. In order to send a message, it is discharged; and it is the latter operation, acting upon instruments of wondrous delicacy, that enables the operator to send the message.

Sir William Thompson's reflecting galvanometer needle is a notable illustration of the perfection to which a galvanometer may be brought; and his original instrument has been surpassed and brought up to a still higher pitch of refinement by Mr. Becker, the learned and obliging head of the instrument department at Messrs. Elliott's. The writer understood him to say that he was making one to show *a resistance of one in a million units.*

Mr. Becker arranged a most excellent series of instruments for demonstrating at the Polytechnic. The Thompson's reflecting galvanometer needle with Wheatstone's bridge are shown above (Fig. 77), as exhibited at the above-named institution by the writer.

The reflecting galvanometer needle must first engage our attention. It consists of two large flat bobbins, B B (Fig. 78), upon which are wound many hundred yards of insulated fine copper wire, and, in the instrument made for the writer, they were placed on hinges, so that they could be placed down, like the lid of a box, to disclose the delicate needle—a small magnet, A, made of watch-spring about an inch long, and weighing only a few grains, and hung by a very narrow piece of tape; because a filament of silk, if made the suspender, would have caused the instrument to be too delicate for lecture-room purposes.

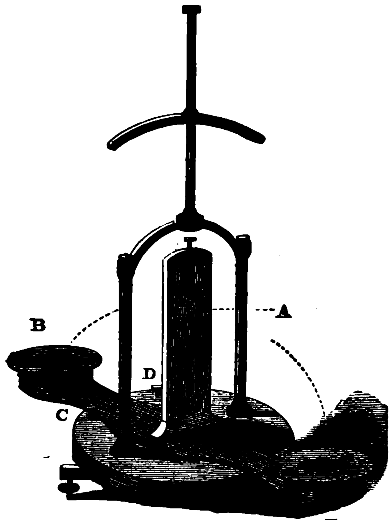


FIG. 78.—*Thompson's Reflecting Galvanometer Needle, with the Bobbins opened to show the suspended Needle.*

Fastened to the little magnet is a circular mirror, ground slightly concave, and weighing only a few grains; upon this is thrown from an aperture in a copper lantern a few rays from the oxy-hydrogen light. These are reflected upon a scale of 5 ft. 6 in. in length, so that the spot of light when it traversed the scale could be seen by an audience of one thousand people.

The movements of the spot of light are, of course, those of the magnet, and in order that the latter should be acted upon only by the currents sent through the instrument, and not by terrestrial magnetism, a curved steel magnet, working up or down or right and left, or a brass rod, is placed above it, and is most convenient for keeping the axis of the little mirror A, with its attached magnet, exactly between and parallel with the two bobbins B B, or, in other words, reflecting the spot of light to zero. C and D represent the connecting screws.

But, perfect as this galvanometer is, it would not have enabled the writer to teach others much about resistances and other interesting points connected with the Atlantic Telegraph cable, unless he had used an instrument for which sufficient credit has not been given to its distinguished inventor, Wheatstone, viz.,

THE DIFFERENTIAL RESISTANCE MEASURER.

This instrument (better known by the name of Wheatstone's Bridge) was also constructed by Mr. Becker on the largest scale (Fig. 77). The board is 8 ft. long and 2 ft. 8 in. wide; the lozenge-shaped brass plates are $1\frac{1}{2}$ in. wide. There are four breaks with binding-screws, and, by using bobbins upon which the B. A. unit of German silver wire was wound, the audience was made to understand that each bobbin represented a mile of pure copper wire, No. 16.

In the lecture-room, the resistance of two miles, as compared with one mile, of wire was clearly demonstrated. The resistance of two equal pieces of wire was shown to be altered by heat, obtained by merely touching one with the hand or putting it into the mouth.

Three tubs of water, containing three lengths of wire, measuring one hundred yards, were supposed to represent the Atlantic Telegraph Cable, and were balanced against a resistance coil. Directly the miniature cable was broken, the spot of light became violently agitated when the key was pressed down; and it was shown that, time permitting, the lecturer could discover not only that the wire *was* broken, but *where* it was broken—just as they can now discover any place thousands of miles from England, and deep down in the bed of the Atlantic Ocean, where an accident may have happened to the cable; they can determine the precise spot, and, by sending a proper vessel with tackle, can pick up and reunite and repair the broken part, as they did in the recovery and resplicing of the old Atlantic Telegraph Cable.

The Differential Resistance Measurer is fully described by Wheatstone in the "Transactions of the Royal Society," 1843, Part II., p. 323.

For the sake of the young student, and considering also that the construction and principle of Wheatstone's bridge frequently form the subject of an examination question, the writer gives the following diagrams and explanations, which he trusts will be found useful.

For the sake of simplicity, the brass bands and breaks only are shown.

The galvanometer is supposed to be resting in the middle of the board, the battery on the right, and the connecting key on the left.

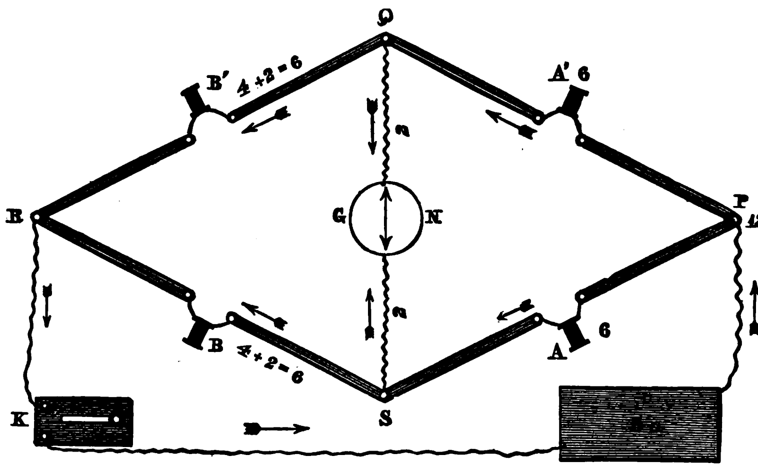


FIG. 79.—DIAGRAM I.

For the sake of discussion, it is supposed that the current coming from the battery, B *a*, is represented by twelve parts: these, on arriving at P, split or divide into equal parts; six go in the direction A′, and six in the other. A.

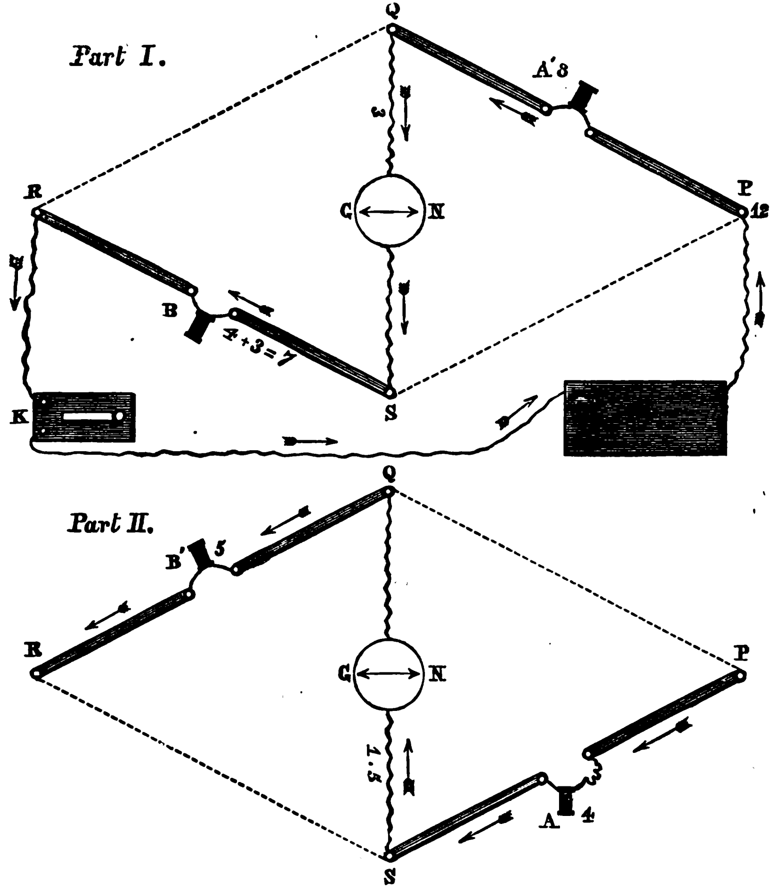


FIG. 80.—DIAGRAM II.

The two currents, represented by arrows, both pass through equal resistance coils, A′ A, and the respective currents might pass direct to the key K (where contact is made or broken), and through that to the other pole of the battery; but the currents are partially arrested by the equal resistance coils, B′ B, and a portion of the currents is forced into or diverted into the galvanometer, G N.

The use of the coils, or any other resisting matter, on the other side of the galvanometer is to force, or rather gently to impel, a part of the current into the galvanometer; because, if this was not done, the deflection would be so small it might be barely perceptible.

Let us say, for the sake of discussion, that two parts pass to the galvanometer from Q, and two parts from S; such currents, coming in opposite directions, must oppose each other's progress through the galvanometer, and therefore the needle of the latter does not move.

We have only now to suppose that 4+2=6 proceed from Q′ to R, and 4+2=6 by S to R; the two added together make 12, the original quantity started with, which proceeds through the key and connecting wire to the other pole of the battery, B *a*.

The second diagram (Fig. 80) consists of two parts, viz., Part I. and Part II., and it is recommended that the latter be traced on tracing-paper by the student, who can place it upon Part I. The current again is represented by twelve parts. The resistance of the coil at A′, Part I., being less than A, Part II., the greater part of the current, say 8 A′ parts, go through the former, and 4 A through the latter, consisting of a piece of copper wire and a resistance coil; therefore, returning to Part I., the current going by A′, through Q′, to G N, the galvanometer needle, forms at the point Q′ a greater partial current (say three parts) than the current going by A, Part II., which divides at S, and is represented by, say, one and a half parts; therefore, the current that deflects the galvanometer is the greater current going by Q′, Part I., and marked 3; consequently it amounts in imagination to a struggle between the current going by Q′, Part I., represented by three parts, and the current going by S, Part II., or one and a half parts. The issue cannot be doubtful; the greater current, three, overcomes the lesser, one and a half. In Part I., 4+3=7 go by B; and in Part II., five go by B′; and, if the two are added together, they again make the twelve parts, which, as before, travel through the key and connecting wire to the other pole of the battery, B *a*.

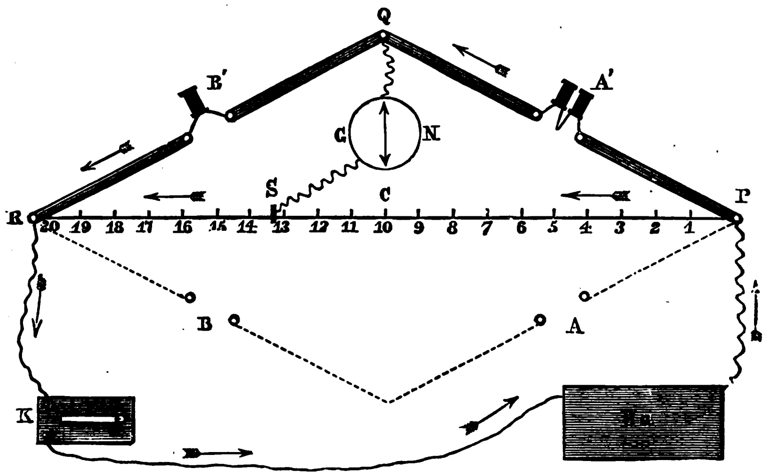


FIG. 81.—DIAGRAM III.

This diagram (Fig. 81) explains the use of the "bridge" for comparing the conductivity or resistance of wires of different metals or different lengths of the same wire. The lower part, A B, of the bridge, marked in dotted lines, is not required, its place being filled by a long German silver wire stretched from P to R, and provided with a scale divided, say, into twenty parts; on this wire slides a clip or binding-screw, S, and this is connected with one of the galvanometer-screws, the other screw of the galvanometer being connected with Q.

In this case, we are to suppose it is being used to ascertain the relative lengths of wire of the same metal, diameter, and conductivity. The clip, S, has been moved from the centre, C, to No. 13·334 on the scale painted below the wire, P R. The clip has been moved to 13·334, or until the galvanometer is at rest; this quantity, 13·334, is double that of R S, therefore the resistance at B′ is shown to be half the resistance at A′, because A′ has two coils, or two miles of wire, and B′ one mile; so that it is shown, without any previous knowledge of the absolute length of the two coils at A′ (the wire under examination), that it is double the length of the known quantity, one mile at B′, because the scale from R to S is 6·666, and that from P to S 13·334, and, if one is added to the other, thev make up the whole scale of 20.

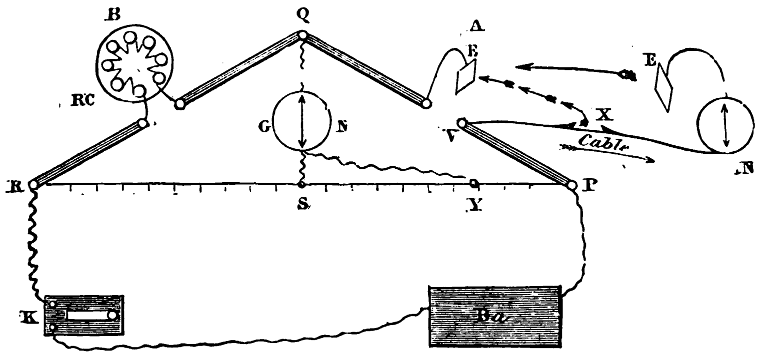


FIG. 82.—DIAGRAM IV.

The object of the diagram (Fig. 82) is to explain the use of the arrangement (Fig. 81, Diagram III.), for the purpose of discovering the exact point under the Atlantic Ocean where the cable is supposed to be broken. As before, the lower part of the bridge is not used: the wire, P R, and scale are employed in this experiment.

The current, starting from the battery B *a*, arrives at P, where it splits into two currents: one passes along the wire, P R, and the other is supposed to go through the cable marked "Cable," at A′. The galvanometer needle is brought to rest by the balancing of the resistance of the cable by various resistance coils, R C, at B′: this supposes the cable to be perfect when the clip, S, is in the centre.

Let us now imagine that the cable is broken at X. The spot of light from Thompson's galvanometer needle (see Fig. 77, p. 74) is now violently agitated or deflected when the contact is made with the battery, because the current, instead of travelling through the whole length of the cable, takes a short cut, as shown by the short arrows; its path or resistance is decreased enormously, and it no longer balances with the resistance coils, R C, at B′. To make it balance, the clip, S, is moved to Y; then by measuring the distance from R to Y, and the distance from P to Y, on the graduated scale, it is easy by a calculation to discover the distance from the shore where the rupture has taken place. V is supposed to be Valentia, and N, Newfoundland; E and E are the wires which go out into the sea, and are usually designated as "earth-plates" in all diagrams, to prevent confusion.

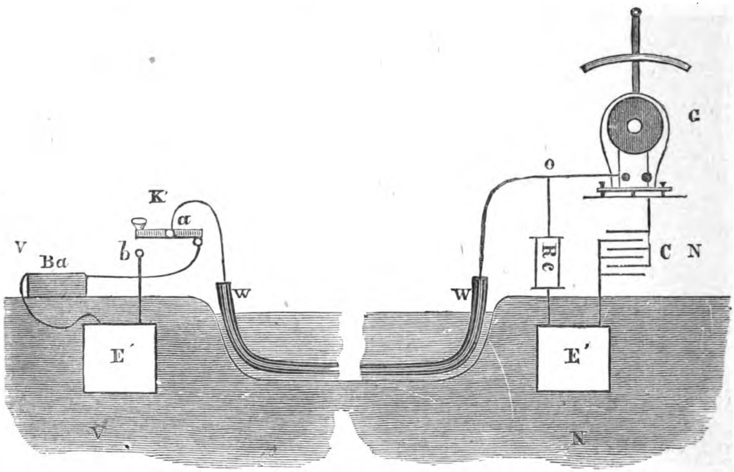


FIG. 83.—DIAGRAM V.

The last diagram (Fig. 83) is intended to give the student a general notion of the apparatus required to send the electric current, *i.e.*, "messages," through the great Atlantic Telegraph cable.

We commence at V, Valentia. B *a* is the battery connected with the earth-plate, E′; K is the key connected with the other pole of the battery at *a;* E′ is the earth-plate (not really so, as it is a wire running into the sea); W W represents the cable under the water, passing across to N, Newfoundland, where the electric force enters the condenser, C (an arrangement of mica plates and tin-foil, fulfilling the same office as a Leyden battery), through the galvanometer, G; R *c* is a large resistance coil connected with the earth-plate and also with the cable at the point O: one side of the condenser is also connected with the earth-plate.

The course of the electric force is certainly tortuous, but, once studied and understood, is one of the most simple and beautiful processes of reasoning that the lover of science can desire.

As the cable is now represented in the diagram, a current can pass from the battery, B *a*, through K, at the point *a*, to the cable, and through it to the point O, where the greater part will pass through G, the galvanometer, into the condenser, C; the other part of the current passing from O, through the resistance coil, R *c*, to the earth-plate E′, and from E′ back to the battery B *a*, through the other earth-plate, E′.

The current, in passing through the galvanometer, deflects it until it has fully charged the condenser, when it returns to zero.

The signals are sent by pressing down the key, K, and so putting the cable to earth as the key is pressed down upon *b*, which is connected with the earth-plate E′. The consequence is that the electrical tension of the cable falls below that of the condenser; a current then flows from the condenser, C, through the galvanometer, G (deflecting it, the deflection being the signal), to the cable, in order to establish the equilibrium of the latter.

At a banquet given, at the Polytechnic, by the chairman and directors of the Royal Polytechnic to Sir Charles Wheatstone and the scientific men of London, at which many noblemen and gentlemen assisted, the writer was enabled, by the kindness of the various telegraphic companies, to bring the wires into the Polytechnic; and, whilst the company were seated, the following message was sent to the President of the United States, and his answer received, as reprinted in "The Evening Post," New York, Wednesday, January 1, 1868:

"CABLE NEWS.—*Advices from Europe to December* 30, 1867.—The following advices by the Atlantic Telegraph have been received:

"INTERNATIONAL COURTESIES.

"*London, December* 24.—At a banquet given at the Royal Polytechnic on Saturday night last, in reply to the following sentiment from the Duke of Wellington and Sir Charles Wheatstone, a despatch from the President of the United States was read amid great enthusiasm. Not a little of the interest attaching to these despatches grows out of their rapid transmission:

"MESSAGE OF THE DUKE OF WELLINGTON TO THE PRESIDENT OF THE UNITED STATES.

"'*Royal Polytechnic, London, December* 21.—The Duke of Wellington, the directors and scientific guests now at the Royal Polytechnic, London, England, send their most respectful greeting to the President of the United States, their apology being that to the discoveries of science the intercourse between two great nations is indebted.'

"[The above message was 9 minutes 30 seconds in transit from London to Washington, as follows: London to Heart's Content, 4 minutes 30 seconds; Heart's Content to Plaister Cove, 1 minute 30 seconds; at Plaister Cove, 30 seconds; Plaister Cove to New York, 1 minute 30 seconds; New York to Washington, 1 minute 30 seconds.]

"REPLY.

"'*Washington, December* 21.

"'*Duke of Wellington, London:* I reciprocate the friendly salutation of the banqueting party at the Royal Polytechnic, and cordially agree with them in the sentiment that free and quick communication between governments and nations is an important agent in preserving peace and good understanding throughout the world, and advancing all the interests of civilization.

"'ANDREW JOHNSON.'

"The reply occupied 29 minutes in actual transmission. On the same evening, a message of twenty-two words was started from the Polytechnic for Heart's Content at exactly 9 p.m., and at 9.10 the reply of twenty-four words was delivered."

The completion of the articles on LIGHT, HEAT, ELECTRICITY, and MAGNETISM, &c., cannot be better consummated than by a report, which appeared in the "Literary Gazette," of Faraday's lecture at the Royal Institution,

ON THE CONSERVATION OF FORCE.

"When we occupy ourselves with the dual forms of power, electricity and magnetism, we find great latitude of assumption: and necessarily so, for the powers become more and more complicated in their conditions. But still there is no apparent desire to let loose the force of the principle of conservation, even in those cases where the appearance and disappearance of force may seem most evident and striking. Electricity appears when there is consumption of no other force than that required for friction; we do not know how, but we search to know, not being willing to admit that the electric force can arise out of nothing. The two electricities are developed in equal proportions; and, having appeared, we may dispose variously of the influence of one upon successive portions of the other, causing many changes in relation, yet never able to make the sum of the force of one kind in the least degree exceed, or come short of, the sum of the other. In that necessity of equality we see another direct proof of the conservation of force in the midst of a thousand changes that require to be developed in their principles before we can consider this part of science as even moderately known to us. One assumption with regard to electricity is, that there is an electric fluid rendered evident by excitement in plus and minus proportions. Another assumption is, that there are two fluids of electricity, each particle of each repelling all particles like itself, and attracting all particles of the other kind always, and with a force proportionate to the inverse square of the distance, being so far analogous to the definition of gravity. This hypothesis is antagonistic to the law of the conservation of force, and open to all the objections that have been, or may be, made against the ordinary definition of gravity. Another assumption is, that each particle of the two electricities has a given amount of power, and can only attract contrary particles with the sum of that amount, acting upon each of two with only half the power it could, in like circumstances, exert upon one. But various as are the assumptions, the conservation of force, though wanting in the second, is, I think, intended to be included in all. I might repeat the same observations nearly in regard to magnetism,—whether it be assumed as a fluid or two fluids or electric currents—whether the external action be supposed to be action at a distance or dependent on an external condition and lines of force—still all are intended to admit the conservation of power as a principle to which the phenomena are subject. The principles of physical knowledge are now so far developed as to enable us not merely to define or describe the *known*, but to state reasonable expectations regarding the *unknown;* and I think the principle of the conservation of force may greatly aid experimental philosophers in that duty to science which consists in the enunciation of problems to be solved. It will lead us, in any case where the force remaining unchanged in form is altered in direction only, to look for the new disposition of the force, as in the cases of magnetism, static electricity, and perhaps gravity, and to ascertain that as a whole it remains unchanged in amount; or, if the original force disappear, either altogether or in part, it will lead us to look for the new condition or form of force which should result, and to develop its equivalency to the force that has disappeared. Likewise, when force is developed, it will cause us to consider the previously existing equivalent to the force so appearing; and many such cases there are in chemical action. When force disappears, as in the electric or magnetic induction after more or less discharge, or that of gravity with an increasing distance, it will suggest a research as to whether the equivalent change is one within the apparently acting bodies or one *external* (in part) to them. It will also raise up inquiry as to the nature of the internal or external state, both before the change and after. If supposed to be external, it will suggest the necessity of a physical process, by which the power is communicated from body to body; and in the case of external action, will lead to the inquiry whether, in any case, there can be truly action at a distance, or whether the ether, or some other medium, is not necessarily present. We are not permitted as yet to see the nature of the source of physical power, but we are allowed to see much of the consistency existing amongst the various forms in which it is presented to us. Thus if, in static electricity, we consider an act of induction, we can perceive the consistency of all other like acts of induction with it. If we then take an electric current, and compare it with this inductive effect, we see their relation and consistency. In the same manner we have arrived at a knowledge of the consistency of magnetism with electricity, and also of chemical action and of heat with all the former; and if we see not the consistency between gravitation with any of these forms of force, I am strongly of the mind that it is because of our ignorance only. How imperfect would our idea of an electric current now be if we were to leave out of sight its origin, its static and dynamic induction, its magnetic influence, its chemical and heating effects? or our idea of any one of these results, if we left any of the others unregarded? That there should be a power of gravitation existing by itself, having *no relation to the other natural powers, and no respect to the law of the conservation of force*, is as little likely as that there should be a principle of levity as well as of gravity. Gravity may be only the residual part of the other forces of nature, as Mossotti has tried to show; but that it should fall out from the law of all other force, and should be outside the reach either of further experiment or philosophical conclusions, is not probable. So we must strive to learn more of this outstanding power, and endeavour to avoid any definition of it which is incompatible with the principles of force generally, for all the phenomena of nature lead us to believe that the great and governing law is one. I would much rather incline to believe that bodies affecting each other by gravitation act by lines of force of definite amount (somewhat in the manner of magnetic or electric induction, though without polarity), or by an ether pervading all parts of space, than admit that the conservation of force can be dispensed with. It may be supposed that one who has little or no mathematical knowledge should hardly assume a right to judge of the generality and force of a principle such as that which forms the subject of these remarks. My apology is this: I do not perceive that a mathematical mind, simply as such, has any advantage over an equally acute mind not mathematical in perceiving the nature and power of a natural principle of action. It cannot of itself introduce the knowledge of any new principle. Dealing with any and every amount of static electricity, the mathematical mind can and has balanced and adjusted them with wonderful advantage, and has foretold results which the experimentalist can do no more than verify. But it could not discover dynamic electricity, nor electro-magnetism, nor magneto-electricity, nor even suggest them; though, when once discovered by the experimentalist, it can take them up with extreme facility. So in respect of the force of gravitation, it has calculated the results of the power in such a wonderful manner as to trace the known planets through their courses and perturbations, and in so doing has *discovered* a planet before unknown; but there may be results of the gravitating force of other kinds than attraction inversely as the square of the distance, of which it knows nothing, can discover nothing, and can neither assert nor deny their possibility or occurrence. Under these circumstances, a principle, which may be accepted as equally strict with mathematical knowledge, comprehensible without it, applicable by all in their philosophical logic, whatever form that may take, and, above all, suggestive, encouraging, and instructive to the mind of the experimentalist, should be the more earnestly employed and the more frequently resorted to when we are labouring either to discover new regions of science, or to map out and develop those which are known into one harmonious whole; and if in such strivings we, whilst applying the principle of conservation, see but imperfectly, still we should endeavour to see, for even an obscure and distorted vision is better than none. Let us, if we can, discover a new thing in *any shape;* the true appearance and character will be easily developed afterwards. Some are much surprised that I should, as they think, venture to oppose the conclusions of Newton: but here there is a mistake. I do not oppose Newton on any point; it is rather those who sustain the idea of action at a distance that contradict him. Doubtful as I ought to be of myself, I am certainly very glad to feel that my convictions are in accordance with his conclusions. At the same time, those who occupy themselves with such matters ought not to depend altogether upon authority, but should find reason within themselves, after careful thought and consideration, to use, and abide by, their own judgment. Newton himself, whilst referring to those who were judging his views, speaks of such as are competent to form an opinion in such matters, and makes a strong distinction between them and those who were incompetent for the case. But, after all, the principle of the conservation of force may by some be denied. Well, then, if it be unfounded even in its application to the smallest part of the science of force, the proof must be within our reach, for all physical science is so. In that case, discoveries as large or larger than any yet made may be anticipated. I do not resist the search for them, for no one can do harm, but only good, who works with an earnest and truthful spirit in such a direction. But let us not admit the destruction or creation of force without clear and constant proof. Just as the chemist owes all the perfection of his science to his dependence on the certainty of gravitation applied by the balance, so may the physical philosopher expect to find the greatest security and the utmost aid in the principle of the conservation of force. All that we have that is good and safe, as the steam-engine, the electric telegraph, &c., witness to that principle,—it would require a perpetual motion, a fire without heat, heat without a source, action without reaction, cause without effect, or effect without a cause, to displace it from its rank as a law of nature."

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