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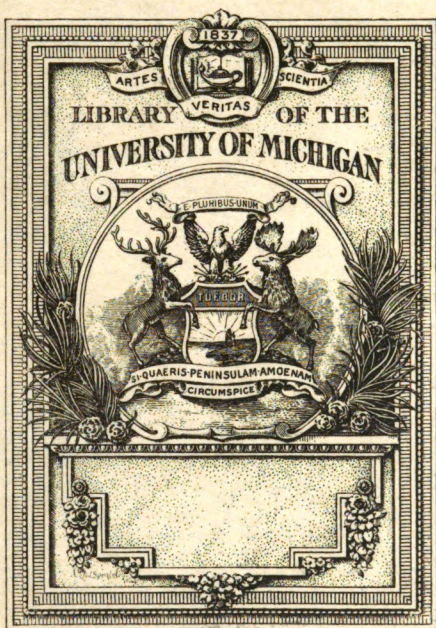
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*Manual of Electricity: Magnetism
and the electric telegraph*

Henry Minchin Noad



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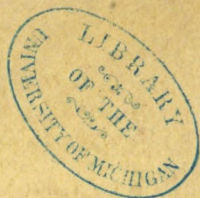
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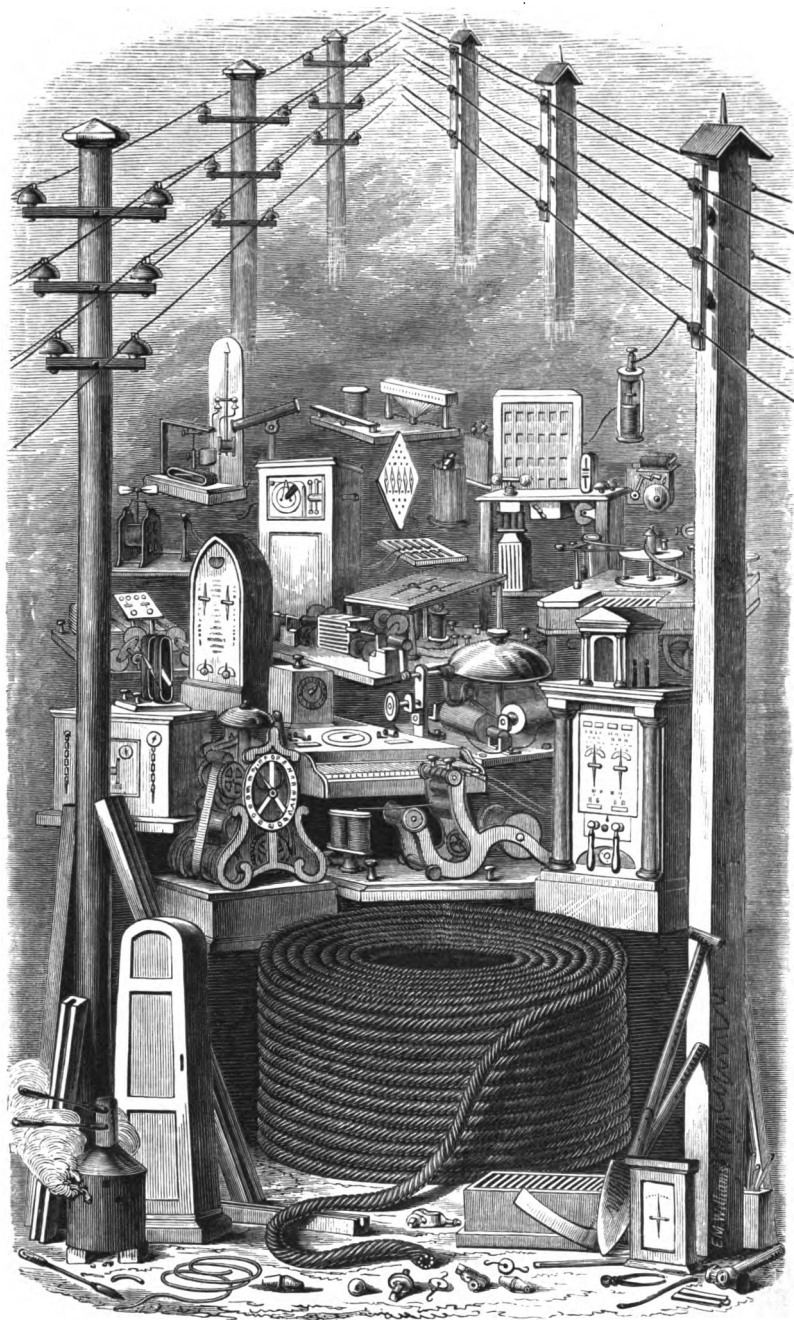
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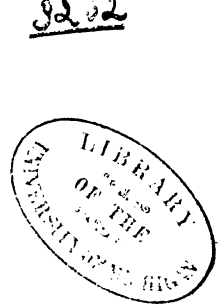
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THE ELECTRIC TELEGRAPH, PAST AND PRESENT.



A
MANUAL
OF
ELECTRICITY:

INCLUDING

GALVANISM, MAGNETISM, DIAMAGNETISM,
ELECTRO-DYNAMICS, MAGNETO-ELECTRICITY,
AND THE ELECTRIC TELEGRAPH.

BY
revised
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AUTHOR OF "CHEMICAL MANIPULATION AND ANALYSIS," ETC.

• Fourth Edition, Entirely Re-written.

PART II.
MAGNETISM AND THE ELECTRIC TELEGRAPH

•
LONDON:
GEORGE KNIGHT AND CO., FOSTER LANE.
1857.

The Proprietors reserve to themselves the right of Translation.

LONDON :
HADDON, BROTHERS, AND CO., PRINTERS,
CASTLE STREET, FINSBURY.

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PART II.

MAGNETISM.

CHAPTER XIII.

Historical sketch—Researches of Gilbert, Halley, Graham, Epinus, Coulomb, Humboldt, Hansteen, Barlow, Morichini, Somerville, Dalton, Cavallo, Brewster, Babbage, Herschel, Harris, Faraday.

(750) ALTHOUGH the *attractive* power of the loadstone—(a ferruginous mineral first discovered in the province of Magnesia in Lydia)—appears to have been known among the nations of the west in times of very remote antiquity, and its properties studied even during the Dark Ages, yet its *directive* power, and that of a needle touched or rubbed with it, was known exclusively to the Chinese. More than a thousand years before our era,* at the obscurely known epoch of Codrus, and the return of the Heraclides to the Peloponnesus, these people employed magnetic cars, on which the figure of a man, whose moveable outstretched arm pointed always to the south, guided them on their way across the vast grassy plains of Tartary; and in the third century of our era, at least seven hundred years before the introduction of the compass in the European seas, Chinese vessels navigated the Indian ocean with needles pointing to the south.

(751) A Neapolitan named Flavio Gioia, who lived in the thirteenth century, has been regarded by many as the inventor of the compass. Dr. Gilbert affirms that Paulus Venetus brought the compass from China to Italy in 1260; and Ludi Vestomannus asserts, that about 1500, he saw a pilot in the East Indies, direct his course by a magnetic needle like those now in use. The *variation* of the needle was discovered two hundred years before the time of Columbus; but the *variation of the variation*, that is, the fact that the variation was not a constant quantity, but varied in different latitudes, was first noticed by the discoverer of America, as appears from the following extract from Irving's "Life and Voyages of Columbus," (vol. i, p. 201): "On

* Humboldt's "Cosmos."

the 13th of September, 1492, he perceived about night-fall that the needle, instead of pointing to the north-star, varied about $\frac{1}{2}$ a point, or between 5 and 6°, to the north-west, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm; but it soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the laws of nature were changing as they advanced, and that they were entering into another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues; and without this guide, what was to become of them in a vast and trackless ocean? Columbus tasked his science and ingenuity for reasons with which to allay their terrors. He told them that the direction of the needle was not to the polar star, but to some fixed and invisible point. The variation was not caused by any failing in the compass, but by the movement of the North star itself, which, like the other heavenly bodies, had its changes and revolutions, and every day described a circle round the pole. The high opinion that the pilots entertained of Columbus, as a profound astronomer, gave weight to his theory, and their alarm subsided."

(752) That ferruginous substances always possess a greater or less degree of Magnetism, has long been known. One Julius Cæsar, a surgeon of Rimini, is said to have first observed the conversion of iron into a magnet. In 1590, he noticed this effect on a bar of iron, which had supported a piece of brick work, on the top of a tower of the church of St. Augustin. The very same fact was observed about 1630, by Gassendi, on the cross of the church of St. John, at Aix, which had fallen down in consequence of having been struck with lightning. He found the foot of it wasted with rust, and possessing all the properties of a loadstone.

(753) In the year 1600, Dr. Gilbert, of Colchester, published a work, entitled "*Physiologia Nova, seu Tractatus de Magneti et Corporibus Magneticis*," which contains almost everything concerning Magnetism, which was known during the two following centuries. He regarded the earth as acting on a magnetized bar, and upon iron, like a magnet, the directive power of the needle being produced by the action of Magnetism of a contrary kind to that which exists at the extremity of the needle directed towards the pole of the globe. He gave the name of *pole* to the extremities of the needle, which pointed towards the poles of the earth, conformably to his views of terrestrial Magnetism; calling the extremity that pointed towards the

north, the south pole of the needle, and that which pointed to the south, the north pole.

(754) Newton, Huygens, and Hooke, with some of the other philosophers who flourished about the end of the seventeenth century, were occupied to a certain extent with the subject of Magnetism. Some of their observations and discoveries are referred to in a manuscript volume of notes and commentaries, written by David Gregory, in 1693, in a copy of Newton's "Principia," and used by Newton in improving his second edition. Newton had supposed that the law of magnetic action approaches to the inverse triplicate ratio of the distance; but Gregory did not adopt this opinion, and invalidates the arguments that were used in its support.

(755) In 1683 Dr. Edmund Halley published his theory of Magnetism. He regarded the earth's Magnetism as caused by four poles of attraction, two of them near each pole of the earth; and he supposes, "that in those parts of the world that lie nearly adjacent to any one of these magnetic poles, the needle is governed thereby, the nearest pole being always predominant over that more remote." He supposes that the magnetic pole, which was, in his time, nearest Britain, was situated near the meridian of the Land's End, and not above 7° from the north pole; the other north magnetic pole being in the meridian of California, and about 15° from the north pole of the earth. He placed one of the two south poles about 16° from the south pole of the globe, and 95° west from London; and the other, or the most powerful of the four, about 20° from the south pole, and 120° east of London.

(756) In order to account for the change in the variation, Dr. Halley, some years afterwards, added to these reasonable suppositions the very extraordinary one, that our globe was a hollow shell, and that within it a solid globe revolved, in nearly the same time as the outer one, and about the same centre of gravity, and with a fluid medium between them. To this inner globe he assigned two magnetic poles, and to the outer one, other two: and he conceived the change in the variation of the needle to be caused by a want of coincidence in the times of rotation of the inner globe and the external shell. "Now supposing," says he, "such an external sphere, having such a motion, we may solve the two great difficulties in every former hypothesis: for, if this exterior shell of the earth be a magnet, having its poles at a distance from the poles of diurnal rotation, and if the internal nucleus be likewise a magnet, having its poles in two other places, distant also from its axis, and these latter, by a gradual and slow motion, change their places in respect of the external, we may then give a reasonable account of the four magnetic poles, as also of the

M M 2

changes of the needle's variation." From some reasons, which Dr. Halley then states, he concludes "that the two poles of the external globe are fixed in the earth; and that if the needle were wholly governed by them, the variation would be always the same, with some little irregularities; but the internal sphere, having such a gradual translation of its poles, influences the needle, and directs it variously, according to the result of the attractive and directive power of each pole, and consequently there must be a period of revolution of this internal ball, after which the variation will return as before."

(757) Mr. Graham, a celebrated mathematical instrument-maker, in London, discovered in 1722, the daily variation of the needle. While the needle was advancing by a gradual motion to the westward, Mr. Graham found that its north extremity moved westward during the early part of the day, and returned again in the evening to the eastward, to the same position which it occupied in the morning, remaining nearly stationary during the night. Mr. Graham at first, ascribed these changes to defects in the form of his needles; but, by numerous and careful observations, repeated under every variation of the weather, and of the heat and pressure of the atmosphere, he concluded that the daily variation was a regular phenomenon of which he could not find the cause. It was generally a maximum, between 10 o'clock A.M., and 4 o'clock P.M.; and a minimum, between 6 and 7 o'clock P.M. Between the 6th of February, and the 12th of May, 1722, he made a thousand observations in the same place, from which he found that the greatest westerly variation was $14^{\circ} 45'$, and the least, $13^{\circ} 50'$; but in general, it varied between $14^{\circ} 35'$ and 14° , giving $35'$ for the amount of the daily variation.

(758) Various speculations respecting the cause of the phenomena of Magnetism, had been hazarded by different authors: but it was reserved for M. Epinus to devise a rational hypothesis, which embraced and explained almost all the phenomena which had been observed by previous authors. This hypothesis, which he has explained at great length in his "*Tentamen Theoriæ Electricitatis et Magnetismi*," published in 1759, may be stated in the following manner:—

- i.—In all magnetic bodies there exists a substance which may be called the magnetic fluid, whose particles repel each other with a force inversely as the distance.
- ii.—The particles of this fluid attract the particles of iron, and are attracted by them in return, with a similar force.
- iii.—The particles of iron repel each other, according to the same law.

iv.—The magnetic fluid moves through the pores of iron and soft steel with very little obstruction; but its motion is more and more obstructed as the steel increases in hardness or temper, and it moves with the greatest difficulty in hard-tempered steel and the ores of iron.

(759) The method of making artificial magnets, which was practised by the philosophers of the seventeenth century, was a very simple, but a very inefficacious one. It consisted in merely rubbing the steel bar to be magnetized upon one of the poles of a natural or artificial magnet, in a plane at right angles to the line joining the poles of the magnet. Towards the middle of the eighteenth century, however, the art of making artificial magnets had excited general attention; and it is to Dr. Gowin Knight, an English physician, that we are indebted for the discovery of a method of making powerful magnets. This method he kept secret from the public, but it was afterwards published by Dr. Wilson. Duhamel, Canton, Michell, Antheaume, Savery, Epinus, Robison, Coulomb, Biot, Scoresby, and others, made various improvements on this art; for a detailed account of their numerous experiments, the reader is referred to the article on Magnetism, drawn up by Sir David Brewster, for the seventh edition of the *Encyclopædia Britannica*.

(760) One of the ablest cultivators of the science of Magnetism was the celebrated Coulomb, who, by the application of the principle of torsion, first used by Michell, determined the correct law of magnetic attraction and repulsion. His first object was to determine the law according to which Magnetism is distributed to a magnetic bar. It was of course well known, that the Magnetism in the middle of a bar was imperceptible, and that it increased according to a regular law, and with great rapidity, towards each of the poles. By suspending a small proof needle, with a silk fibre, and causing it to oscillate horizontally opposite different points of a magnetic bar placed vertically, Coulomb computed the part of the effect that was due to terrestrial Magnetism, and the part that was due to the action of the bar; and in this way he showed the extreme rapidity with which Magnetism is increased towards the poles.

(761) In examining the distribution of Electricity in a circular plane, Coulomb found that the thickness of the electric stratum was almost constant from the centre, to within a very small distance of the circumference, when it increased all on a sudden with great rapidity (as has been shown in a previous Chapter.) He conceived that a similar distribution of Magnetism took place in the transverse section of a magnetic bar; and, by a series of nice experiments with

the torsion balance (56) he found this to be the case, and established the important fact that the magnetic power resides on the *surface* of iron bodies, and is entirely independent of their mass.

(762) The effect of temperature on magnets was another subject to which Coulomb directed his powerful mind; but he did not live to give an account of his experiments, which were published after his death by his friend M. Biot. Coulomb found that the Magnetism of a bar, magnetized to saturation, diminished greatly, by raising its temperature from 12° of Reaumur to 680° , and that when a magnetic bar was tempered at 780° , 860° , and 950° of Reaumur, the development of its Magnetism was gradually increased, being more than double at 900° of what it was at 780° . He found also that the directive force of the bar reached its maximum when it was tempered at a bright cherry red heat at 900° , and that at a higher temperature the force diminished.

(763) Coulomb made many valuable experiments on the best methods of making artificial magnets, and he subjected all the various processes that had previously been employed to the test of accurate measurement. His experiments on the best forms of magnetic needles are equally valuable; but the most interesting of his researches, and the last to which he devoted his great talents, were those which relate to the action of magnets upon all natural bodies. Hitherto iron, steel, nickel, and cobalt, had been regarded as the only magnetic bodies; but in the year 1802, Coulomb announced to the Institute of France, that all bodies whatever are subject to the magnetic influence, even to such a degree as to be capable of accurate measurement. In order to determine if the phenomena were owing to particles of iron disseminated through the bodies which he subjected to experiment, he tried a needle of silver, purified by cupellation, and another needle of silver alloyed with $\frac{1}{415}$ th part of iron; and he found that the action of a magnet on the former was 415 times less than upon the latter. Hence, as he had previously shown, that the forces exerted by magnets on needles are proportional to the absolute quantities of iron which they contain, there will be 415 times less iron in the pure than in the impure silver; and since the latter contained $\frac{1}{415}$ th part of its weight of iron the first will contain $\frac{1}{415}$ th part of $\frac{1}{415}$ th, or $\frac{1}{172,275}$ th, or it will contain 172,279 parts of pure silver, and one of iron—a quantity of alloy beyond the reach of chemical detection.

(764) Amongst the scientific travellers who have contributed to our knowledge of terrestrial Magnetism, Baron Alexander Humboldt was one of the most distinguished. Himself a careful and scientific observer, and possessed of accurate instruments and exact

methods of research, he made numerous observations on the dip and variation of the needle in various parts of the earth, and particularly near the magnetic equator; and by means of these valuable data, M. Biot was enabled to throw much light on the subject of terrestrial Magnetism, and to deduce a formula which represented the observations with extraordinary accuracy. Professor Krafft, of St. Petersburg, undertook the same inquiry in the year 1809, and after comparing the same observations which were used by Biot with the respective situations of the places where they were obtained, he arrived at the following simple law: "If we suppose a circle circumscribed about the earth having the two extremities of the magnetic axis for its poles, and if we consider this circle as a magnetic equator, the tangent of the dip of the needle in any magnetic latitude will be equal to double the tangent of this latitude;" and to this simple law, Biot, upon re-examining his former formula, found that it was reducible.

(765) An able work on the Magnetism of the earth was published in 1817, by Professor Hansteen of Christiana; the result of his researches was favourable to that part of Halley's theory, which assumes the existence of four poles and two magnetic axes. He also deduced the law of magnetic action, and showed that "the attractive or repulsive force with which two magnetic particles affect each other, is always directly as their intensities, and inversely as the squares of their mutual distances." And he likewise demonstrated that "the distance from the middle of a magnet being the same, the force opposite the poles, or in the direction of the axis, is double the force in the magnetic equator. Hansteen collected all the observations of value that had been made on the variation of the needle, and from these he proved that there were *four points* of convergence among the lines of variation, *viz.*, a weaker and a stronger point in the vicinity of each pole of the globe. The strongest poles, N. S., lie almost diametrically opposite to each other, and the same is true of the weaker poles, n., s. These four poles he found to have a regular motion obliquely. The two northern ones, N, n, from west to east, and the two southern ones, S, s, from east to west. The following he found to be their periods of revolution, and their positions in 1830:—

	Lat.	Long. from Greenwich.	Time of revolution round each pole of the globe.
Pole N.	69° 30' N.	87° 19' N.	1,740 years.
Pole S.	68° 44' S.	131° 47' E.	4,609 "
Pole n.	85° 6' N.	144° 17' E.	860 "
Pole s.	78° 29' S.	137° 45' W.	1,804 "



And on comparing these results with the magnetical observations made by Captain Parry in the Arctic regions in 1819, he found them to differ so little as to give them a high degree of probability. Hansteen showed that the changes in the variation and dip of the needle in both hemispheres, may be well explained by the motion of the four magnetic poles. The same enterprising philosopher, with a view to the determination of the intensity of the earth's Magnetism at different parts of its surface, caused observations on the oscillation of the *same* needle to be made in every part of Europe, and undertook himself a journey to Siberia for the same purpose. From these observations, he deduced the following law, according to which the magnetic intensity varies with the dip of the needle.

Magnetic dip.					Magnetic intensity.
0	.	.	.	.	1.0°
24	.	.	.	.	1.1
45	.	.	.	.	1.2
64	.	.	.	.	1.3
73	.	.	.	.	1.4
76½	.	.	.	.	1.5
81	.	.	.	.	1.6
86	.	.	.	.	1.7

Hansteen was the first to determine the diurnal variation of the needle. He found that the *minimum* intensity took place between 10 and 11 A.M., and the *maximum* between 4 and 5 P.M.

(766) In an *aërostatic* voyage made by Gay Lussac and Biot, in 1804, at the height of nearly 13,000 feet, they were unable to detect any change in the intensity of terrestrial Magnetism. Saussure, however, had found that the intensity was considerably less on the Col du Géant than at Chamouni and Geneva; the difference in the levels of these places being in the one case, 10,000, and in the other 7,800 feet; but his observations contradict his conclusions. M. Kupffer has more recently obtained a similar result, by observations on Mount Elbrouz; having found a decrease in intensity in rising 4,500 feet above his first station; and he explains the result obtained by MM. Gay Lussac and Biot, by supposing that an increase of intensity was produced by a diminution of temperature. Mr. Henwood, on the other hand, has made observations at the surface of Dolcoath mine; at 1,320 feet beneath its surface; and on a hill, at 710 feet above the level of the sea; without being able to detect any difference in the intensity. To the late Captain Foster we are indebted for many valuable observations on the magnetic intensity, made at Spitzbergen and elsewhere. From these he concluded that

the diurnal change in the horizontal intensity is principally, if not wholly, owing to a small change in the amount of the *dip*. The maximum took place at about 3h. 30min. A.M., and the minimum at 2h. 47min. P.M.; its greatest change amounting to $\frac{1}{3}$ rd of its mean value. Captain Foster is of opinion, that these changes have the sun for their primary agent, and that his action is such as to produce a constant inflection of the pole towards the sun during the twenty-four hours; an idea which had been previously stated by Mr. Christie.

(767) About the year 1818, Professor Barlow, of Woolwich, turned his attention to the subject of Magnetism, with a view principally of calculating the effect of ship's guns on the compass. In trying the effect of different iron balls, he was led to the curious facts—that there exists round every mass of iron, a great circle inclined to the horizon, at an angle equal to the complement of the dip of the needle;—that the plane of this circle is a plane of no attraction upon a needle whose centre is in that plane;—that if we regard this circle as the magnetic equator, the tangent of deviation of the needle from its north or south pole will be proportional to the rectangle of the sine of the double latitude and cosine of the longitude;—that when the distance of the needle is variable, the tangent of deviation will be reciprocally proportional to the cube of the distance, and that all things else being the same, the tangent of deviation will be proportional to the cubes of the diameters of the balls, or shells, whatever be their masses, provided their thickness exceeds a certain quantity. Mr. Barlow was, from these discoveries, enabled to invent a most ingenious method of correcting the error of the compass arising from the attraction of all the iron on board ships. This source of error had been noticed by Mr. Wales, Mr. Downie in 1794, and by Captain Flinders; but it is to Mr. Bain that we owe the distinct establishment and explanation of this source of error. As a hollow shell of iron, about 4 pounds in weight, acts as powerfully at the same distance as a solid iron ball of 200 pounds' weight, Mr. Barlow happily conceived that a plate of 5 or 6 pounds' weight might be made to represent and counteract the amount of the attraction of all the iron on board a vessel; and, therefore, leave the needle as free to obey the action of terrestrial Magnetism as if there was no iron in the ship at all. After this ingenious contrivance had been submitted to the Admiralty, it was tried in every part of the world; and even in the regions which surround the magnetic pole, where the compass becomes useless, it never failed to indicate the true magnetic direction, when the connecting plate was properly applied. "Such an

invention as this," says Captain Parry, "so sound in principle, so easy in application, and so universally beneficial in practice, needs no testimony of mine to establish its merits; but when I consider the many anxious days and sleepless nights which the uselessness of the compass in these seas had formerly occasioned me, I really should have esteemed it a kind of ingratitude to Mr. Barlow, as well as great injustice to so memorable a discovery, not to have stated my opinion of its merits, under circumstances so well calculated to put them to a satisfactory trial." For this beautiful invention, the Board of Longitude conferred upon Mr. Barlow the highest reward of five hundred pounds; and the Emperor of Russia, who was never inattentive to the interests of science, sent him a fine gold watch and a rich dress chain for the same contrivance.

(768) The late Dr. Morichini, an eminent physician at Rome, first announced it as an experimental fact, that an unmagnetized needle could be rendered magnetic by the action of the violet rays of the sun. His experiments were successfully repeated by Dr. Carpi, at Rome, and the Marquis Ridolfi, at Florence; but M. D'Hombre Firmas, at Alais, in France, Professor Configliachi, of Pavia, M. Bérard, of Montpellier, failed in obtaining decided magnetic effects from the violet rays. In 1814, Dr. Morichini exhibited the actual experiment to Sir Humphry Davy, and in 1817, Dr. Carpi showed it to Professor Playfair. A few months after Sir Humphry witnessed the experiment, Sir David Brewster met him at Geneva, and learned from him the fact, that he had paid the most diligent attention to one of Morichini's experiments, and that he saw an unmagnetized needle rendered magnetic by violet light. The following account of the experiment made by Dr. Carpi, was given to Sir David, by Professor Playfair: "The violet light was obtained in the usual manner, by means of a common prism, and was collected into a focus by a lens of sufficient size. The needle was made of soft wire, and was found, upon trial, to possess neither polarity, nor any power of attracting iron filings. It was fixed horizontally upon a support, by means of wax, and in such a direction, as to cut the magnetic meridian at right angles. The focus of violet rays was carried slowly along the needle, proceeding from the centre towards one of the extremities, care being taken never to go back in the same direction, and never to touch the other half of the needle. At the end of half-an-hour after the needle had been exposed to the action of the violet rays, it was carefully examined, and it had acquired neither polarity nor any force of attraction; but after continuing the operation 25 minutes longer, when it was taken off and placed on its pivot, it traversed with great

alacrity, and settled in the direction of the magnetical meridian, with the end over which the rays had passed turned to the north. It also attracted and suspended a fringe of iron filings. The extremity of the needle that was exposed to the action of the violet rays, repelled the north pole of a compass needle. This effect was so distinctly marked, as to leave no doubt in the minds of any who were present, that the needle had received its Magnetism from the action of the violet rays." In this state of the subject, Mrs. Somerville made some simple and well conducted experiments, which seemed to set the question at rest, from the distinct and decided character of the results. A sewing needle, an inch long, and devoid of Magnetism, had one-half of it covered with paper, and the other exposed to the violet rays of the spectrum, 5 feet distant from the prism. In two hours it acquired Magnetism, the exposed end exhibiting north polarity. The *indigo* rays produced an equal effect, and the *blue* and the *green* the same in a less degree. The yellow, orange, and red rays had no effect even after 3 days' exposure to their action. Pieces of blue watch-spring received a higher Magnetism. When the sun's light fell upon the exposed end through blue-coloured glasses, or through *blue* or *green* riband, the same magnetic effects were produced. The experiments of Mr. Christie, an account of which was read to the Royal Society, a short time before Mrs. Somerville's, confirmed her results to a certain degree, by a different mode of observation. The general opinion seems, however, now to be, that light does not exercise any decided effect in producing Magnetism. The experiments of M.M. P. Ries and Moser were made with needles both polished and oxidated, and also with wires half-polished, and polarized as well as common light was made to fall on them in a concentrated state, but no decided effect upon their number of oscillations could be observed; and they state that they think themselves justly entitled to *reject totally a discovery which for seventeen years has at different times disturbed science.*

(769) On 24th February, 1840, the following account of some experiments on this subject was laid before the Royal Irish Academy by Mr. G. J. Knox and the Rev. T. Knox: "Having procured several hundred needles, of different lengths and thicknesses, and having ascertained that they were perfectly free from Magnetism, we enveloped them in white paper, leaving one of their extreme ends uncovered. Taking advantage of a favourable day for trying experiments upon the chemical ray (known by the few seconds required to blacken chloride of silver), we placed the needles at right angles to the magnetic meridian, and exposed them for 2 hours, from 11 till 1 o'clock, to the

differently refrangible rays of the sun, under coloured glasses. Those beneath the red, orange, and yellow, showed no trace of Magnetism, while those beneath the blue, green, and violet, exhibited, the two first feeble, but the last strong traces of Magnetism.

“To determine how far the oxidating power of the violet ray is concerned in the phenomenon, we exposed to the different coloured light, needles whose extremities had been previously dipped in nitric acid, and found that they became magnetic (the exposed end having been made a north pole) in much shorter time than the others, and that this effect was produced in a slight degree, under the red (when exposed a sufficient length of time), strongly under white glass, and so strong under violet glass, that the effect took place even when the needles were placed in such a position along the magnetic meridian, as would tend to produce, by the earth's influence, a south pole in the exposed extremity.

“Conceiving that the inactive state produced in iron (as observed by Schoenbein, 292 *et seq.*) when plunged into nitric acid, sp. gr. 9.36, or being made the positive pole of a battery, or by any other means, might throw some light upon the nature of the change produced, experiments were instituted to this effect, which showed that no trace of Magnetism could be thereby produced.”—(See some curious experiments on the magnetic influence of the *lunar spectrum* in 20th vol. of *Phil. Mag.*)

(770) A valuable series of observations on the influence of the aurora borealis on the Magnetic needle, was made by Dr. Dalton at Kendall and Keswick, during seven years, from May, 1786, to May, 1793, and has been published in his Meteorological Observations and Essays, which appeared in 1793. During these observations he noticed the effect produced on the magnetic needle, and he was thus led to study the phenomena of the aurora, and to establish, beyond a doubt, the relation of all its phenomena to the magnetic poles and equator. In some cases, however, Dr. Dalton did not observe any perceptible disturbance of the needle.

(771) Professor Hansteen, who occupied himself extensively with the subject of magnetism, observes, that large extraordinary movements of the needle, in which it traverses frequently, with a shivering motion, an arc of several degrees on both sides of its usual position, are seldom, perhaps never exhibited, unless when the aurora borealis is visible, and that this disturbance of the needle seems to operate at the same time in places the most widely separate.

(772) From the extensive series of accurate observations, made by M. Arago, at Paris, since 1818, the needle was almost invariably

found to be affected by auroræ that were seen in Scotland ; and so striking was the connexion between the two classes of facts, that the existence of the aurora could be inferred from the derangements of the needle. M. Arago has likewise discovered, that early in the morning, often 10 or 12 hours before the aurora is developed in a very distant place, its appearance is announced by a particular form of the curve, which exhibits the diurnal variation of the needle, that is, by the value of the morning and evening maxima of elongation.

(773) During the journey of Captain Back to the polar regions, in 1833, 1834, and 1835, he found that the needle was generally affected by the aurora ; and on one occasion the deviation which it produced was 8° ; he repeatedly observed that when the aurora was concentrated in individual beams, the needle was powerfully affected ; but that it generally returned to its mean position, when the aurora became generally diffused. On several occasions, the needle was restless, and exhibited the vibrating action produced by the aurora, when this motion was not visible ; and Captain Back states that he could not account for this, except by supposing the invisible presence of the aurora in full day.

(774) The only metals which were supposed to have a distinct and decided power, and were, therefore, called magnetic metals, are iron, cobalt, and nickel. A needle of the latter metal carefully purified by M. Thenard, was found by Biot to have a magnetic directive power $\frac{1}{3}$ that of a similar-sized needle of steel. Mr. David Lyon has endeavoured to show that these metals resemble one another, not only in their principal qualities, but in the numerical values of their qualities ; and, he adds, that whilst these three magnetic substances have the values above referred to, near each other, there are no other substances in which the same values come very near, or fall within those of the three magnetic substances. The values to which Mr. Lyon alludes are the following :—

	Specific gravity.	Atomic weight.	Atoms contained in a given space.
Nickel . . .	8.27 . .	739.51 . .	1118
Iron . . .	7.21 . .	678.43 . .	1062
Cobalt . . .	7.8 . .	738 . .	1057

(775) M. Pouillet, on the other hand, thought that there were five simple magnetic bodies, viz., iron, manganese, nickel, cobalt, and chrome ; and in consequence of having observed some remarkable analogies, between the distance of the atoms of bodies, and their magnetic properties, he was led to suppose that the magnetic limit of different bodies ought to be found at very different temperatures. "I have, indeed," says he, "demonstrated by experiment, first, that

cobalt never ceases to be magnetic, or rather that its magnetic limit is at a temperature higher than the brightest white heat; second, that chrome has its magnetic limit a little below the temperature of dark blood-red heat; third, that nickel has its magnetic limit about 350° centigrade, nearly at the melting point of zinc; and fourth, that manganese has its magnetic limit at the temperature of from 20° to 25° below zero. Experiments on these five magnetic bodies seem to prove, first, that heat acts upon Magnetism only, in consequence of the greater or less distance which it occasions between the atoms of bodies; and second, that all bodies would become magnetic if we could by any action whatever, make their atoms approach within a suitable distance." It was afterwards shown by Faraday that to Pouillet's list of magnetic metals must be added platinum, palladium, osmium, titanium, and cerium; he has found, moreover, that not only the pure metals, but solutions of their salts are acted on by a powerful electro-magnet in a manner similar to iron.

(776) A series of careful experiments was made by Cavallo on the magnetism of *brass* when hammered. He found that this compound, whether old or new, was made magnetic, when placed between two pieces of card, and hammered, either on an anvil by a hammer, or between two flints. He observes: "It appears that the property of becoming magnetic in brass, by hammering, is rather owing to some peculiar configuration of its parts than to any admixture of iron; which is confirmed still further, by observing, that Dutch plate brass (which is made, not by melting the copper, but by keeping it at a strong degree of heat, whilst surrounded by *lapis calaminaris*,) also possesses that property; at least, such was the case with all the pieces I tried. From this it follows, that when brass is to be used for the construction of instruments wherein a magnetic needle is concerned, as dipping needles, variation compasses, &c., the brass should either be left quite soft, or it should be chosen of such a sort as will not be made magnetic by hammering, which sort, however, does not occur very frequently."

(777) These suggestions of M. Cavallo were not attended to as their importance deserved, and there is no doubt that considerable errors have arisen from their neglect. Many examples have indeed occurred in which the errors were detected; and it is now the invariable practice of well informed instrument makers, to reject hammered brass bowls for compasses, and to use those which are cast and turned for the purpose.

(778) The existence of magnetism in brass, while there was not the least trace of it either in the copper or zinc of which it is composed, led philosophers to investigate the effects produced by the

union of different metals, or by their combination with other substances. Iron itself is a simple chemical body. Steel is a combination of iron and carbon. The loadstone is a combination of iron and oxygen; and as no Magnetism is found either in carbon or in oxygen, we are naturally led to believe, as M. Pouillet has remarked, that the magnetic fluid resides in the substance of the iron, and that it is carried with the atoms of that metal into all the chemical combinations which they form; we may, therefore, expect to find magnetic properties in all ferruginous bodies, whether the iron be an accidental or a necessary ingredient; and indeed cast-iron, plumbago, and the oxides and sulphurets of iron, exert a sensible action on the needle.

(779) On the other hand, Dr. Matthew Young found that the smallest admixture of antimony was capable of destroying the polarity of iron; and M. Seebeck states, that an alloy of one part of iron and four parts of antimony was so completely destitute of magnetic action, that even when put into rotation, it exerted no action on the magnetic needle. The magnetic qualities of nickel (which stands next to iron in magnetic susceptibility, and which is usually found to possess considerable power), are also destroyed by a mixture with it of other metals. Chevenix found that a very small portion of arsenic deprived a mass of nickel, that had previously exhibited a strong magnetic power, of the whole of its Magnetism; and Dr. Seebeck found that an alloy of two parts of copper with one of nickel was entirely devoid of Magnetism, and on this account he recommends it as well suited for the manufacture of compass boxes. On the other hand, Mr. Hatchett ascertained, that when a large proportion of carbon, or sulphur, or phosphorus, was combined with iron, the iron was enabled fully to receive and retain its magnetic properties; but he, at the same time found, that there was a limit beyond which an excess of any of these three substances rendered the compound wholly incapable of receiving Magnetism.

(780) Animal and vegetable substances, after combustion, are said to be attracted by the magnet. The flesh, and particularly the blood, is acted on more powerfully than other parts, and bone less powerfully. Burned vegetables have the same property, and also soot and atmospheric dust; and M. Cavallo has maintained that brisk chemical effervescences acted upon the magnetic needle.

(781) In 1802, the supposition of universal Magnetism was put to the test of rigorous experiment by Coulomb. He employed a glass receiver, from the top of which was suspended, by a silk fibre, the needle of the substance to be examined, about 1 inch long, and $\frac{1}{16}$ th thick. The receiver was then placed so as to enclose the opposite poles of two powerful bar magnets, each formed of four bars

of steel tempered to a white heat, and the number of oscillations of the needle between these poles was noted. It was found that *all substances whatever, when formed into small needles, turned themselves in the direction of the poles of the magnets, and after a few oscillations, finally settled in that position.* When these bodies were moved a very little way out of their position of equilibrium, they immediately began to oscillate round it, the oscillations being always performed more rapidly in the presence of the magnets than when they were removed out of their influence. Gold, silver, brass, wood, and all other substances, whether organic or inorganic, thus obeyed the power of magnets. Hence it was concluded, either that all bodies are susceptible of Magnetism, or that they contain minute quantities of iron, or other magnetic metals, which give them their susceptibility. Various other methods have been employed in developing Magnetism in all bodies whatever, since the time of Coulomb; but we must refer for an account of them to the excellent treatise on Magnetism drawn up for the *Encyclopædia Britannica* by Sir D. Brewster. The interesting question of the universal prevalence of Magnetism subsequently derived new interest from the beautiful discovery of M. Arago. This distinguished philosopher conceived the idea of studying the oscillations of a magnetic needle when placed above or near any body whatever. Having suspended a magnetic needle above metal, or even water, and caused it to deviate a certain number of degrees from its position, it began, when left to itself, to oscillate in arcs of less and less amplitude, as if it had been placed in a resisting medium; and what was peculiarly curious in these experiments, this diminution in the amplitude of the oscillations did not alter the number of oscillations which were performed in a given time. Dr. Seebeck found, that in alloying magnetic with non-magnetic substances, *he formed compounds which exercised no action on the needle.* The alloys which had particularly this singular property, were those consisting of four parts of antimony, and one of iron, or two parts of copper, and one of nickel. In these cases the Magnetism of the two ingredients must have been neutralized by their opposite actions.

(782) In consequence of these experiments of M. Arago, which were announced at the sitting of the French Institute, on the 22nd of November, 1824, and repeated in London, on the 7th of March, 1825, philosophers in every part of Europe turned their attention to the development of Magnetism by rotation. The most important results were obtained by Messrs. Babbage and Herschel. A horse-shoe magnet, which lifted 20 pounds, was made to revolve rapidly round its axis of symmetry, placed vertically with its poles uppermost. A circular disc of copper, 6 inches in diameter, and $\frac{1}{4}$ th

of an inch thick, was suspended above the revolving magnet. As soon as the rotation of the magnet commenced, the copper began to turn in the same direction, at first slowly, but afterwards with an increased velocity. When the magnet was made to turn in an opposite direction, the disc of copper changed the direction of its motion also, and exhibited the same phenomena. Metallic plates 10 inches in diameter, and $\frac{1}{4}$ -inch thick, when interposed between the magnet and the copper disc, did not sensibly modify the results, as M. Arago had observed. Glass produced no effect; but a sheet of tinned plate iron diminished greatly the influence of the magnet, while two such plates almost destroyed it. They found also that a disc of copper, 10 inches in diameter, and $\frac{1}{4}$ -inch thick, and revolving with a velocity of 7 revolutions in a second, did not communicate any motion to a similar disc freely suspended above it.

(783) Messrs. Babbage and Herschel next sought to determine the effect produced by a solution of continuity in the metallic disc, upon which the revolving magnet acted. For this purpose a disc of lead 12 inches in diameter, and $\frac{1}{16}$ th of an inch thick, was suspended at a given distance from a horse-shoe magnet, revolving with the ordinary rapidity, first in its entire state, and afterwards in the state shown in the annexed figures, the black lines in the direction of the radii being the planes where the lead was cut through. (Figs. 256, 257, 258, 259, 260.) The accelerating forces, represented

Fig. 256.

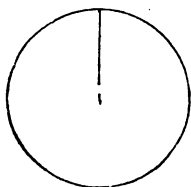


Fig. 257.

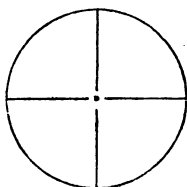


Fig. 258.

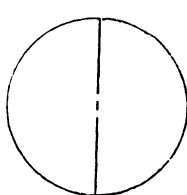


Fig. 259.

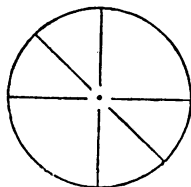
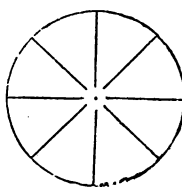


Fig. 260.



by $\frac{s}{t}$, where s is the number of the revolutions, and t the time employed, are as follow:—

N N

Uncut disc.	Disc as in Fig. 256.	Disc as in Fig. 257.	Disc as in Fig. 258.	Disc as in Fig. 259.	Disc as in Fig. 260.
1258	1047	918	564	432	324

Effects similar, but differing in degree, were obtained with other metals: with soft tinned iron, the cutting produced a very slight diminution of effect, while in copper the same operation reduced the accelerating force in the ratio of 5 to 1.

They next tried the effect of filling up the cuts with different metals. A light upper disc suspended at a given distance above a revolving magnet, performed 6 revolutions in 54" 8. When cut as in Fig. 260. its magnetic action was so weakened, that it took 121" 3, to perform 6 revolutions; when the right open radial spaces were filled up with tin, its magnetic action was restored to such a degree, that it made 6 revolutions in 57" 3. This fact is very interesting, as tin has less than half the energy of copper.

(784) M. Haldat made some very interesting experiments on this subject. He found that every needle, however weak its Magnetism, obeyed the action of the revolving disc; but that this action disappeared entirely when its polarity disappeared. He found it impossible to magnetize needles by the action of the revolving disc, however rapid; and in consequence of ascribing this effect to the want of coercitive power, he employed discs of iron and steel, both soft and hardened.

A disc of soft iron acted with more energy than one of copper, and with the same velocity, it dragged the needle twice the distance that a disc of brass did. Iron, strongly hammered, acted like soft iron, and was unable to give polarity to a steel needle; but a disc of untempered steel, $\frac{1}{4}$ th of an inch thick, did not produce any appreciable effect on the magnetic needle, which, after a few irregular oscillations, maintained its ordinary position of equilibrium. Hence, he concluded, that the force which acted upon it was in the inverse ratio of the coercitive force. M. Haldat also found, that discs in a state of incandescence exercised the same action as those at the ordinary temperature.

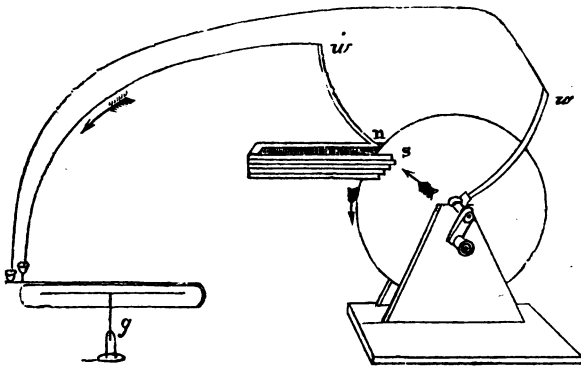
(785) Sir Wm. Snow Harris has since shown that several substances not supposed to contain iron, have the power of intercepting the influence of a revolving magnet, contrary to the observations of Messrs. Babbage and Herschel. A circular magnetic disc being delicately balanced on a fine central point by means of a rim of lead, was put into a state of rotation on a small agate cup, at the rate of 600 revolutions in a minute; and a light ring of tinned iron, also finely balanced on a central pivot, was placed immediately over it at about 4 inches distance, by means of a thin plate of glass, on which its

pivot rested. When the ring of tinned iron began to move slowly on its pivot by the influence of the magnet revolving below, a large mass of *copper* about *three* inches thick, and consisting of plates a foot square, was carefully interposed between the magnet and the iron ring. The interposition of the copper soon sensibly diminished the motion of the iron disc, and at length *arrested it altogether*. On again withdrawing the copper, the motion of the disc was restored; and the same effects were repeatedly obtained. In this experiment both the magnet and the disc were enclosed by glass shades, and supported on a firm base.

The same effects were produced by a mass of silver and zinc: but when their thickness was considerably diminished by removing the central plates, the motion of the disc was not impeded. A very great thickness of *lead* was necessary to stop the disc, in consequence, as Sir W. Harris supposes, of its magnetic energy being so much less than that of copper.

(786) It was about the period of these researches that Faraday made the capital discovery that a permanent current of Electricity may be produced by ordinary magnets. Fig. 261. represents the form of apparatus employed.

Fig. 261.

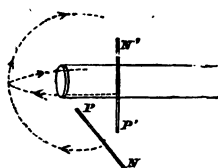


A copper plate mounted on an axis, is furnished with a handle for giving it motion; *w w*, are conducting wires,—the one retained in perfect metallic contact with the axis, and the other with the circumference of the disc. A powerful horse-shoe magnet is then placed so as to allow of the revolution of the disc between its poles, and the wires *w w*, are connected with the galvanometer, *g*; the wire *w*, is retained on the circumference of the disc, at the point between the poles of the magnet. When this machine is made to revolve from right to left, a current of Electricity from the centre to the circum-

ference is determined in the direction of the arrows, and the galvanometer is deflected accordingly. If the revolution of the disc, or the poles of the magnet be reversed, the electric current moves in an opposite direction;—while the plate is at rest, there is no disturbance of the needle of the galvanometer. The same effects are produced when electro-magnets, or coils of wire are substituted for the permanent magnetic poles; and when instead of employing a circular disc of metal, a strip of copper plate is placed between the magnetic poles, while two conductors from the galvanometer are held in contact with its edges, a current of Electricity is shown to be produced by simply drawing the slip of metal between the poles of the magnet.

(787) The law which governs the evolutions of Electricity by magneto-electric induction, is thus illustrated by Faraday.* If in Fig. 262 P N represent a horizontal wire passing by a marked magnetic pole, so that the direction of its motion shall coincide with the curved line proceeding from below upwards; or if its motion parallel to itself be in a line tangential to the curved line, but in the general direction of the arrows, or if it pass the pole in other directions, but so as to cut the magnetic curves in the same general direction, or on the same side as they would be cut by the wire if moving along the dotted curved line; then the current of Electricity in the wire is from P to N. If it be carried in the reverse directions, the electric current will be from N to P: or if the wire be in the vertical position P' N', and it be carried in similar directions, coinciding with the dotted horizontal curve so far as to cut the magnetic curves on the same side with it, the current will be from P' to N'. If the wire be considered as a tangent to the curved surface of the cylindrical magnet, and it be carried round that surface into any other position; or if the magnet itself be revolved on its axis so as to bring any part opposite to the tangential wire; still if afterwards the wire be moved in the directions indicated, the current of Electricity will be from P to N; or if it be moved in the opposite direction, from N to P; so that, as regards the motions of the wire past the pole, they may be reduced to two, directly opposite to each other, one of which produces a current from P to N, and the other from N to P.

Fig. 262.



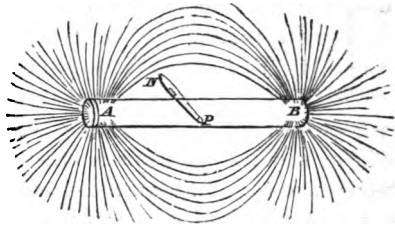
The same holds true of the unmarked pole of the magnet, except that if it be substituted for the one in the figure, then, as the wires are moved in the direction of the arrows, the current of Electricity would be from N to P, and when they move in the reverse direction, from P to N.

* Experimental Researches, 114.

(788) The direction of the current of Electricity which is excited in a metal when moving in the neighbourhood of a magnet is thus shown to depend upon its relation to the magnetic curves. Faraday, with his usual happy method of illustration, has given us this popular expression of it. Let

Fig. 263.

AB (Fig. 263) represent a cylinder magnet, A being the marked, and B the unmarked pole; let P N be a silver knife-blade, resting across the magnet with with its edge upward, and with its marked or notched side toward the pole A; then in



whatever direction or position this knife be moved, edge foremost, either about the marked or unmarked pole, the current of Electricity produced will be from P to N, provided the intersecting curves proceeding from A, abut upon the notched surface of the knife, and those from B upon the unnotched side; or if the knife be moved with its back foremost, the current will be from N to P, in every possible position and direction, provided the intersected curves abut on the same surfaces as before. A little model is easily constructed, by using a cylinder of wood for a magnet, a flat piece for the blade, and a piece of thread connecting one end of the cylinder with the other, and passing through a hole in the blade for the magnetic curves; this readily gives the result of any possible direction.

(789) From this discovery of Faraday's, then, viz., that when a piece of metal is passed before a single pole, or between the opposite poles of a magnet, electrical currents transverse to the direction of motion, are produced across it, a very satisfactory explanation of the phenomenon first observed by Arago, and afterwards examined in detail by Babbage, Herschel, and Harris can be given, without having recourse to the supposition of the formation in the revolving copper of a pole of the opposite kind to that approximated, surrounded by a diffuse polarity of the same kind. It is evident that as the plate revolves, in the neighbourhood of the magnet, or *vice versa*, electrical currents are produced from the centre to the circumference, or from the circumference to the centre, in the direction of the radii; and the effect is precisely the same as in the electro-magnetic rotations, which, as we shall hereafter see, are governed by the following law: If a wire P N (Fig. 264) be connected with the positive and negative ends of a voltaic battery so that the positive Electricity shall pass from P to N, and a marked magnetic pole N, be placed near the wire, between it and the spectator, the pole will move in a direction

Fig. 264. tangential to the wire, that is towards the right, and the wire will move tangentially towards the left, according to the direction of the arrows. So also when a plate of metal is made to rotate beneath a magnetic pole (suppose an N pole), a series of currents of Electricity will pass from the centre to the circumference of the plate if it is rotating in the direction of the hands of a watch, or from the circumference to the centre if it is rotating in the contrary direction; and it is at once evident that, according with the above law, both

magnet and plate must move in the same direction; it is also evident why the phenomena cease when the magnet and metal are brought to rest, for then the electrical currents cease. The effects of a solution of the continuity of the disc in the experiments of Babbage and Herschel are likewise readily explained.

The question as to the universality of Magnetism has been placed in a new and intensely interesting light by the recent discoveries of Faraday and others relating to diamagnetic action, a full account of which we reserve for a future chapter.

(790) With regard to the influence of *heat* on magnetism, Mr. Christie, from a number of experiments made with the torsion balance, the needle being suspended by a brass wire $\frac{1}{16}$ th of an inch in diameter, ascertained the following facts:—

i. Beginning with 3° Fahr. up to 127° , the intensity of magnets decreased as their temperature increased.

ii. With a certain increment of temperature the decrement of intensity is not constant at all temperatures, but increases as the temperature increases.

iii. From a temperature of about 80° , the intensity decreases very rapidly as the temperature increases; so that, if up to this temperature, the differences of the decrements are nearly constant, from this point the differences of the decrements also increase.

iv. Beyond the temperature of 100° , a portion of the power of the magnet is permanently destroyed.

v. On a change of temperature, the most considerable portion of the effect on the intensity of the magnet is produced instantaneously, showing that the magnetic power resides on, or very near the surface.

vi. The effects produced on soft iron by changes of temperature, are directly the reverse of those produced on a magnet; an increase of the temperature causing an increase in the magnetic power of the iron. This was observed between the temperatures of 50° and 100° Fahr. Mr. Christie regards this as a strong argument against

the hypothesis, that the action of iron upon the needle arises from the polarity which it receives from the earth.

(791) In the year 1820 Sir David Brewster announced the discovery of two poles of maximum cold on opposite sides of the north pole of the earth, and he was led to entertain the opinion that there might be some connexion between the *magnetic* poles and those of maximum cold. "Imperfect," says he, "as the analogy is between the isothermal and magnetic centres, it is yet too important to be passed over without notice. Their local coincidence is sufficiently remarkable, and it would be to overstep the limits of philosophical caution, to maintain that they have no other connexion but that of accidental locality; and if we had as many measures of the mean temperature as we have of the variation of the needle, we might determine whether the isothermal poles were fixed or moveable." The connexion between the poles of maximum cold and those to which the isodynamical magnetic lines are related was considered as a probable supposition by the late Dr. Dalton. Other philosophers have expressed similar opinions. Dr. Traill says, "The disturbance of the equilibrium of the temperature of our planet by the continual action of the sun's rays on its inter-tropical regions, and by the polar ices, must convert the earth *into a vast thermo-magnetic apparatus*; and the disturbance of the equilibrium of temperature, even in stony strata, may elicit some degree of Magnetism." Mr. Christie also thinks it not improbable "that difference of temperature may be the primary cause of the polarity of the earth, though its influence may be modified by other circumstances." And in his treatise on "Thermo-Electricity," M. Oersted remarks, "that the most efficacious excitation of Electricity upon the earth appears to be produced by the sun producing daily evaporation, deoxidation, and heat, all of which excite electrical currents." . . . "Thus the earth seems to have a *constant magnetic polarity* produced in the course of time by the electrical currents which surround it, and a *variable Magnetism* produced immediately by the same current."

(792) Sir Wm. Snow Harris's Memoirs were published in the Transactions of the Royal Society of Edinburgh for 1827, and in the Philosophical Transactions for 1831. In the first, entitled "Experimental Inquiries concerning the Laws of Magnetic Forces," he shows by a beautiful series of experiments, that the magnetic development in masses of iron by induction is, *cæteris paribus*, *directly proportional to the power of the inductive force, and inversely as the distance*; and that the forces which magnets develop in a mass of iron at a given distance, within certain limits, may be taken as a fair measure of their

respective intensities ; he also shows that the absolute force of attraction, exerted between a magnet and a piece of iron, varies with the power of the magnet, and consequently with the force induced in the iron, *cæteris paribus* ; and that when the force induced in the iron is a constant quantity, while its distance from a temporary or permanent magnet is variable, *the absolute force varies with the distance*. Sir William made a number of nice experiments on the absolute force of attraction and repulsion between two magnetized bodies, which he found to be in the inverse ratio of the square of the distance. When in the case of attraction, the magnets however were nearly approximated in relation to their respective intensities, the increments in the forces began to decline, and in some instances at near approximations, the absolute force was in the simple inverse ratio of the distance. In the experiments with the repelling poles, the deviations from the regular force were still more considerable, and what is curious in this case, the force became less and less until the polarity of the weaker magnet appeared to be so counteracted by induction *that the repulsion was at length superseded by attraction*. The law according to which the forces are developed in different points of the longitudinal magnetic axis between the centre and poles of a magnet he found to vary directly, as the square of the distance from the magnetic centre, a law which is uniform in bars of steel regularly hardened and magnetized throughout. This law of distribution is exactly the same as that which had been given by Hansteen. Sir W. Harris repeated the experiment of Mr. Christie, and found with that philosopher that the oscillations of a magnetic bar were diminished in bright sunshine, but he found all differences to disappear when the needle was made to oscillate in an exhausted receiver, from which it would appear that Mr. Christie's results must have been owing to currents of air.

MAGNETISM (CONTINUED).

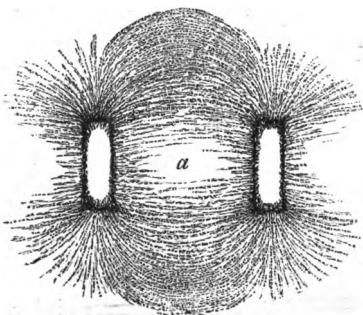
CHAPTER XIV.

General Facts and Principles—Duality of the Magnetic Force—Magnetic Curves
—Haldat's Magnetic Figures.

(793) The native magnet, or natural loadstone, is an ore of iron, consisting chiefly of the two oxides of that metal, together with a small proportion of quartz and alumina. It is usually of a dark grey hue, and has a dull metallic lustre. It is found in considerable masses in the iron mines of Sweden and Norway, and also in different parts of Arabia, China, Siam, and the Philippine Islands. Small loadstones have occasionally been met with among the iron ores of England. The smallest loadstones have generally a greater attractive power, in proportion to their size, than larger ones. They have been found of such a strength, that, though weighing only about 25 grains, they could lift a piece of iron *forty-five* times heavier than themselves. Sir Isaac Newton had a small specimen, set in a ring, which was capable of lifting 746 grains of iron, or 250 times its own weight; and it is stated by Cavallo, that he has seen a loadstone which weighed only $6\frac{1}{2}$ grains, which lifted a weight of 300 grains.

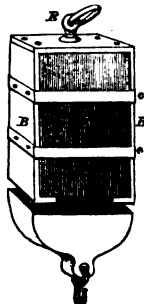
(794) If we immerse a natural loadstone—no matter of what shape—in a quantity of clean iron filings, we shall find that there are two points exactly opposite each other, on which the filings are accumulated more abundantly than on any other place, assuming the form shown in Fig. 265, the lines diverging from the ends of the magnet in *curves*, the centre *a*, being nearly free from them. These are called its poles; and if we balance a small needle of iron on a pivot, and bring it near either of these poles, we shall find that it will be attracted towards it; or, conversely, if we suspend the loadstone by a fine fibre, and bring into the vicinity of its poles, a

Fig. 265.



piece of soft iron, it will be drawn towards the iron; a reciprocal attraction is exerted between them, action and re-action being equal and opposite.

Fig. 266.

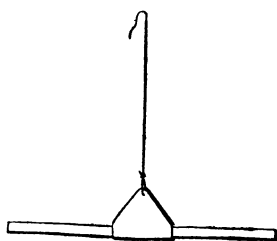


The power of the natural magnet is greatly increased by adapting two pieces of flat soft iron to its poles, and enclosing it in a silver or brass case. In Fig. 266 a magnet thus *armed*, is shown: A is the loadstone; BB, two pieces of soft iron placed against its opposite poles, the lower ends turning inwards, and fastened by transverse bars of copper, *c c*, to the brass case which surrounds the sides and upper part of the stone. In the top of the box is inserted a ring, R, for the purpose of suspending the whole; and to the lower part of the armature is adapted a piece of soft iron, with a hook, on which is hung as much weight as the strength of the magnet will bear.

(795) When a piece of steel has been rendered magnetic, it exhibits the same properties as the natural loadstone; and since we are in the possession of a variety of methods of communicating to it this state, the artificial magnet is always employed in experimental investigations. We shall describe some of the most approved methods of magnetizing iron presently: in the meantime, we shall only observe that, for the exhibition of the experiments we shall first have to allude to, the following simple and ready method will be found amply sufficient for communicating to small bars of steel the requisite degree of Magnetism. (Scoresby.)

Break off sharply with a pair of pliers, about 3 inches of a thick steel knitting needle, and give it several smart blows with a hammer, while its smooth and rounded end rests on the knob of a poker held vertically between the knees, the poker itself having been previously hammered while in this position. The wire will, by this treatment, become magnetic. The downward end, while under percussion, being a *north pole*. If the bar to be magnetized be placed between two iron rods (the lower one having been previously

Fig. 267.



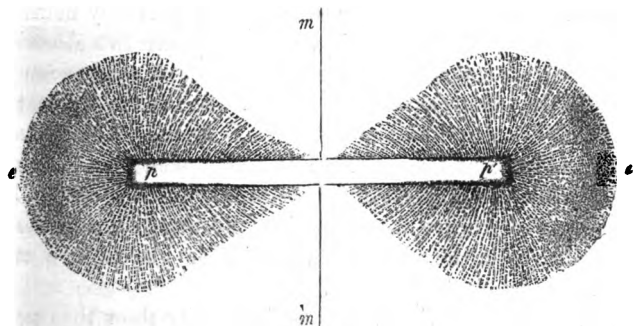
hammered) and the hammer then applied to the top of the pile, increased effects are obtained.

If the bar which has been thus treated, be suspended horizontally in a little stirrup of paper or metal by a fibre of silk, (Fig. 267), and if all bodies of a ferruginous nature be removed from its vicinity, it will, after a few oscillations, take

up a position nearly north and south; and if it be disturbed from this position, and placed in any other, it will not remain there; but as soon as it is at liberty to move, it will resume its former position. It will also possess the power of communicating Magnetism to hard steel *permanently*, and to soft iron *temporarily*, the degree of strength, of course, depending on its own power, and with respect to the steel, on the time which it is suspended. If two magnetized bars be poised and placed in different positions respecting each other, it will be found that in some cases they appear to be attracted towards each other, while in others they manifest a mutual repulsion. This, however, does not happen capriciously; the two north poles and the two south poles invariably repel each other; but the north pole of one magnet always attracts, and is of course attracted by the south pole of the other. An excellent extemporaneous pivot for a needle or bar may be formed by inverting a common precipitating glass on a pivot, and laying the bar on it. The bar may likewise be laid upon the centre of a clean watch-glass, on which, because of the curvature of the glass, it will rest as on a point, and perfect freedom of motion will be obtained by tapping the table near the watch-glass with the knuckle.

(796) If the bar thus rendered magnetic be sprinkled over with, or rolled into, fine iron filings, the filings will be observed to adhere to it, in the form of bristling tufts (Fig. 268), but by no means in a uniform manner: at the extremities, $e e'$ the iron filaments will be

Fig. 268.



very long, standing out perpendicularly from the surface. As the centre of the bar is approached they will become shorter, gradually taking up a more and more inclined position, and adhering in smaller and smaller tufts as the central line $m m'$ is approached. In the immediate neighbourhood of this line no filings are attracted; this, therefore, is called the *neutral line*, and the two halves of the bar $p p'$ are called the *magnetic poles*. Every magnet, natural or artificial,

possesses essentially this neutral line and these magnetic poles; it sometimes, however, happens that a magnetized bar possesses more than two poles, two or more poles alternating between those situated at either extremity of the bar. A magnet in this condition is said to have "*consecutive poles*."

(797) In order to communicate Magnetism from a natural or artificial magnet to unmagnetized iron or steel, it is not necessary that the two bodies should be in contact. The communication is effected as perfectly, though more feebly, when the bodies are separated by space. Thus, in Fig. 269, if

Fig. 269.

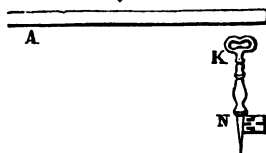
the north pole of an artificial steel magnet *A*, be placed near the extremity *S*, of a piece of soft iron *B*, the end *s*, will instantly acquire the properties of a south pole, and the opposite end *n*, those of a north pole. The opposite poles would have been produced at *n* and *s*, if the south pole *s*, of the magnet *A*, had been placed near the iron *B*.

In like manner, the iron *B*, though only temporarily magnetic, will render another piece of iron *C*, and this again, another piece *D*, temporarily magnetic, north and south poles being produced at *n'*, *s'*, and *n''*, *s''*.

(798) Here we cannot fail to observe a pointed analogy between the phenomena of magnetic attraction and repulsion, and those of electrical. In both there exists the same character of double agencies of opposite kind, capable, when separate, of acting with great energy, and being, when combined together, perfectly neutralized, and exhibiting no signs of activity. As there are two electrical, so there are also two magnetic powers; and both sets of phenomena are governed by the same characteristic laws. So also in the last experiment, the Magnetism inherent in *B*, *C*, *D*, is said to be *induced* by the presence of the real magnet *A*; and the phenomena are exactly analogous to the communication of Electricity to unelectrified bodies by induction, the positive state inducing the negative, and the negative the positive, in the parts of a conductor placed in a state of insulation near an electrified body.

(799) A simple experiment will satisfactorily show that soft iron possesses magnetic properties, while it remains in the vicinity of a magnet. Let *A* (Fig. 270) be a magnet, and *K* a key, held either horizontally near one of its poles, or near its lower edge. Then if another light piece of iron, such as a small nail, be applied to the other end of the key, the nail will hang from the key, and will continue to do so while

Fig. 270.



the magnet is slowly withdrawn; but when it has been removed beyond a certain distance, the nail will drop from the key, because the Magnetism induced on the key becomes at that distance too weak to support the weight of the nail. That this is the real cause of its falling off, may be proved, by taking a still lighter fragment of iron, such as a piece of very slender wire, and applying it to the key. The Magnetism of the key will still be sufficiently strong to support the wire, though it cannot the nail; and it will continue to support it, even when the magnet is yet further removed; it at length, however, drops off.

If the key be held above a portion of iron filings, they will not be attracted by it; but if the magnet be then brought near the ring of the key, as in the figure, the iron filings will instantly start up, and be attracted by the key.

(800) It has been observed, that in all cases where a magnet attracts iron, a reaction takes place, the iron attracting the magnet; it is the same with a bar of iron on which Magnetism has been induced. It reacts upon the magnet, which induces its Magnetism, and increases its magnetic intensity. Hence, we derive a distinct explanation of the remarkable facts, that a magnet has its power increased by having a bar of iron placed in contact with one of its poles, and that we can gradually add more weight to that which is carried by the magnet, provided we make the addition slowly, and in small quantities, the power of the magnet being increased by the reaction of each separate piece of iron that it is made to carry.

These facts enable us to explain the phenomena of magnetic attraction and repulsion. The magnet attracts a piece of iron by inducing an opposite polarity at the end in contact with it; and the two opposite principles attract each other. In like manner, the north pole of one magnet attracts the south pole of the other; and the north and south poles repel each other, in consequence of the attraction and repulsion of the opposite and similar principles. The attraction of iron filings is explained in the same way. The particle of iron next the magnet, has Magnetism induced on it, and it becomes a minute magnet, like *B*, Fig. 269. This particle again makes the next particle a magnet, like *C*, and so on, the opposite polarity in each particle of the filings attracting one another, as if they were real magnets.

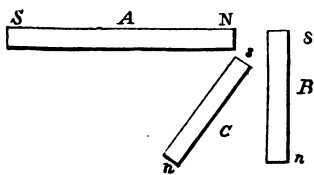
(801) In comparing the amount of the *attractive* force of two *dissimilar* poles of two magnets, with the amount of the *repulsive* force of the two similar poles, it has been found that the former force is considerably greater than the latter. This result is a necessary consequence of the inductive process above described. When the

two attracting poles are in contact, each magnet tends to increase the power of the other, by developing the opposite magnetic states in the adjacent halves, and thus increasing their mutual attraction. But when the two repelling poles are brought into contact, the action of each half brought into contact, has a tendency to develop in that half, a Magnetism opposite to that which it really possesses, and thus to diminish the two similar principles, and weaken their repulsive power. This injurious influence of opposite poles upon the repulsive power of the magnets in action, is well exhibited when one of the magnets is very powerful, and the other very weak. When the two similar poles are held at a moderate distance, a repulsion is distinctly exhibited; but when they are brought into contact, the stronger *attracts* the weaker magnet, an effect which is produced by its actually destroying the similar weak Magnetism in the half next to it, and inducing in that half the opposite Magnetism, which of course occasions attraction.

(802) The law regulating the variation of the intensity of the magnetic forces, both attractive and repulsive at different distances, has been submitted to careful investigation by several eminent mathematicians, and the general result has been it is the same that obtains in Electricity and in gravitation, viz., that the intensity of the force by which magnetic polarities act on each other is inversely as the square of the distance, a law which seems common to all forces emanating in every direction from a central agent.

(803) The process of induction is in its operation independent of the relative positions of the magnet and the soft iron. Thus in Fig.

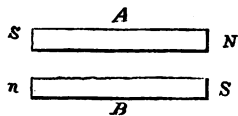
Fig. 271.



271, let A be the permanent steel magnet, and B and C pieces of soft iron. The two ends *s s* will become south poles, and the opposite ends *n n*, north poles, under the inducing influence of A; but C will become more powerfully magnetic than B, because from its inclined position the pole S of the steel bar A begins

to exert an inductive influence on *n*. From this it is evident that the most favourable position in which a bar can be placed for receiving the full inductive influence of both poles is that of

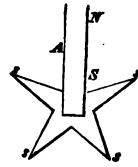
Fig. 272.



parallelism, as shown in Fig. 272. The effects become somewhat complicated when the inducing bar is brought either very near, or in contact with, the iron bar in other positions than the ends. Thus if we bring the north end of a magnetized

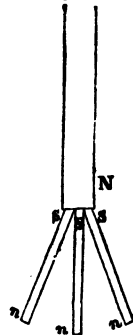
bar opposite the centre of a soft iron rod, the two ends of the rod will become temporarily two north poles, a south pole being induced in the centre. In like manner the star-shaped piece of iron (Fig. 273) will have south poles at *s s s s*, on bringing the S pole of the bar S opposite its centre. If a circular iron plate be substituted for the star, then every part of its circumference will have a southern polarity.

Fig. 273.



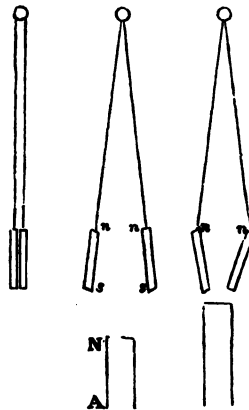
(804) The experiment illustrated in Fig. 274, shows the operation of magnetic induction in a very instructive manner. Several soft iron wires are suspended from the N pole of a strong bar magnet. The wires immediately become temporarily magnetic, their S poles being determined towards the N pole of the inducing bar, and their opposite extremities becoming *n* poles. Both ends have a natural tendency to repel each other, but the S ends are prevented from yielding to their repulsive influences in consequence of their strong adhesion to N. The *n* poles not being under the influence of this restraining power avoid one another, as represented in Fig. 274. Again, in the

Fig. 274.



following experiment of Cavallo, we have well illustrated the mutual repulsive action of similar poles. Two pieces of soft iron (Fig. 275) are suspended by threads from a ring or hook, so as to have free liberty of motion, on bringing either, say the N pole of a strong bar magnet, at a certain distance below the wires, the wires become inductively magnetic, and their similar S poles being determined towards N, a mutual repulsion is set up. If now the magnet A be approached very near to the wires, the repulsion of the *s s* ends of the wires gives place to an apparent attraction; this is caused by the stronger attraction of A, for both wires overcoming their own mutual repulsions; the repulsion of the *n* ends of the wires is, however, now rendered evident, and the nearer the inducing magnet is brought to the wires the stronger will this repulsion be manifested. On removing A, the wires immediately collapse, and fall into a parallel and vertical position, the Magnetism induced upon them being merely of a temporary nature. When fine steel needles

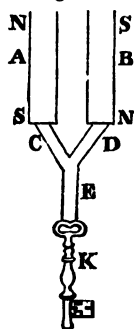
Fig. 275.



are substituted for soft iron wires, it often happens that they acquire a certain amount of permanent Magnetism, in which case they, of course, continue to repel each other after the removal of the magnetic bar.

(805) The following experiment of Dr. Robison is likewise instructive as showing the neutralization or destruction of induced Magnetism by two equal and opposite magnetic actions. A forked piece of

Fig. 276.

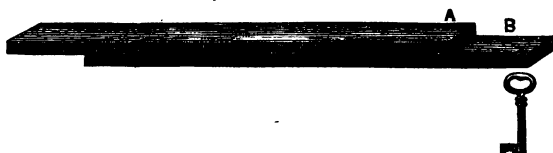


soft iron, C D E, is suspended by one of its branches from the N pole of the magnetic bar, A B; if the power of B be pretty strong, it will induce sufficient temporary Magnetism in C D E to enable it to hold in suspension the key K; but if we now bring into contact with the other branch of the fork the S pole of a second magnetic bar, the key will immediately drop off. The reason is evident: the N pole of B induces a N pole at the lower end E of the fork; hence its power of sustaining the key; but the S pole of A tends to give a southern polarity to the same end, and the two actions mutually destroy or

neutralize each other.

Again,

Fig. 277.

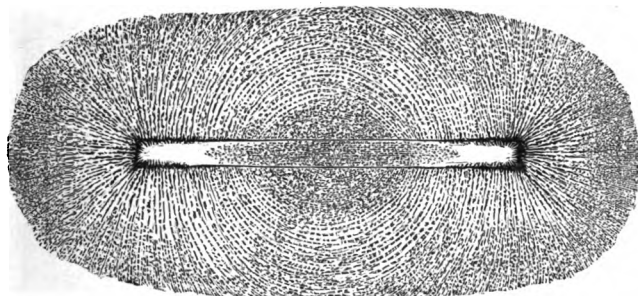


suspend any object of soft iron, as a key, from either pole of the magnetic bar A, then gradually slide over A a second similar bar B, taking care that the opposite poles of the two bars shall come into contact when the end of B arrives within a certain distance of A, the key will fall off as if the bar had lost its magnetic power; this, however, is not the case, for on removing B the key will be again supported.

(806) We have seen the close analogy which exists between the phenomena of Electricity and those of Magnetism, as far as relates to the law of action, and the influence of induction, but beyond this point it fails us entirely. No natural or artificial magnet has ever been seen with only *one pole*, or with one kind of Magnetism; Electricity, on the other hand, whether positive or negative, is not only capable of being excited by induction, but it may be actually transferred from one body to another. A body may without difficulty be electrified positively or negatively as has been shown in a previous

chapter (30—42); but with Magnetism there is never any transfer of properties, but only the excitation of those which were already inherent in the body operated on. If we examine a magnetized bar, by laying it on a table, covering it with a sheet of white paper, or with a plate of thin glass, and then sifting some fine iron filings over it from a muslin bag, the filings will, on gently tapping the table, be found to arrange themselves round and about the poles of the magnet in a very beautiful manner, forming a succession of curves known as the “magnetic curves,” (Fig. 278), or “the curved lines of magnetic

Fig. 278.



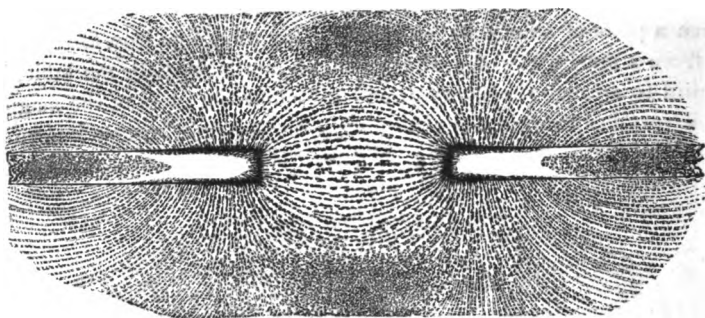
force” (Faraday). On examining these curves, it will be found that the force decreases gradually from the poles towards the centre, or some point intermediate between the two poles, where it vanishes altogether. This is the neutral point, or as it may be called the *equator* of the magnet. If we break the magnet at this point, we shall not find a north polar Magnetism distributed uniformly over one portion, and a south polar Magnetism over the other, but each half will be a perfect magnet in itself, and if examined by iron filings, will be found to exhibit the “curved lines of magnetic force” as perfectly as the unbroken bar; the same will be the case if the pieces be again broken—other magnets will be formed, each having an equator and two poles; and in like manner, however numerous and minute the fragments into which a magnet may be divided, each part will be still a complete magnet with two poles and a neutral point.

(807) Beautiful visual evidence of the existence of two distinct magnetic forces—of their mutual attractions, repulsions, and neutralization—are afforded by the phenomena presented when iron filings are submitted to the influence of the opposite and similar poles of two pairs of magnetic bars. Let the two dissimilar poles of two powerful bars be placed in the same line, about $1\frac{1}{2}$ or 2 inches apart, and let the filings be sifted through a sieve on a frame of drawing paper, placed over them, the filings will arrange themselves as shown in Fig. 279, the curved and straight

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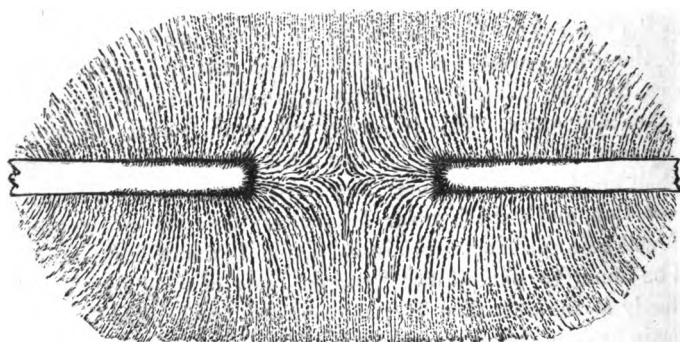
lines of magnetic force issuing from similar points of each bar joining the two poles,

Fig. 279.



and showing reciprocal attraction. Then let the two similar poles be placed opposite each other and the filings again sifted over them; evidence of mutual repulsion will now be obtained, the lines of force being apparently conflicting, as shown in Fig. (280.)

Fig. 280.

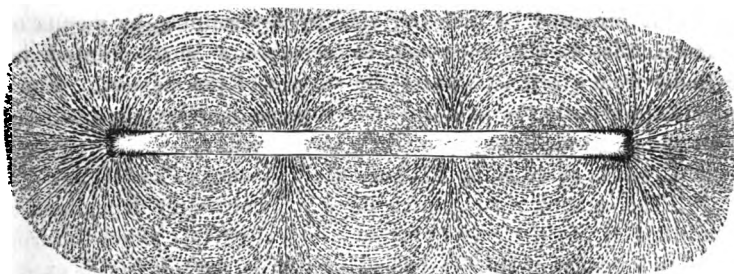


It sometimes happens, that either from some peculiarity in the structure of the bar, or from some irregularity in the magnetizing process, a magnet is met with having more than two poles. This curious condition is readily detected by examining the magnetic curves into which iron filings are thrown when sprinkled over the bar. They will be found to be distributed in the manner shown in Fig. 281.

A magnetic bar in this condition is said to have *consequent* or *consecutive* poles.

The fundamental properties of the magnetic curves were investigated mathematically by Dr. Roget (*Journal of the Royal Institution*, Feb., 1831). He describes them as having the following remarkable

Fig. 281.



property, viz., that the difference of the cosines of the angles, which lines drawn from any point in the curve to the two poles, make with the axis, taken on the same side, is constant; and he constructed a system of rulers by which these curves may be mechanically delineated.

(808) *Sustaining Power of Electro-Magnets*.—The experiments of Jacobi and Lenz (*Pogg. Ann.* xlvii., 403) led them to the conclusion that under conditions in other respects similar, the total attraction, i.e., the mutual adherence of two straight cylindrical electro-magnets, or of one electro-magnet and one armature of soft iron, is proportional to the *square of the strength* of the current; to this proposition Müller assents (*Ann. rep. Prog. Chem.* 1850). According to Barral (*Comptes Rendus*, xxv. 757), the attraction increases with the weight of the keeper, and reaches its maximum when the electro-magnet and keeper are of equal weight. The experiments of Dub agree with this indication only so far that for a given electro-magnet, and a given diameter of keeper, a certain amount of sustaining power cannot be exceeded. This limit seems to depend more upon the length than on the weight, and to be more slowly attained the greater the strength of the current. He corroborated the result that the single coils contribute more to the development of the magnetic intensity of the poles, the nearer they are to the latter; and that when the coils are arranged in different systems of equal power, the lifting power, with a constant current, is proportional to the square of the number of systems in action.

The distribution of Magnetism in the polar surfaces of an electro-magnet was determined by Von Kolke (*Pogg. Ann.* lxxi., 321). The magnetic force in any given zone of the surface which intersects the axis of the magnet at right angles, is always greater at the edges than upon the surfaces; in fact, in the case of a large horse-shoe electro-magnet, he found the force almost twice as great at the rim as at the centre. In consequence of the action of the poles upon each other, the weakest point was not found to be at the exact centre, but

approached it more and more, the less the two limbs could act inductively upon each other. The method of measurement adopted was that proposed by Plücker, viz., by determining by means of a balance, the weight necessary to separate a small-pointed iron cylinder from a given point on the surface of the magnet. For all practical purposes the numbers thus obtained may be taken to represent the magnetic intensity of the places tested.

The results obtained by Pfaff are the following (*Peschel*):—

1°. The amount of suspensive force is immediately dependent on the intensity of the electric current which circulates about the iron; and the intensity of the Magnetism excited in the soft iron is exactly proportional to that of the electric current.

2°. The intensity of the current continuing the same, the magnet's suspensive force increases with the number of turns made by the wire; or the total effect of all the coils is equal to the sum of their effects, if taken singly.

3°. The attractive force of an electro-magnet increases as the mass of the iron composing it, and this increase is proportional to the diameters of the iron cylinders, their lengths being equal.

4°. The purer and softer the iron, and the more homogeneous the mass, the stronger the Magnetism it is capable of receiving.

5°. The form of the iron influences its suspensive power, cylinders carry greater weights than rectangular bars, and a hollow cylinder, from which a portion has been cut away so as to form a long horse-shoe magnet, when viewed in the direction of its axis, but a very short one if taken, as to its height, is capable of receiving a very great suspensive force; and lastly, a slight curvature of the polar surface adds considerably to its power.

(809) We are indebted to M. Haldat, of Nancy, for the discovery of magnetic figures analogous to those first produced with Electricity by M. Lichtenberg, and which may easily be exhibited. For this purpose he employs plates of steel, from 8 to 12 inches square, and from $\frac{1}{8}$ th to $\frac{1}{4}$ th of an inch thick. The plates which he used were of that kind of steel which is used for the manufacture of cuirasses; so that it did not require to be tempered, being sufficiently hard to preserve the Magnetism communicated to it. Figures of any kind may be traced on the surface of the steel plate, either by one magnet or by several combined, and the best form for this purpose is that in which the poles are rounded. In this way we may write on a steel plate the name of a friend, or sketch a flower or figure, with the extremity of a magnet. If it is the south pole that we use, all the traces that we make will have north polar magnetism; and if we shake steel filings on the plate out of a gauze bag, the

filings will arrange themselves in the empty spaces between the lines traced by the pole of the magnet, and thus represent in vacant steel the name which has been written, or the flower or figure which has been sketched. "These figures," says M. Haldat, "have a perfect resemblance to those which are formed on the surface of non-magnetic plates, viz., wood, card, glass, or paper, under which a magnet is placed. The resemblance between the two sorts of figures, when the magnets and the parts magnetized have the same form, is not only exact in the whole figure, but likewise in the smallest details. The filings collect at the parts where the Magnetism is most intense, and they arrange themselves in pencils and radii. These curves, and pencils, and rays, so similar at the two poles of the same magnet, have such a resemblance that they do not allow us to distinguish the two parts from one another."

(810) In sifting the iron filings upon the steel plate, a general vibration of the plate, by tapping its edge with the ring of a small key, will assist the filings in taking their proper places; but we must avoid such vibrations as will produce regular acoustic figures, unless we wish, as M. Haldat has found to be practicable, to unite the magnetic with the acoustic figures, which produces very interesting and varied forms.

In order to remove the Magnetism from the steel plates, they may be heated over charcoal, till they become of the straw-coloured temperature; and to render the repolishing of them unnecessary, M. Haldat tins them, and the temperature at which the tin melts, when it is required to efface the Magnetism, indicates the necessary heat.

(811) As the figures traced on the steel are nothing more than magnets of different forms, and are surrounded on all sides with a substance capable of acquiring the Magnetism which may be developed by communication, we might expect, as M. Haldat remarks, that this means of communication between the opposite poles of the magnets would bring them into a neutral state. This, however, is not the case; and the portion of the metal which surrounds the magnetic figure, performs the part of the *armature* of a loadstone, and the Magnetism is thus kept up.

The figures might be rendered permanent, by covering the steel plate either with a gummy or balsamic solution, which will become hard by exposure to the air; or with a coating of some easily melted substance which becomes fixed at ordinary temperatures. If we sift the iron filings on the steel plate when covered with such a fluid, the filings will take their magnetic position round the traced lines, and will become fixed by the induration or solidification of the fluid coating.

Mr. Faraday gives (*Ex. Researches*, Series 29), the following process for *fixing* the designs on the paper: A piece of cartridge paper is well moistened with a solution of one part of gum in three or four of water, by means of a broad camel's hair brush, and after wafting it through the air once or twice to break the bubbles, it is laid carefully on the filings, then covered with ten or twelve folds of equable soft paper; a board is placed over the paper, and a half-hundred weight on the board for thirty or forty seconds; or with a large design, the hand should be applied so as to rub with moderate pressure all over the surface equably in one direction. If after that, the paper be taken up, all the filings will be found to adhere to it, and when dry are firmly fixed. If a little solution of red ferro-prussiate of potash, and a small proportion of tartaric acid is added to the gum water, a yellow tint will be given to the paper, and Prussian blue will be formed under every particle of iron, and then if the filings be removed, the designs still remain recorded. When the designs are to be preserved in blue only, the gum may be dispensed with.

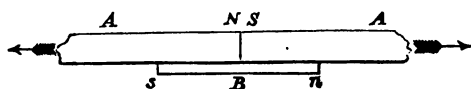
MAGNETISM—CONTINUED.

CHAPTER XV.

Methods of making artificial magnets—Processes of Knight, Scoresby, Duhamel, Michell, Canton, Epinus, Coulomb, Barlow, Elias—Circumstances which affect the energy of artificial magnets—Laws of magnetic combinations—Useful application of the magnetic powers—Laws of magnetic force.

(812) *Methods of making Artificial Magnets.*—For the impregnation of small bars or plates, the following simple process will be effectual. Draw the bar (which should be of a well hardened steel, tempered by plunging it at a cherry-red heat into cold water, and afterwards polished) a few times across the poles of an armed natural loadstone, or an artificial horse-shoe magnet, taking care not to remove the bar from either extremity of the inducing magnet, and to terminate the operation when its extremities are equi-distant from either pole of the horse-shoe, that is, when the poles of the latter are as nearly as possible at the centre of the bar. In this position remove it, and it will be found to have acquired all the magnetic power it is capable of receiving. For larger bars, a great variety of processes have been invented. The first of these was that of Mr. Knight. This method which was kept a secret during his lifetime, but which was made public after his death by Mr. Wilson, consisted in placing the bar to be magnetized, after having tempered it at a cherry-red heat, under the poles N S, (Fig. 282) of two equal magnets. These magnets are then separated in opposite directions, S A, N A, so that the south pole of the one should

Fig. 282.



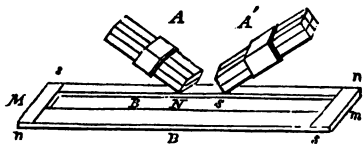
pass over the north polar half, B n, of the bar, B, and the north pole, N, of the other half over the south polar half, B s, of B; this operation is repeated several times till the magnetization of the bar B is fully developed.

(813) This method is modified by Scoresby (*Magnetical Investigations*, 1839), by placing the bar to be magnetized, *above*, instead of *beneath*, the magnets employed in the operation, by which great facility is given for the performance of the requisite manipulations, and for the maximum development of the magnetic condition. The plate to be magnetized is laid flat upon the magnets, so as to extend equally over the surface of both. The bars are then drawn asunder,

till the plate just rests with its extremities in contact with the extreme poles of the magnets, and then it is slid off sideways, and removed to some distance, preserving the parallelism of its position with that of the magnets, till these are restored to the proximity with which the operation commenced. The process is repeated with the other side of the plate in contact with the magnets, and in the case of thin small plates—sea compass—needles for instance—the condition of saturation is found to be obtained. Usually, however, four strokes are given, two on each side; and in hard short bars, six or eight strokes are given, partly on the edges. A dozen compass—needles may thus be magnetized to saturation in five or six minutes, and by means of a pair of strong two-feet magnets, compass needles or dipping needles of the usual form, can be brought to their maximum power without removing their agate caps or centres.

(814) Soon after the publication of Dr. Knight's method, small bars thus magnetized were distributed all over Europe, and were eagerly sought after by the cultivators of natural philosophy. When the process, however, was applied to bars of large size, it was found to be defective; philosophers therefore renewed their efforts to devise methods of greater and more universal efficacy. The next improvement was made by M. Duhamel, of the Academy of Sciences, in conjunction with M. Antheaume. The process is represented in Fig. 283. The bars *B B* to be magnetized, are placed paralld to each other, and

Fig. 283.



have their extremities united by two pieces, *Mm*, of soft iron, at right angles to the bars; two strong magnets, or two bundles of small bar magnets, *A A'*, having their similar poles together, are placed as in the figure, at an angle of about 90°, or inclined at 45° to the bar *B*, and then separated from each other, as in Dr. Knight's method; the same operation is repeated on the other bar *B*, and continued alternately on both, till the Magnetism is supposed to be completely developed in both bars. When *A A'* are placed on the second bar *B*, the disposition of the poles must be reversed; the pole that was formerly to the right hand being now turned to the left. The two bars *B B* are then turned, so that the undermost faces are uppermost, and the same process carried on as before.

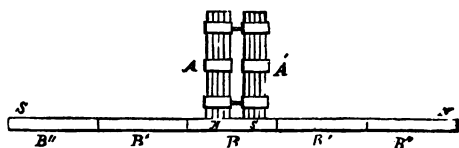
The peculiarity of Duhamel's process consists in the employment of the pieces of iron *M m*, and in the use of bundles of small bars, which are more efficacious than two single ones of the same size. In

proportion also as the steel bars acquire Magnetism, the connecting pieces participate in the acquisition of a similar power, and serve to retain it in the bars themselves; just as the Electricity which is imparted to the inner coating of a Leyden jar, is retained by the reciprocal influence of the induced, and contrary Electricity of the outer coating. The Magnetism of the bars is retained by a similar influence, and greater facility is thus afforded to increase its amount, by the subsequent additions it is receiving from the action of the magnets, as they pass along the surface.

(815) About the same time that Duhamel was occupied with this subject, Mr. Michell, of Cambridge, and Mr. Canton, were separately engaged in the same inquiry. Mr. Michell published his method in 1750, to which he gave the name of *method by double touch*. Having joined together, at the distance of $\frac{1}{4}$ th of an inch, two bundles

of strongly magnetized bars, $A A'$ (Fig. 284), their opposite poles, NS , being together, he placed five or more equal steel bars, $B B' B' B' B'$, in the same straight

Fig. 284.



line, and resting the extremity of the bundle of magnets, $A A'$, upon the middle of the central bar, B , he moved them *backwards and forwards* throughout the whole length of the line of bars, repeating the operation on each side of the bars, till the greatest possible effect was produced. By this method Mr. Michell found that the middle steel bars, $B B' B'$, acquired a very high degree of magnetic virtue, and greater than the outer bars, $B'' B''$; but by placing these last bars in the middle of the series, and repeating the operation, they acquired the same power as the rest. Mr. Michell states that two magnets will, by his process of *double touch*, communicate as strong a magnetic virtue to a steel bar as a single magnet of five times the strength when used in the process of single touch. The bars $A A'$ act with the sum of their powers in developing Magnetism in all parts of the line of the bars between them, and with the difference of their powers in all parts of the line beyond them. The external bars act the same part in this process as the two pieces of soft iron in the method of Duhamel.

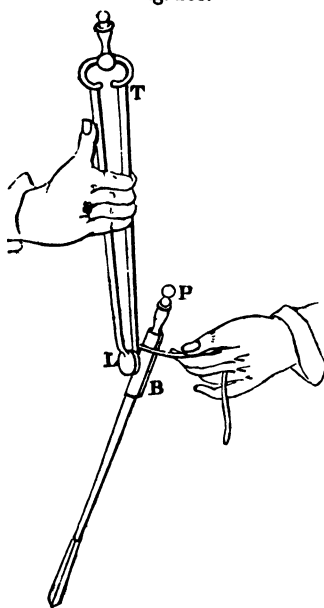
(816) Mr. Canton placed the bars as in Duhamel's method, joined by pieces of soft iron. He then applied Michell's method of double touch, and afterwards he separated the two bundles of magnets, $A A'$; and having inclined them to each other, as in Duhamel's method, he made them rub upon the bar from the middle to

its extremities. The peculiarity of Canton's method is the union of these two processes; but Coulomb and others are of opinion that the latter part of the process is the only effectual one.

(817) In order to make artificial magnets, without the aid either of natural loadstones or artificial magnets, Mr. Canton gives the following detailed process:—

He takes six bars of soft, and six of hard steel; the former being smaller than the latter. The bars of *soft* steel should be 3 inches long, $\frac{1}{4}$ th of an inch broad, and $\frac{1}{16}$ th thick; and two pieces of iron must be provided, each having half the length of one of the bars, and the same breadth and thickness. The bars of *hard* steel should be each $5\frac{1}{2}$ inches long, $\frac{1}{2}$ an inch broad, and $\frac{1}{16}$ ths of an inch thick, with two pieces of iron of half the length, and of the same breadth and thickness.

Fig. 285.



All the bars being marked with a line quite round them at one end, take an iron poker and tongs, or two bars of iron (the larger and the older the better), and fixing the poker upright, as in Fig. 285, hold to it with the left hand near the top, P, by a silk thread, one of the soft bars, B, having its marked end downwards; then grasping the tongs, T, with the right hand a little below their middle, and keeping them nearly in a vertical line, let the bar, B, be rubbed with the lower end, L, of the tongs, from the marked end of the bar to its upper end, about ten times on each side of it. By this means the bar, B, will receive as much Magnetism as will enable it to lift a small key at the marked end; and when suspended by its

middle, or made to rest on a point, this end will turn to the *north*, and is called its *north* pole, the unmarked end being the *south* pole.

When four of the soft steel bars are thus rendered magnetic, the other two, *A C, B D*, Fig. 286, must be laid parallel to each other, at the distance of about one-fourth of an inch, having their dissimilar poles united by the smallest pieces of iron, *A B, C, D*. Two of the magnetized bars are then to be placed together, as at *G*, with their similar poles united, and when separated by a piece of wood, at *I*,

they are slid four or five times backwards and forwards along the whole length of the bar, $A C$, so that the marked end, F , of G is nearest the unmarked end of $A C$, and *vice versa*.

This operation is carefully repeated on $B D$, and on the other sides of both $A C$ and $B D$.

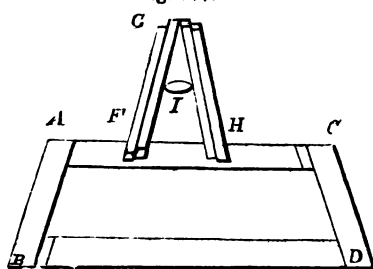
When this is done, the bars $A C$ and D are to be taken up and substituted for the two outer bars of the bundles $G K$; these last being laid down in the place of the former, and magnetized in a similar manner. This operation must be repeated, till each pair of the soft bars has been magnetized three or four times.

When the six soft bars are thus magnetized, they must be formed into two bundles of three each, with their similar poles together, and must be used to magnetize two of the *hard* bars in the manner already described; and when they are magnetized, other two of the hard bars must be touched in a similar manner. The soft bars are now to be laid aside, and the remaining two *hard* bars magnetized by the *four* hard bars already rendered magnetic; and when this is done, the operation should be repeated by interchanging the hard bars, till they are impregnated with the greatest degree of permanent Magnetism which this method is capable of communicating to them.

(818) In performing the above operations, which may be completed in about half an hour, the bars $A C$, $B D$, and the pieces $A B$, $C D$, should be placed in grooves or fixed between pins of wood or brass, to keep them steady during the successive frictions which are applied to them. According to Canton, each of the six artificial magnets thus made, will lift about twenty-eight ounces troy. They should be kept in a wooden box, and placed so that no two poles of the same name may be together,—the pieces of iron being placed beside them.

(819) The method of “double touch,” introduced by Michell and Duhamel, was much improved by Epinus, who substituted magnetic bars for the pieces of soft iron $M m$, forming the rectangle (Fig. 283). He then inclined the bundles of magnetic bars which formed his battery, and separating their dissimilar poles by a piece of wood, he passed them backwards along the whole length first of one of the steel bars, and then of the other, taking care to reverse the poles when passing from one bar to the other; the process was then repeated on the other sides of the bars. Epinus found that a maximum

Fig. 286.

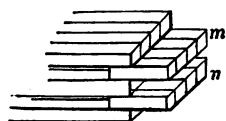


effect was produced when the magnetizing bars were inclined 20° or 30° to the steel bars over which they passed.

Scoresby modifies this process by passing a horse-shoe magnetic battery round the whole parallelogram of steel bars in the same direction, terminating at the middle of one of the bars, instead of limiting the manipulations to the extent of the steel bars separately from end to end. For a pair of bars, tempered from end to end, 2 feet in length, 1.5 inch broad, and 0.6 inch thick, two circuits only of the parallelogram on each side of the bars by the large magnets were necessary, and in order to avoid hitching, and to make the magnet pass smoothly, the surfaces of the bars should be slightly oiled. By this modification of Epinus, Scoresby states that he was enabled to obtain one-seventh the additional power in two heavy bars.

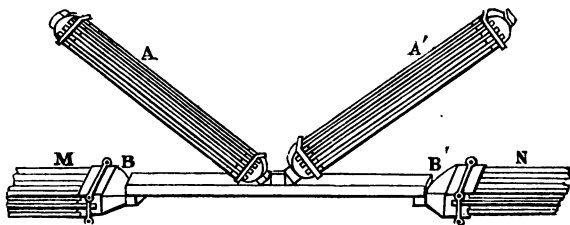
(820) The following is an account of Coulomb's method of making artificial magnets, which consists of the most efficacious parts of the preceding processes, improved and extended by long experience. The apparatus which he uses consists of *fixed* and *moving* bundles of magnets. Each of the fixed bundles consists of *ten* bars of steel, tempered at a cherry-red heat, their length being about 21 inches, their breadth $\frac{1}{8}$ ths of an inch, and their thickness $\frac{1}{4}$ th of an inch. Having rendered them as strongly magnetic as possible, with a natural or artificial magnet, he joined them with their similar poles together, and formed them into two beds of four bars each, these beds being separated by small rectangular parallelepipeds, *m n*, of soft iron, projecting beyond their extremities, as

Fig. 287.



shown in Fig. 287. The *moving* bundles consist of four bars tempered at a cherry-red heat, each being about 16 inches long, $\frac{1}{8}$ ths of an inch wide, and $\frac{1}{8}$ ths of an inch thick. When these bars were magnetized in the same way as the other bars, he united two of them by their width, and two of them by their thickness, so that each bundle was $1\frac{1}{8}$ th inch wide, and $\frac{1}{8}$ ths thick. The bars being separated as before, by pieces of soft iron, Coulomb found that all kinds of steel, provided the quality was good, were capable of receiving the same degree of Magnetism. In order to magnetize a bar, he placed the large fixed *bundles*, *M N*, (Fig. 288) in the same straight line, and at a distance of a little less than the length of the bar to be magnetized; and this bar, *B B*, was placed as in the figure, so as to rest on the projecting pieces of iron, so that the contact took place only over a length of $\frac{1}{4}$ th of an inch: the two moving bundles, *A A'*, having their dissimilar poles separated by a small piece of wood or copper, about $\frac{1}{4}$ th of an inch wide, between them; and each being in-

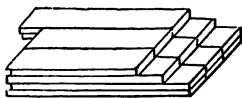
Fig. 288.



clined at an angle of 20° or 30° to the bar, $B B'$. The united poles of the moving bundles are then moved successively from the centre to each extremity of the bar, $B B'$, so that the number of frictions upon each half of the bar may be equal. When the last friction has been given, the united poles are brought to the middle point of the bar, $B B'$, and then withdrawn perpendicularly. The same operation is then repeated on the other side of the bar, $B B'$. If we wish to employ the method of Duhamel, we do not require the piece of wood or copper, but have only to separate the bars when the united poles are in the middle of the bar, $B B'$, making each pole pass to the extremity of it.

(821) If the pieces composing the moveable magnets have not received their full power, they will, notwithstanding, communicate to the bars subjected to their action, a *greater* degree of Magnetism than they possess themselves. We may therefore now increase *their* power, by repeating the process on them with the bars which they have themselves impregnated: by so doing three or four times, we shall succeed in effecting their complete saturation. If the bars to be magnetized be very large, Coulomb recommends an increase of the number of the moveable magnets, each of the bars projecting beyond the last, as shown in Fig. 289. Thus the pole of each, which Coulomb supposes generally to reside at the very extremity of the bar, will come immediately in contact with the bar to be magnetized, when the compound magnet is applied to it with the proper inclination, and the whole will powerfully conspire to produce the same effect.

Fig. 289.



(822) *Horse-shoe Magnets*.—The form of a horse-shoe is generally given to magnetic bars when both poles are wanted to act together, which frequently happens in various experiments; such as for lifting weights by the force of magnetic attraction, and for magnetizing steel bars by the process of double touch, for which they are exceedingly convenient; fulfilling in this operation all the purposes of compound magnets.

(823) The following is the method of making a powerful magnetic battery of the horse-shoe form, recommended by Professor Barlow: "Take bars of steel, 12 inches long, and bend them into a horse-shoe shape, their length being 6 inches, their breadth 1 inch at the curved part, and $\frac{1}{4}$ ths of an inch at their extremities, and their thickness $\frac{1}{4}$ th of an inch. Let them be filed nicely, so as to correspond, and lie flatly upon each other. Then drill two holes

Fig. 290.

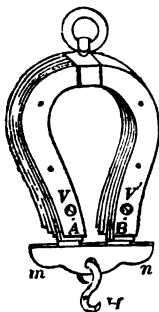


Fig. 291.

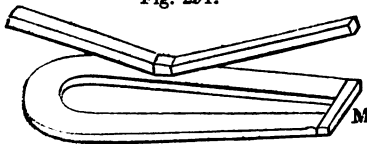
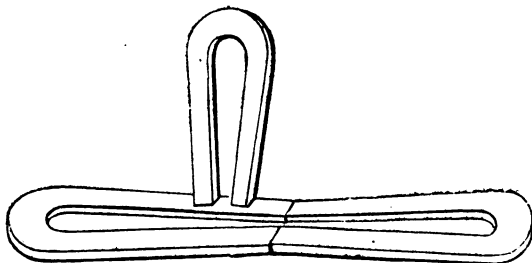


Fig. 292.



in each, as shown in Fig. 290, and by means of screws, V V, passing through these holes, let *nine* horse-shoe bars be bound together. When the heads and ends of the screws are constructed so as to leave the outer surfaces smooth, the mass of bars must be filed as if they were one piece, and the surface made flat and smooth. When the bars are separated, let them be carefully hardened so as not to warp; and when they are cleaned and rendered bright, but not polished, magnetize them separately in the following manner: When the two extremities of the bar are connected by a piece

of soft iron, M, the Magnetism may be developed in the two halves by Duhamel's method, as in Fig. 283; or, following Epinus, a strong magnet may be applied to each pole, and their extremities

connected either with a piece of soft iron or another magnet, or two horse-shoe magnets may be applied to each other, as in Fig. 292, uniting the poles which are to be of contrary names. When the magnets are prepared in any of these ways, they are then to be magnetized with another horse-shoe magnet, by placing its north pole next to what is to be the south pole of one of the horse-shoe bars, and then carrying the moveable magnet round and round, but always in the same direction. In this way, a very high degree of magnetic

virtue may be communicated to each of the *nine* bars. When this is done, they are to be reunited by the three screws; and their poles or extremities connected by a piece of soft iron, or lifter, as in Fig. 34, having in its middle a hook, H, for suspending any weight. As the lifting power depends on the accurate contact of the poles of the magnet with the lifter, the extremities should, after hardening, be properly rubbed down with putty on a flat surface.

A magnet of this size and form was found by Professor Barlow to suspend *forty pounds*; but he afterwards found, that a greater proportional power could be obtained by using bars that were long in comparison with their breadth.

(824) The following is another simple and efficacious method of making artificial magnets, which has been successfully practised by Mr. Barlow. Having occasion for thirty-six magnets, 12 inches long, $1\frac{1}{2}$ inch broad, and $\frac{1}{4}$ ths of an inch thick, he placed thirty-six bars of steel of these dimensions on a table, so as to form a square, having *nine* bars on each side, the marked or north pole of each bar being in contact with the unmarked or south pole. At the angular points of the square, the under edges of the bars were brought into contact, and the external opening thus left was filled up by a piece of iron $1\frac{1}{2}$ inch square, and $\frac{1}{4}$ ths of an inch thick. The horse-shoe magnet described in the preceding section, was set upon one of the bars, so that its *north* pole was towards the unmarked end of the bar, and was then carried or rubbed along the four sides of the bars, and the operation was continued till the compound magnet had gone twelve times round the square. Without removing the magnet, each bar was turned one by one, so as to bring their lower sides uppermost, and the horse-shoe magnet was made to rub along the four sides of the square other twelve times. The bars were then highly magnetized, and the whole process did not occupy more than half an hour.

(825) This last process is the simplest, quickest, and most efficacious of all the methods that have been described; so that when a person is in possession of one good horse-shoe magnet, consisting of three or four bars joined together, he may afterwards make any number at the same time: indeed, the more the better. In removing the bars from each other after they have undergone the operation, it is advisable to place small pieces of soft iron on the poles of each before they are separated; for it is a fact well known to experimentalists, that a very considerable portion of the power of a bar is lost at the moment of its separation from others that have been impregnated with it; nor is it possible by any means to secure the whole of the Magnetism that has been given to it. By following the plan recom-

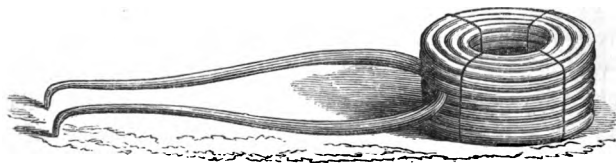
mended above, however, it will be found that a much larger portion is retained. The whole of the bars become in fact, as one single magnet; and the act of separation is, of course, analogous to that of fracture.

(826) Magnets should, when laid aside, be placed as nearly as possible in the position which they would assume in consequence of the action of terrestrial Magnetism. If this be neglected, in process of time they will become gradually weaker; and this deterioration is most accelerated when its poles have a position the *reverse* of the natural one. Under these circumstances indeed, unless the magnet be made of the hardest steel, it will eventually lose the whole of its magnetic power. Two magnets may also very much weaken each other, if they be kept, even for a short time, with their *similar* poles fronting each other. This will readily be understood from what has been said with regard to magnetic induction. The polarity of the weaker magnet is rapidly impaired, and sometimes actually reversed. All rough and violent treatment of a magnet should also be carefully avoided: every concussion or vibration amongst its particles tends to weaken its power.

(827) Horse-shoe magnets should have a short bar of soft iron, adapted to connect the two poles; and should never be laid by without such a piece of iron adhering to them. Bar magnets should be kept in pairs, with their poles turned in contrary directions, and the dissimilar poles on each side connected by a bar of soft iron, so that the whole may form a parallelogram. They should fit into a box when thus arranged, so as to guard against accidental concussion, and to preserve them from the dampness of the atmosphere. They should be polished, not with a view of increasing their Magnetism, but because they are then less liable to contract rust. Both single magnets and needles have their powers not only preserved but increased, by keeping them surrounded with a mass of dry filings of soft iron, each particle of which will react, by its induced Magnetism, upon the point of the magnet to which it adheres, and maintain in that point its primitive magnetic state.

(828) The following simple method of magnetizing steel bars was published by M. P. Elias, of Haarlem (*Phil. Mag.*, vol. 25, p. 348).

Fig. 293.



From 23 to 25 feet of well insulated copper wire are wound so as to form a hollow, very short, but very thick, cylinder. A current from a strong voltaic pair is passed through the wire, and the steel bar to be magnetized is placed in the cylinder in which it is moved up and down to the very ends. When the central portion of the steel bar again occupies the cylinder, the circuit is opened, and the bar, which is now perfectly magnetized, is withdrawn. When the bar is curved in the form of a horse-shoe, it is well to close it with its keeper during magnetizing; and when a straight one, to provide it at top and bottom with a piece of soft iron. The wire employed is $\frac{1}{4}$ th of an inch in thickness. The voltaic apparatus is a single pair of Grove's (368), which has $\frac{1}{4}$ rd of a square foot of active platinum. The resistance which the current meets with in this battery, is equal to that of a clean copper wire, $\frac{1}{4}$ th of an inch in diameter, and 13 inches long. The hollow cylinder is 1 inch high; the bore nearly $1\frac{1}{4}$ inch in diameter, and the sides $1\frac{1}{4}$ inch thick. By means of this process, a steel horse-shoe bar, weighing 34 pounds, was magnetized to saturation by one single passage through a cylinder, constructed purposely for the experiment.

This mode of magnetizing is nothing more than the double passing of Duhamel or Michell, by means of galvanism; and far more powerful, easy, and certain. As in the double passing, the opposite poles of the magnet employed must be kept close together, so as to exert successively their greatest action upon each small part of the bar to be magnetized; in like manner the cylinder is made quite short, that each portion of the bar may experience the entire force of the voltaic element. Instead of a helix, Böttger (*Pogg. Ann.*, lxvii. 115) recommends a band-spiral of copper, which admits of obtaining the required amount of inductive power with the smallest amount of copper. By means of a spiral, weighing $4\frac{1}{2}$ lbs., 1 millimetre thick, and 20 broad, a 6-lbs. bar of very hard cast steel, when its poles were united with an armature of soft iron, was magnetized to saturation, as completely as it could have been by any known process of communicating permanent Magnetism, merely by passing the spiral once backwards and forwards along the bar. The same bar without the aid of the armature, even if the spiral were passed over it many times, did not assume more than 0.6 of this power. The celebrated Logeman magnets are made according to the method of Elias; their strength in proportion to the quantity of steel, is unusually great. Poggendorff describes a small horse-shoe magnet, weighing rather over a pound, which possessed a constant lifting power of $31\frac{1}{2}$ lbs.

(829) *Circumstances which affect the Energy of Artificial Magnets.*—

P P

Quality of steel denomination (such as cast steel, shear steel, &c.), temper or hardness, mass and form, are stated by Scoresby (*Brit. Assoc., Cork, 1843*) to be among the principles. From the varying influence of these circumstances, it is impossible to give a general answer to the inquiry as to the best kind of temper of steel bars for permanent magnets. For large compass magnets, the best cast steel made as hard as possible, is the most effective; for small magnets and thin compass-needles, cast steel tempered, is the best. The power of a magnet is essentially dependent on both quality and hardness. Scoresby has determined experimentally, that proportional magnets of similar steel and temper, do not energetic proportionally with their masses; in other words, that two magnets, one for instance, in all its dimensions being double that of the other, will not exhibit power corresponding with the mass or in proportion to the cubes of their lengths; the proportions instead of being as $1^3 : 2^3 = 8$, would perhaps be found to be as 1 to 5 or 8 only. From this he infers that magnets cannot be advantageously enlarged to an indefinite extent. Scoresby also found that the same condition did not obtain with straight bars and with horse-shoes; that whereas with the former, in large combinations, extreme hardness is the most effective; in horse-shoes, the bars must be annealed at a temperature of about 505° , to give them their greatest lifting powers.

(830) *Directive Power of Magnetized Bars.*—For ascertaining this point, Coulomb employed his balance of torsion (56). Dr. Scoresby, however, recommends as sufficiently exact for practical purposes generally, the method of deviations. The bars to be examined and compared are laid in a horizontal position, and at right angles to the magnetic meridian, so as to be precisely in the plane of the magnetic equator of the earth, in order that they may receive no inductive influence whatever from terrestrial Magnetism, and thus exhibit only their own actual energy. A compass needle is suspended at a given distance, say five or six times the length of the compass needle, and the *tangents of deviation* produced by the different bars, provided they are of the same length, afford a satisfactory estimate of their proportional powers.

In order to ascertain the relative strength or tenaciousness of magnetic bars, compass needles, &c., Scoresby first ascertains their directive energy separately, and then binds them up into a bundle with their corresponding poles in contact; he then takes them apart, and again determines their directive energy. Sometimes the bars have their poles reversed by this treatment. In this way, surprising differences were detected in bars apparently similar. The following

is an example: 32 large uniform plates of cast steel, tempered throughout their length, of 2 feet long, $1\frac{1}{4}$ inch broad, and .042 inch thick, and weighing on an average 2,869 grains, were each magnetized to saturation by his modification of Knight's process. The mean power of deviation on a compass at one length distance as tried separately, was $16^{\circ} 10'$, the weakest bar causing a deviation of about 15° , and the strongest about $18^{\circ} 30'$. They were all then placed for a short interval in one fasciculus with their similar poles together, and before being entirely separated, the several plates were alternately changed as to positions, and transferred to different parts of the mass. The whole series being now separately examined again, the average deviating power was found to be reduced to $7^{\circ} 35'$, but the amount of deterioration suffered by the individual plates was singularly different, some retaining a deviating power of 10° , others retaining only from 2° to 4° , and some losing their power altogether. Yet these bars were constructed out of the same mass of steel, wrought by the same hand, and tempered precisely alike; and the manufacturer was probably not at all aware of the difference, nor could he by any decided or satisfactory means, separate the good from the bad.

(831) For testing the bars or needles of compasses of uniform, or nearly uniform dimensions, Scoresby employs a powerful, perfectly hard bar-magnet, of length and width corresponding pretty nearly with the dimensions of the plate to be tried. The test magnet he usually employs consists of a rectangular prism of best cast steel, thoroughly hardened throughout the mass, 6 inches in length, and $\frac{1}{2}$ an inch square. Its power is great, occasioning a deviation of 38° to 39° on a compass at 12 inches, or two lengths distance. When employed for testing, its power is first reduced by laying it on a similar bar with corresponding poles coincident, which brings its deviating power down to about 33° or 34° . In this reduced state, the testing of any number of compass needles, or other small bars produces no further deterioration, so that the degree of violence to which each is subjected, may be considered as precisely similar. The bars to be tried after being thoroughly magnetized, are laid in succession upon the test bar, with similar poles in contact. The mere momentary contact of the two sides of the plate is sufficient, care being taken to bring the plate or bar evenly down upon the test magnet, without sliding or friction. The time required for the whole routine of this process, is only about a minute to a minute and a half for each bar; and the precision of the result is such, that the whole series, though amounting to several dozens, can be satisfactorily arranged in the order of their relative tenaciousness, or strength,

in a numerical succession. The bars best adapted for compasses those in which the product of the forces of the original power the reduced power is greatest.

(832) *Ratio of Power to Mass.*—Captain Kater had deduced his investigations on “the best kinds of steel, and form for a compass needle” that the directive force in needles of nearly the same length and form is as the mass. Scoresby’s experiments do not confirm but they show on the contrary, that the ratio of augmentation of power diminishes as the thickness increases. The softer the metal the less its tenacity, and he found an undeviating accession of power or capacity with the increase of hardness.

(833) *Steel for Magnetical Instruments.*—It results from Dr. Scoresby’s experiments that the system prevalently acted on in the construction of magnetical instruments generally, is grounded on an erroneous supposition, as to the capacity of steel of different degrees of hardness for the magnetic condition. It was imagined that a moderate hardening of the ends only of bars destined for magnets was necessary, but this mode of tempering possesses no advantage as to capacity, whilst it has much disadvantage as to tenaciousness, except in very thin bars. Thus, Scoresby could only give a very weak power to a large bar 3 feet long and 3 inches wide, made out of a flat bar of iron, steeled and tempered at the ends. A moderate hardening of the steel throughout was abundantly proved by Scoresby to be the most efficacious. As a general proposition also it is erroneous to suppose that perfectly hard steel bars, have an inferiority in capacity for the magnetic condition. It was found that in all masses above the weight of 130 grains, *perfectly hard steel* was superior in capacity to soft steel, in masses above 250 grains’ weight, superior to bars tempered only at the ends, and above 400 grains, superior to any of the kinds of tempering with which it was compared. Scoresby, moreover, found no difficulty in magnetizing to any degree of energy *very hard bars*, even when of considerable thickness.

(834) *The Magnetic Test applicable to the Determination of the Quality of Steel Bars.*—Dr. Scoresby examined in the state as nearly as possible of raw material, both when soft, and when hardened at a white heat in salt water, bars of common spring steel, single shear steel, double shear, blister, and common cast steel, perfectly similar (as to weight and size), and the results revealed such a relation between the magnetical properties of the several bars, and the respective qualities of their denomination of steel, as to show that the magnetical properties may be rendered available not only for ascertaining the degrees of carbonization, but for the determination of the essential quality of the iron out of which it may have been manufactured. He

adds: "It is not perhaps unreasonable to expect, that were all the varieties of magnetic capacity in each denomination of steel, and in each quality as respects the iron out of which the steel is 'converted,' experimentally ascertained, a strictly scientific process of testing founded on these principles, might be devised—a process which might possibly exhibit results, if not as exact, at least as conclusive in certain most important relations of value in the metal, as are obtained by the beautiful process of assaying." Scoresby found a constant relation between the *ductility* of iron, and its magnetic capacity. The best iron possesses the highest magnetic quality, and therefore the best steel; the cast steel for example converted out of the best Swedish iron, such as that known technically, with reference to its mark, as "*hoop L*" would be expected to possess higher magnetic properties than the cast steel made out of iron of acknowledged inferiority of quality.

(835) *Construction of Magnetic Batteries*.—By combining the principle of the diffusion of energy by the combination of *separated* plates, with that of the selection by testing of powerful and tenacious plates, very powerful magnetic batteries may be constructed. When the plates were of a *spring* temper only, Scoresby found that a limit to the number that could usefully be combined was soon attained; but with hard plates, in which the power of sustaining violence was very great, he has constructed magnetic batteries of 15-inch plates, the power of which has gone on efficiently accumulating to the amount of 192, the power being five or six times as great as could possibly be obtained in any extent of combination whatever, in bars of similar length of the usual kind employed. He found it impossible, by the ordinary process, to communicate the full charge of magnetic influence to very hard shear steel, or cast steel bars, or such as were best suited for retaining it, and therefore best for the manufacture of compasses; but by interposing thin bars of soft iron between the charging poles of the magnet, and the steel to be magnetized, he could give a remarkably strong charge by a single stroke of the poles of the magnet over the bar.

(836) *Laws of Magnetic Combinations*.—The following general results of a long and laborious course of experiments, conducted by the same indefatigable magnetician, are of too high a practical value to be omitted. It was established:—

1°. That any *single* bar is proportionally more powerful than two or more corresponding and equal bars.

2°. That a *combination* of magnetic bars is always more powerful than any single bar of precisely the same steel of equal weight.

3°. That the *absolute gain* of power in the combined mass by each additional plate or bar *progressively diminishes*.

4°. That, beyond a certain extent, continued additions to a powerful combination of bars is not only not beneficial, but positively injurious.

5°. That a certain amount of deterioration in the permanent energy of all the bars in combination takes place by every addition of power to the mass.

6°. That the measure of tenacity or strength of a plate may be tested by its relative deterioration when combined.

7°. That though a weak plate may have its power totally destroyed in a large combination, it may be capable of considerable power and retentiveness of energy in a smaller combination.

8°. That besides a *permanent* deterioration of power, magnetic bars suffer by combination a certain amount of *transient* deterioration, which they recover on separation.

(837) *Separation of the Combined Bars by Limited Spaces.*—The following results were arrived at:—

1°. That the effect of combination is increased in proportion as the spaces between the plates are enlarged.

2°. That by thus preventing the plates from coming into contact, a larger number of plates may be advantageously combined.

3°. That in proportion as the density of the mass is thus diminished by separation, the amount of permanent deterioration in the several plates is also diminished.

4°. That when separated by discs or blocks, weaker plates can be combined advantageously to a much greater extent than when in contact.

5°. That an advantage is gained by a partial separation, such as that in the middle of the plates, but the effect is not so good as when the separation is complete.

(838) *Hardness and Temper.*—It was established:—

1°. That the relative powers of combinations of magnetized plates or bars of steel, as well as those of simple pieces, are greatly affected by differences in the state of the steel, both as to its quality and temper.

2°. That various degrees of hardness have an influence on the magnetic capacity and energy of steel, differing both in the nature and quality, in proportion to the magnitude of the masses employed; so that the kind of tempering which may exhibit superiority with a certain mass, may be greatly inferior in other magnitudes.

3°. That though with certain limited masses, partially tempered or slightly hardened bars have a pre-eminence, nevertheless, in fixity or permanence of power, the softer magnets are always inferior.

4°. That under certain conditions, and with small combinations,

an advantage is gained by heating the middle of thoroughly tempered plates, and so softening them.

5°. That for all practical uses, the limits of hardness may be considered as comprised between a brittle hardness like that of files, and that of an elastic or spring temper.

6°. That in sustaining power, hard bars have a superiority; and that for heavy bars, the greater the hardness the more powerful the magnet.

7°. That in the construction of magnetic batteries, the steel should be similar in quality throughout, and the bars as near the same size as possible.

(839) *Qualities of Steel*.—Dr Scoresby ascertained:—

1° That the magnetic capacity differs in each denomination of hard steel, being the lowest in those kinds susceptible of the greatest hardness.

2°. That in thin and medium plates made quite hard, *shear steel* possesses a higher capacity, and exhibits a greater energy in the individual plates, than blister or cast steel, and cast steel the least of all.

3°. That the comparative magnetic powers of different denominations of steel change their relation to each other *in combination*; each denomination under powerful combinations exhibiting a degree of effectiveness, according apparently, to its susceptibility for hardness.

4°. That *cast steel* being capable of the greatest hardness, is as a denomination, most effective in large straight-bar magnets, whether consisting of single massive plates, or of combinations of thin plates.

5°. The better the iron out of which the cast steel is made, the better the magnetic properties of the steel; the harder the steel also, the better for magnets of great energy, but for single thin plates cast steel from Bradford iron is the best.

(840) Hard *thin* plates gain in power by boiling in linseed oil, while medium or thick plates lose by a similar treatment. The tenaciousness of the magnetic condition is much impaired by annealing large thick straight bars or combinations, but the result is different with thin best cast steel bars.

(841) Although no universal answer can be given to the question—What is the best kind of steel, and the best kind of hardness, or mode of tempering for magnetical instruments? yet the following summary deduced by Scoresby, from his innumerable experiments, may prove very useful to the practical magnetician.

For all large or massive single and compound magnets of the straight-bar form, *the best cast steel* made quite hard; for horse-shoe

magnets, if single, cast steel annealed from file hardness at a temperature of about 550° , or *shear steel* a little reduced; and for compound horse-shoe magnets, cast steel annealed at 480° to 500° , or shear steel perfectly hard: for compass needles, if single and heavy, such as are suited for stormy weather, *hard cast steel*; if light or of moderate weight, whether single or compound, the best cast steel annealed at 500° or 550° , or hard shear steel, or hard cast steel from Bradford iron; and for very light needles or other small magnets the best cast steel annealed at the heat of boiling oil.

(842) *Measure of Permanency*.—The degree of retentiveness of magnets is directly as the hardness, and inversely as the energy. The loss of energy by time in unprotected magnets is much more considerable at first than subsequently. The retentiveness of combinations of thin bars is quite equal to that of single massive bars, especially if the plates be separated by a little distance; and soft magnets if properly protected, are as enduring as hard; and when the maximum power of a magnet is slightly reduced by unfavourable proximity to another magnet, the resulting energy is still less influenced by time.

(843) *Cast Iron Magnets*.—The magnetic capacity and retentiveness of cast iron, though considerable, is greatly inferior to that of properly hardened steel. The better the quality of the cast iron, and the more rapidly the casting is cooled, the more favourable the metal for Magnetism. Scoresby found that good cast iron was quite equal to *soft* steel for single plates, and much superior for large combinations. Hard thin bars of No. 1 pig metal are capable of forming powerful compound bar magnets, quite as strong as solid massive bars of ordinary steel, if only hardened slightly at the ends. Mr. Hearder constructed a compound cast iron horse-shoe magnet, which was capable of lifting 60 lbs., and the power was very permanent. It was composed of 24 bars of the best pig-iron, as hard as green sand could make them. The bars weighed 3 lbs. each, the weight of the combined series being about 70 lbs. The cost of this magnetic battery was not more than twelve or fourteen shillings, whereas a steel magnet of equal power would cost two or three pounds.

(844) *Useful Applications of the Magnetic Powers*.—Among these may be mentioned the magnetic steel masks, worn by the Sheffield needle-grinders to arrest the minute particles of steel which are constantly flying from the wheel, and which would otherwise enter their lungs. These masks are found, after the day's work, fringed with fine particles of steel—a proof of their protecting power. Magnets are also used in paper mills to abstract from the pulp the little particles of iron which arise from the abrasion of the machinery, and

which, under the form of peroxide, frequently disfigure the commoner kinds of paper. The attractive power of magnets is also employed for abstracting the filings of iron from among the dust of other metals of a more valuable character. An exceedingly ingenious application of the magnetic influence to the determination of the thickness of rocks was made by Dr. Scoresby. It is founded on the method of deviations (83), the direction of the needle obeying the same laws, whether the forces act in it merely through an interval of air, or through rock, iron, or other materials. We have seen (830) that the deviations of a small compass needle by the action of a magnet placed in the line of its centre at right angles to the meridian, may be taken as a measure of the force of the magnet; if, therefore, we determine beforehand the amount of deviations for different distances between the magnetic bar and the compass needle, we can apply the instruments to the determination of the thickness of any substance placed between them. The needle is placed on one side of the rock, and the magnetic bar perpendicular to its centre on the other, and the amount of deviation of the former is compared with the table of deviations deduced from the preliminary experiments. In this way Dr. Scoresby states that he can determine the thickness of 2 or 3 feet of rock to $\frac{1}{4}$ th of an inch, and that he can measure distances of from 125 to 150 feet with great approximation to truth. He found that neither iron nor ironstone interfered with the results, for on placing the magnets and the needle one each side of a locomotive engine, the effect was not interfered with. The application of this method to mining operations, and especially to tunnelling, is likely to be very valuable.

(845) *Laws of Magnetic Force.*—This subject has occupied the attention of many of the most profound mathematicians. Newton inferred “from some rude observations” that the power of a magnet decreases not in the *duplicate* but almost in the *triplicate* ratio of the distance. Hawksbee’s experiments (*Phil. Trans.* 1712, vol. xxvii.) gave a law of force which varies as the *sesquiduplicate* ratio of the distances, and his results were subsequently confirmed by Whiston and Taylor (*Phil. Trans.* 1721). Muschenbroek’s researches, made a few years later, led him to the conclusion “that no assignable proportion exists between the forces and the distances, whether of attraction or repulsion.” Mayer and Martin, who wrote on the subject between the years 1750 and 1760, both came to the conclusion that the true law of the magnetic force is identical with that of gravitation, and that in the previous experiments of Hawksbee and others, proper allowance had not been made for the disturbing changes in the magnetic forces so inseparable from the nature of the experi-

ments. Lambert's researches* (*Historie de l'Academie Royale des Sciences, Berlin, 1776*), which were described by Dr. Robinson as worthy of Newton himself, determined that the action of Magnetism on a magnetic needle, considered as a lever, is proportional to the lines of the angle of obliquity of its direction; and that hence the effective force which operates in restoring the needle to its meridian when drawn aside from it, is directly as the line of the angle of its deflection. The law of force was found to be the inverse duplicate ratio of the distances. The directive or polar force of a magnet upon a small needle, was shown by Lambert in a subsequent memoir to be "as the absolute force or magnetic intensity of the particles directly, and as the squares of the distances inversely." Lambert's deductions were confirmed twenty years later by Coulomb, by means of his torsion balance, and more recently (about the year 1817), by Professor Hansteen, of Christiania.

(846) Amongst the latest inquiries are those of Sir W. SNOW HARRIS. (*Edinb. Phil. Trans.*, 1829; and *Rudimentary Magnetism*, Part III.) He first investigates the laws and operation of the elementary forces of induction—the essential function of all magnetic development. When a bar of soft iron and a magnetic bar are opposed to each other, the near pole of the latter induces on the near parts of the former, a polarity the reverse of its own, and a polarity of a similar nature on parts at a distance. The temporary polarity of the iron reacts on the magnet by a kind of reflection or reverberation, inducing on it a new temporary polarity of the same character as its own permanent one; this new force again reacts on the iron, and thus a series of magnetic waves is produced, each becoming weaker until they vanish into rest. Magnetic attractions and repulsions being the results of this inductive reverberation, the study of the laws of the elementary force of induction became necessary as a preliminary to the investigation of the laws of the magnetic force generally.

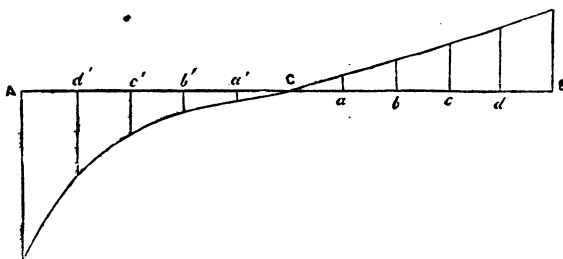
(847) The apparatus employed by Harris was his Hydrostatic Balance, which he found well adapted to the measurement of very small magnetic forces. It appears that there is a limit in respect of the elementary inductive forces, different for different magnets, and varying with the magnetic conditions of the experiment; but as a general rule, it was concluded, that the elementary force of magnetic induction is as the Magnetism directly, and from the $\frac{1}{2}$ or square root to the $\frac{3}{2}$ power, or sesquiduplicate ratio of the distance inversely. Applying these results to the explanation of the different laws of

* For a full discussion of these profound researches, the reader is referred to Sir Wm. Snow Harris's *Rudimentary Magnetism*, Part III.

force, deduced experimentally by Lambert, Coulomb, and others, Harris shows that their seeming contradictions and differences may be reconciled, and that the deduction of Brook Taylor, "that magnetic attraction as commonly observed, is quicker at greater distances than at small ones, and different for different magnets," is a necessary result of the elementary laws of Magnetism.

(848) *Law of Force in different Points of a Magnetic Bar.*—Harris also applied his Hydrostatic Magnetometer to the determination of this problem. The investigation had previously been made by Coulomb, by observing the vibrations of a delicately suspended magnetic needle when brought into various positions, in respect of a long magnetic wire, placed vertically in the magnetic meridian, the dissimilar polarities being opposed to each other. The force due to any given point of the magnetic wire was considered to be proportional to the square of the number of vibrations; the constant and previously determined force, by which the needle vibrated when away from the wire, being deducted. In this way Coulomb obtained as a curve of intensity, a logarithmic curve, the ordinates of which a, b, c , &c., are in geometrical progression, while the abscissæ $C a, C b$,

Fig. 294.

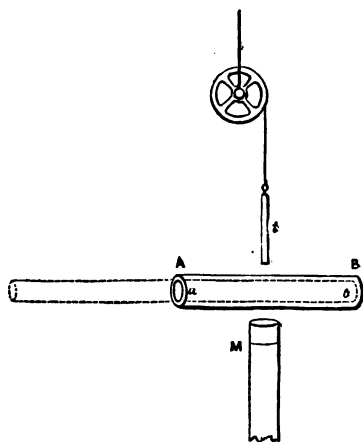


&c., corresponding to these ordinates, are in arithmetical progression, From the many difficulties attending this method of examination, and from the irregular distribution of the Magnetism in the bar, arising from the imperfection of its temper, &c., it is to be doubted whether the true law of intensity is really represented by this peculiar curve. Harris examined the forces at successive points of an accurately divided, powerfully magnetized, and equably tempered bar through a small cylindrical armature of soft iron; the square root of the forces taken in degrees on the graduated arc of the balance being considered to represent very nearly the comparative magnetic development. His results showed that the Magnetism in different parts of a regularly tempered and magnetized steel bar of uniform texture is directly as the distance from the magnetic centre,

whilst the reciprocal force between any given point and soft iron, is as the square of the distance from that centre.

(849) *Law of Magnetic Charge*.—The amount of Magnetism in a bar of well tempered steel, under a given attractive force, is independent of the mass of the magnetized body. This, Harris proved by a very beautiful experiment. He placed between the magnet *M*, Fig 295, and the trial rod, *t*, of his magnetometer a small cylinder of soft iron, *A B*, into which could be inserted as a core, a closely fitting solid cylinder, *a b*, also of iron.

Fig 295.



The magnet was placed at a constant distance below the cylinder, and the attractive forces on the trial rod were measured when the interposed cylinder was hollow, when its core was in its place, and when it was drawn out (as represented by the dotted lines in the figures), so far as to double the extent of the interposed surface; when the joint cylinders were taken together as a mass, and when the interior

cylinder was altogether removed, the force was in both cases the same, amounting to 10° , but when the core was drawn out so as to extend the surface to the greatest limit, the intensity fell to 5° , being diminished one-half. Hence Magnetism, like Electricity, is only influenced by surface, and a hollow steel cylinder may be made to acquire as much magnetic power as a solid cylinder of the same dimensions.

(850) In order to determine experimentally the intensity of Magnetism in respect to the quantity developed, and the extent of surface over which it is dispersed, Harris surrounded a soft iron bar with three distinct and similar coils of wire, which could be connected with three distinct and similar voltaic batteries; he then examined the attractive forces on the trial cylinder of the magnetometer, when the iron rod was magnetically excited by one, two, and three of the coils; the batteries being precisely similar, were assumed to develop each when taken singly, the same amount of magnetic force, and it was found on trial that the intensity was very nearly as the *square of the quantity* of Magnetism, being precisely the same law as that deduced for electrical charge, and therefore to obtain the relative quantity of Magnetism in operation we must take the square roots

of the respective intensities, the magnetic surface and all other things being the same. We have no experiments to show whether this law holds good with dissimilar magnetic bodies of variable size and surface, though it is probable that the law of surface is the same with that of Electricity, and that the intensity is as the square of the surface inversely, *i. e.*, that the same quantity of Magnetism developed upon a doubled surface would have only $\frac{1}{4}$ th the intensity.

(851) The latest experimental investigation of the laws of Magnetism is that of Tyndal (*Phil. Mag.*, N. S. vol. i. p. 295). The subjects of his inquiry were:—

1st. To determine the general relation between the strength of a magnet, and the mutual attraction of the magnet and a mass of soft iron when both are in contact.

2nd. To determine the same relation, when the magnet and the mass of soft iron are separated by a fixed distance.

3rd. A constant force being applied to the mass of soft iron, in a direction opposed to the pull of the magnet, to determine the conditions of equilibrium between this force and Magnetism, when the distance between the magnet and the mass varies.

4th. To determine the general relation between force and distance, *i. e.*, the law according to which the magnetic attraction decreases when the distance is increased.

(852) The following are the principal results:—

1st. The mutual attraction of a magnet and a sphere of soft iron, when both are in contact, is directly proportional to the strength of the magnet.

2nd. The mutual attraction of a magnet and a sphere of soft iron, when both are separated by a small fixed distance, is directly proportional to the *square* of the strength of the magnet.

3rd. The mutual attraction of a magnet of constant strength, and a sphere of soft iron, is *inversely* proportional to the distance between the magnet and the sphere.

4th. When the distance between the magnet and the sphere varies, and a constant force opposed to the pull of the magnet is applied to the latter, to hold this force in equilibrium, the strength of the magnet must vary as the *square root* of the distance.

CHAPTER XVI.

MAGNETISM—CONTINUED.

Terrestrial Magnetism—Magnetical instruments—The land compass—The mariner's compass—The Admiralty compass—Harris's compass—Local attraction in ships—Scoresby's investigations—The dipping needle—The variation compass—The declination magnet—The horizontal force galvanometer—The vertical force galvanometer.

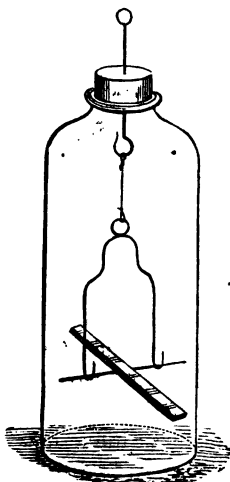
(853) THE tendency of the magnetized needle or bar to turn *nearly* to the north and south, when left at liberty to move freely on a pivot, or otherwise suspended so as to allow of freedom of motion in a horizontal plane, is derived from a force supposed to reside naturally in the earth. The earth in fact must be regarded as a magnetic mass, operating on the magnetic needle, precisely in the same way as one magnet operates upon another.* If we communicate Magnetism to a steel bar which in its previous condition had been exactly equipoised when suspended freely from its centre, we shall find that it no longer maintains its horizontal position, but assumes an oblique one, being inclined with its north pole downward at an angle of about 69° . If we take this needle to different parts of the earth, we shall find its inclination to be different in different parts, the angle becoming greater and greater as we approach the poles, and less and less as we approach the equatorial regions.

(854) The following simple method of constructing a magnetic direction needle is given by Dr. Scoresby (*Magnetical Investigations*, vol. ii.) Two pieces of watch spring, each 2 inches in length, are slightly heated in the candle, and then coated on the concave side with the wax of a common taper; the waxed surfaces are then placed

* The total magnetic power, or "moment of Magnetism" of the earth, as compared with that of a saturated steel bar, 1 pound in weight, is calculated by Gauss to be as 8,464,000,000,000,000,000 to 1, which, supposing the magnetic force uniformly distributed, will be found to amount to about 6 such bars to every cubic yard.

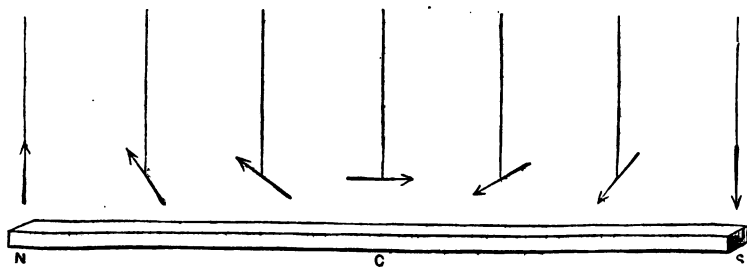
together, and the two pieces bound closely together by thread. A fine sewing needle is introduced as an axis between the two plates midway from each extremity. A piece of brass wire of the thicker size employed for the pianoforte, is bent into the form of a staple, the ends being turned up to receive the axis of the bar. The watch-spring needle is adjusted by a minute quantity of sealing-wax, and the centre of gravity adapted to the axis by accurately straightening the plates with the fingers; on magnetizing the needles, and suspending them by a silk fibre in a large jar, it acts beautifully as an inclination or dipping needle; any deviation from torsion of the silk may be detected by comparing it with a horizontal needle placed at a little distance, and may be avoided by suspending a weight equivalent to that of the needle from the fibre previous to using it.

Fig. 296.



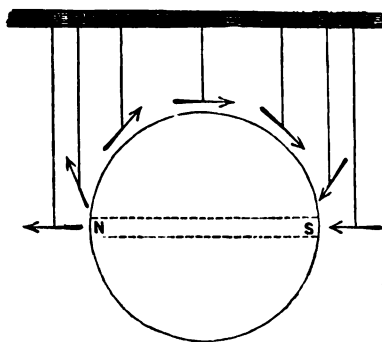
(855) The analogy of the earth to a magnet is beautifully illustrated, by holding a light and sensitive magnetic needle over different parts of a magnetic bar, laid horizontally on a table. The bar should be about 30 inches long, and powerfully and equally magnetized; the needle will assume the various positions indicated in Fig. 297.

Fig. 297.



Thus in the magnetic equator of the bar C it will be exactly horizontal; at N and S it will hang vertically, the N pole downwards at S and the S pole downwards at N, between the poles and the equator; the needle will take up different positions as it is moved along, becoming less and less oblique as it passes from the former to the latter, precisely as it would do if carried from the polar to the

Fig 298.



equatorial regions of the earth ; or a bar magnet may be enclosed in a light wooden or pasteboard sphere, as shown in Fig. 298, and on passing a short dipping needle over the exterior surface of the globe, from pole to pole, the magnetic conditions of our planet may be still more strikingly illustrated.

(856) We have seen that when a piece of soft iron is brought into the neighbourhood of a magnet, it acquires by induction temporary magnetic properties; now it has long been known that rods of iron that have been kept for a long time in a fixed position acquire magnetical polarity : this property they have derived from terrestrial magnetic induction. The position most favourable for developing Magnetism in an iron rod, is that of the dipping needle, and accordingly we find that old kitchen pokers that have been standing for many years nearly in that position have become feeble magnets, their lower ends being N. poles ; any piece of soft iron however, when held in the position of the dipping needle, is *pro tempore* a magnet. The following experiments of Scoresby are instructive on this point (*Magn. Invest.* vol. i.). Lay a compass very near the edge of a square table on the E. or W. side of it, so that the direction of the needle is parallel to the proximate side of the table ; adjust the compass with its needle and N. and S. line in correspondence, and holding the kitchen poker horizontally in the direction of the E. and W. points of the compass, strike it a blow or two with a hammer to neutralize any Magnetism it may have ; the poker whilst held in a vertical position being now brought within 3 or 4 inches of the compass E. or W. of its centre, will strongly *attract* the N. pole when the *upper end* is on a level with the compass, and *repel* the same pole when the lower end is raised to the same level, indicating a *southern* polarity in the upper, and a *northern* in the lower. The evanescent character of this induced Magnetism is further shown by placing the knob end of the poker held horizontally, against the edge of the table, with the compass about 3 inches within ; raising the point with one hand, whilst the knob is kept steady against the table with the other (like a ball moving in a socket) ; the N. pole of the needle will gradually recede till the poker becomes vertical, and then lowering

the point, the N. pole will gradually approach the knob till the poker becomes again vertical, in the direction opposite to its former position; thus showing that the knob had obtained northern polarity, when the bar was vertical with the knob *downward*, and southern polarity with the knob *upward*. By alternately raising and depressing the point of the poker, the needle may be kept in oscillation, and even in unceasing rotation if the movements are consistently continued. The point of the poker being down, and the rod in a vertical position, the quantity of magnetic action on the needle diminishes as the poker is brought to a horizontal position; if the poker be moved in an E. or W. plane, the action on the needle is *nil* when it is horizontal; but if it is moved in a N. or S. plane, and traversed northward of the compass, it will pass beyond the horizontal about 20° before the same neutral effect takes place.

The kitchen poker should be used in these experiments, as the parlour poker with a view to polish and firmness is usually steeled. The influence by which the Magnetism of iron bodies is thus spontaneously elicited, acts in a direction, not like gravitation, perpendicular to the earth's surface, but in a direction inclined in the same degree as that of the earth's magnetic action, and the plane of no attraction is at right angles to the line of the dipping needle.

(857) Soft iron may even be made to acquire temporary lifting power under the influence of terrestrial magnetic induction; thus Scoresby found that a piece of annealed iron plate, 15 inches long and 1.5 inch broad, with a smooth and polished end, when held in the position of the dipping needle could support an iron nail weighing 3 grains, and a thicker rod weighing 3,830 grains supported a nail weighing 10 grains; by combining a dozen such plates some further capabilities were elicited, but by no means corresponding with the increase of mass. By bending a piece of annealed iron plate 15 inches long and $\frac{1}{4}$ -inch wide, reversely at the end, in the form of an architectural ogee, and suspending it by silk fibres, a meridional iron needle was made, that assumed true magnetic direction (though quite free from Magnetism), and was found, moreover, to obey extraneous influences precisely like a steel magnetic needle.

(858) Dr. Scoresby gives ("Magnetical Investigations," vol. iii.) the following general results of a very extensive investigation into the phenomena of terrestrial induction.

1°. That true Magnetism is induced in soft iron by terrestrial induction.

2°. That in masses of uniform temper and quality, the neutral plane is parallel with a plane at right angles to the dip, and obliquely through, or near to, the centre of gravity.

Q Q

3°. That in spherical and other formed bulky masses, the magnetic axis coincides with that of the earth, the chief energy being at the extremities of such magnetic axis, and the neutral plane at right angles to the axis in the middle; but in bars and other elongated forms, the direction of the magnetic forces follows the course of the longitudinal extent of the bars, exhibiting the two polarities in maximum degree, at the opposite ends of the bar, with a neutral plane in the middle.

4°. That different kinds of iron, steel, and iron ores, differ in their respective capacities for terrestrial Magnetism; and that the capacity of each is influenced by its temper, hardness, and mass.

5°. That fasciculæ of thin plates have developed in them a somewhat higher power than solid masses of like dimensions, but that a progressive diminution of power attends the combination of plates—this being more marked in pure annealed iron than in cast steel.

6°. The magnetic energy of a mass of iron under terrestrial induction, is the resultant of two antagonistic forces—the developing force of the earth, and the tendency of the molecular Magnetism of the metal to a state of neutrality; hence bulky masses of iron receive inferior polarity to elongated masses of equal weight, and hollow shells and solid shots have equal magnetic development; this, however, is only true in certain special cases, when similar qualities of metal are compared.

7°. That the Magnetism terrestrially induced, becomes like that in permanent magnets, so highly concentrated at the extremities of elongated bars or plates of malleable iron, as to yield an attractive power sufficient to lift small portions of iron like a feeble magnet, and a directive power adequate to correct adjustment of position, in a plate duly suspended like the needle of a compass.

(859) The effects of percussion and of flexure in communicating Magnetism to soft iron bars while held in a vertical position, is very remarkable, and well worth stating, from its bearing on the important subject of the Magnetism of iron ships. A kitchen poker carefully deprived of Magnetism, by giving it a few smart blows while held *horizontally* E. and W., affected the compass needle at a given distance, when held *vertically*, point upwards, 21° ; in the position of the dip, 22° . A smart blow with the hammer on the square side of the lower end, increased the *upright* deflecting power of the knob from 21° to 35° ; six blows increased it to 44° , and gave it when in a *horizontal* position a deflecting power of 26° . On inverting the poker, a single blow not only neutralized its previous Magnetism, but changed the poles to an extent of 19° of deviating power; and six more blows gave it a *horizontal* deflecting power of 27° . The poker now being held horizontally *east and west*, a single blow

reduced its power to 3° . The effects were increased when the poker was hammered while held in the position of the dip.

(860) The following experiments are instructive as illustrating the effect of percussion and flexure:—

1°. Lay a small delicate compass needle on a table about 3 inches from the E. or W. side, the needle being adjusted to zero. Hold an iron poker (kitchen) point *upwards*, and strike it several smart blows on the top with a hammer; now turn it point *downwards*, and bring the knob against the edge of the table near the compass—little or no action will take place, because although a little northern polarity will have been communicated to the knob by the percussions, still the position in which the poker is now held will tend to produce in the knob a southern polarity by terrestrial induction, and the one will neutralize the other. Should, however, the N. pole of the compass be attracted, a few more blows with the hammer on the point (point upwards) will destroy this attraction. Whilst now the knob of the poker is on a level with the compass (point downwards), let a smart blow be struck on the top, the needle will start aside or whirl round the N. end, being attracted by the poker as if acted upon by some magical power.

2°. Provide two or three plates of thin sheet iron, about 18 inches long, 2 broad, and the thickness of a shilling. After having annealed them by heating them to redness, and allowing them to cool gradually, tie them flat in a bundle in brown paper, one end being marked. Destroy all Magnetism by moderate flexure without permanent bending, the handle being held horizontally E. and W. till there is no action on the needle. Hold the plates vertically, marked end *downward*, and give them a moderate flexure both ways, the marked end will now repel the *north* pole of the needle, probably 25° or 30° . Now bend the plates with the marked end *upwards*, and the polarity will be reversed. Next hold the plates E. and W., and bend them backwards and forwards; the polarity will, in all probability, be wholly, or nearly wholly destroyed.

Scouring, filing, polishing, or any other process acting on the surface of a piece of iron or soft steel, has a corresponding magnetizing or demagnetizing tendency with reference to the position of the metal when thus operated on.

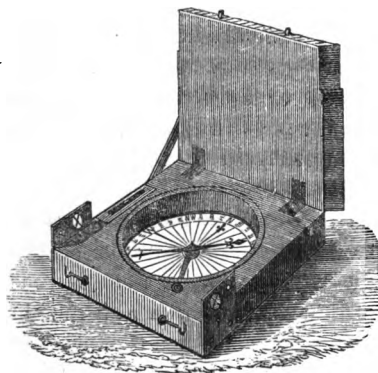
(861) On this principle, iron rods may be completely deprived of Magnetism. We have only to strike them a few blows while held in a horizontal position E. and W., testing them from time to time with a compass. For demagnetizing thin plates of iron which might become bent by hammering, the application of *flexure* is quite as effective and much readier. Scoresby magnetized an unannealed piece of iron

plate, 18 inches long, 1 inch broad, and $\cdot 12 \cdot 12$ inch thick, as highly as possible, and found that six smart blows with a hammer, while the plate was in an upright position, N. pole upwards, were sufficient to disperse the Magnetism.

(862) When *steel* bars are hammered while held vertically or in the position of the dip, they acquire *permanent* Magnetism, but the magnetic lifting power is increased 30 to 1 when they are hammered while resting on the top of an iron bar also held vertically. Powerful magnets may thus be formed. Thus, Scoresby took 6 bars of soft steel, and having magnetized them by percussion, 2 of them connected at their extremities by two short pieces of soft iron, in the form of a parallelogram, were rubbed with the other 4 bars after Canton's method (816), by which their original power was greatly increased. These being substituted for two of the bars of the operating set, were applied with increasing efficacy to the new parallelogram; and the latter, after being thus strengthened, became effectively available for the improvement of the third pair of the series. After treating each pair of bars in regular succession, and through several repetitions of the process, the whole of the bars were found to be in a very high degree magnetical, apparently to the extent of their capacity, each pair readily lifting a weight of above 8 ounces.

(863) *The Land Compass.*—The needle is placed upon a point in the centre of a brass or wooden box, furnished with a graduated limb, and sometimes the ends of the needle are made to carry a vernier scale in order to bring down the readings to a minute or lower. The box which may be square, round, or octangular, is furnished with two straight edges of brass, or index marks to set to any proposed line, and sometimes with sights, the top being covered with glass to pre-

Fig. 298.



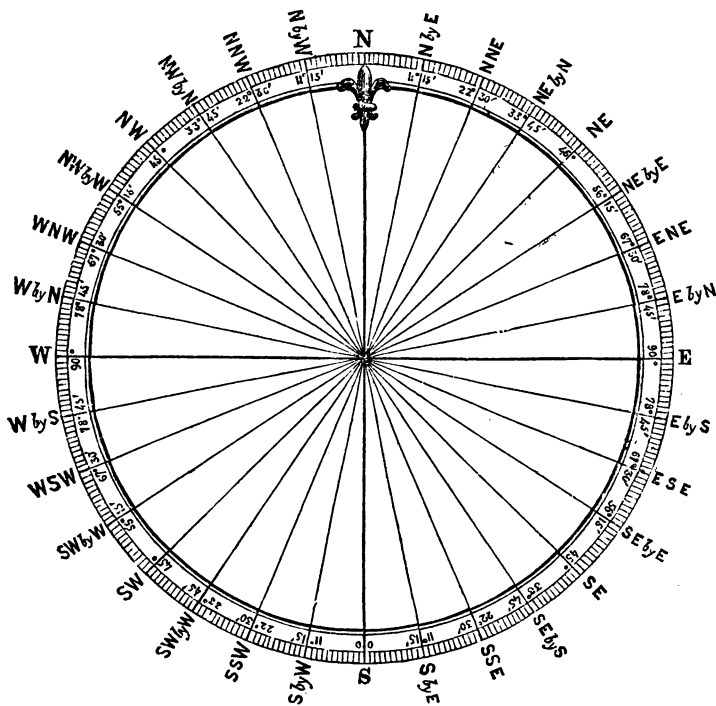
vent the needle from being disturbed by the action of the air. There are also two small pieces of brass, one of them turning on a fixed point, seen in the figure, which is used to check the oscillation of the needle, by pressing upon the upper end; the ring at the other end of the lever is raised till it touches the needle which is thereby rendered steady; the lever is then let down, and the needle left to find its

proper direction. In the figure the needle is mounted with a card

divided into points and quarter-points of the compass; the N. and S. points being made to correspond very exactly with the needle; in this form the general direction of an object will be known by observing its bearing, which will always arrange itself according to the magnetic meridian of the place of observation.

(864) *The Mariner's Compass*.—In its ordinary form it consists of a magnetic needle attached to a circular card, the surface of which is divided into the four cardinal points N., S., E., W.; these again are subdivided into 32 points which are called in nautical language *Rhombs*, from the Greek word *ῥεμβω*, to turn. In the azimuth compass the circle is divided into 360° parts. The position of the needle is usually estimated in terms of the 32 points, but for refined purposes it is found better to estimate the angular deviation of the needle from the line of the magnetic meridian, in degrees and minutes taken in reference to either the N. or S. pole of the card. Thus instead of the Rhomb S. W., we say S. 45° W.; instead of E. N. E., we say N. 67° 30' E., and so on. The card (Fig. 299) is balanced

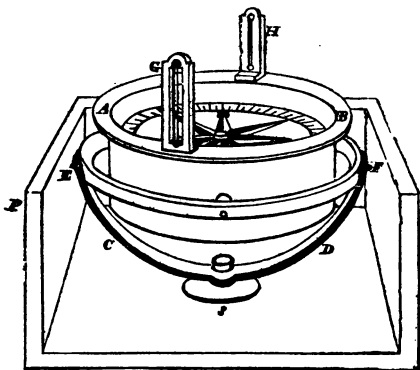
Fig. 299.



upon a pivot fixed in the bottom of a circular box, and the top of the box is a plate of glass for protecting the needle from the motion of

the air. In Fig. 300, A B is the compass box, suspended within a larger box P Q, upon two concentric brass circles or *gimbals*, the outer circles being both fixed by horizontal pivots to the inner circle which carries the compass box; the two axes upon which the gimbals move being at right angles to each other. The effect of this construction is that the compass box A B, will retain a horizontal position during the motions of the vessel. The instrument

Fig. 300.



shown in the figure, is the Azimuth Compass; it is furnished with sights, GH, through which any object may be seen, and its angle with the magnetic meridian increased. For this purpose, the whole box is hung in detached gimbals, CD, EF, which turn upon a stout vertical pin, seen above S. In this compass the card is divided on its

rim into 360° , but the divisions are more frequently placed on a light metallic rim which it carries. The eye is applied to the sight H, which is a slip of brass, containing a narrow slit. The other sight G, which is turned towards the object, contains an oblong aperture, along the axis of which is stretched a fine wire, which is made to pass over the object whose angular distance, or *azimuth*, from the magnetic meridian is to be determined.

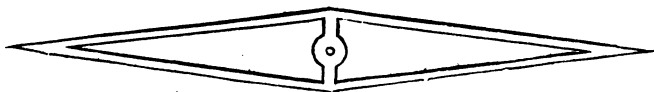
(865) The questions—Which is the best form, and What the best construction of compass needles, have been frequently discussed, and many valuable experiments have been made on the subject; the most important perhaps are those of Captain Kater and Dr. Scoresby.

The principal inferences to be drawn from the experiments of the former are the following (*Phil. Trans.*, 1821.)

1°. That the best material for compass needles is clock spring, but care must be taken in forming the needle, to expose it as seldom as possible to heat, otherwise its capability of receiving Magnetism will be much diminished.

2°. That the best form for a compass needle is a pierced Rhombus

Fig. 301.



in the proportion of about 5 inches in length to 2 inches in width, this form being susceptible of the greatest directive force.

3°. That the best mode of tempering a compass needle is first to harden it at a red heat, and then to soften it from the middle to about 1 inch from each end, by exposing it to a heat sufficient to cause the blue colour which arises again to disappear.

4°. That in the same plate of steel of the size of a few square inches only, portions are found varying considerably in their capability of receiving Magnetism, though not apparently differing in any other respect.

5°. That polishing a needle has no effect on its Magnetism.

6°. That the best mode of communicating Magnetism to the needle appears to be by placing it in the magnetic meridian, joining the opposite poles of a pair of bar magnets (the magnets being in the same line), and laying the magnets so joined flat upon the needle with their poles upon its centre; then having elevated the distant extremities of the magnets, so that they may form an angle of about 2° or 3° with the needle, they are to be drawn from the centre of the needle to its extremities, carefully preserving the same inclination, and having joined the poles of the magnets at a distance from the needle, the operation is to be performed 10 or 12 times on each surface.

7°. That in needles of from 5 to 8 inches in length, their weights being equal, the directive forces are nearly as the lengths.

8°. That the directive force does not depend upon the extent of surface, but in needles of nearly the same length and form, is as the mass.

9°. That the deviation of a compass needle occasioned by the attraction of soft iron, depends, as Mr. Barlow has advanced, on extent of surface, and is wholly independent of the mass, except a certain thickness of the iron amounting to about 1/4ths of an inch, which is requisite for the complete development of the attractive energy.

(866) The pierced Rhombus was the form of needle used in merchant ships previous to the researches of Dr. Gowan Knight in 1750. This form he considered objectionable, as likewise the needle employed at that time in the Navy, which was a single piece of spring tempered steel, broad towards the ends, which were pointed, and tapering towards the middle; and he proposed as the most advantageous form, that of a regular parallelopiped, or straight narrow-edged bar, hardened throughout and suspended upon an agate attached to its under surface, and this kind of needle is now usually employed.

(867) The general results of Dr. Scoresby's experiments on the magnetical capacities and powers of steel plates adapted for sea compasses, have already been given. The following is a more complete resumé of his investigations.

1°. For single bar needles exceeding in weight 400 to 500 grains, the 6-inch bar, *hard* cast steel; for lighter needles, the directive energy is improved by annealing.

2°. The most energetic *cast* steel is that from Bradford iron; next comes *shear* steel SS, or of *hoop* L iron; then *blister* steel *hoop* L; and lastly *cast* steel *hoop* L.

3°. *Thin* plates of cast steel for single needles have their magnetical capacities improved by annealing in oil, at a temperature of from 500° to 550°.

4°. A great advantage is gained by employing two or more thin plates not in contact, but separated from each other; the plates being either of hard shear steel, or of slightly annealed cast steel.

(868) The compass recommended by the Committee of Inquiry appointed by the Admiralty is constructed in accordance with Scoresby's principles. It consists of 4 compound magnetic bars secured together with a card within a light ring of brass: the card is made of mica, and covered with thin paper, on which the impression of the cardinal points is printed; the caps are of agate or ruby, and the points of suspension of native alloy; the bowl is made of copper. It is a beautifully constructed instrument, but costly, and is said to be not very steady at sea.

(869) Sir William Harris's compass, which is also used in the Navy and by the Honourable East India Company, is thus constructed by the patentees, Messrs Lilley and Son, Opticians, Limehouse. The needle is a simple light bar magnet, from 5 to 7 inches in length, turned on its edge, and mounted on an agate centre. It is regularly and accurately formed, hardened and tempered throughout, and previous to being magnetized is nicely balanced in a horizontal position; in this state two small silver sliders are placed on each arm equally distant from the extremities and centre of the bar. When the bar is made magnetic, it is magnetized in such a way, that the centre of the magnetic forces falls in the line of the point of suspension, and any inclination in the direction of the dip is corrected by moving one of the sliders a little towards the centre on one arm, and a little from the centre on the other arm. By this new distribution of the matter, the bar is again brought into a horizontal position, and all undue tendency to an oscillating or swinging motion so far avoided, for there is still as much matter to be moved on one arm of the lever as on the other, whilst the change of the angular inertia of the sliders is so small that

it may, for all practical purposes, be neglected in the calculation. The needle, though light, has considerable magnetic power, lifting at either pole three times its own weight of iron, and producing according to Scoresby's method of deflections, a deviation of 22° at a distance of twice its length from the centre of the trial needle.

The needle and card are placed closely within a dense ring of pure copper, the influence of which, as has been already shown (785) is to bring the needle rapidly to rest in its meridian, whenever from any cause it is put into a state of oscillation; so that the effect of disturbing forces on the card (a very light disc of talc), such as that of a ship's motion at sea, is checked at the instant without the aid of mechanical restraint,* and the needle is thus prevented from moving out of its natural position, at least to any inconvenient extent, by means of an invisible agency, and without any interference with its directive property. This effect of the copper ring in calming the oscillations of the compass, may be immediately seen by attracting the needle aside 90° from its meridian, with a small piece of iron, and allowing it to swing from that point, when it will be observed to be rapidly reduced to rest at each swing. Thus in an experiment described by Messrs. Lilley, a needle and card of 7 or 6 inches in diameter, were observed in an open space to make 25 swings and to occupy 200 seconds, in coming to rest from an angle of 90° , whereas within a ring of copper, it came to rest in 5 swings and only occupied 40 seconds. The needle point is centrally fixed in a transverse bar placed as a diameter to the ring of copper. Should the point wear, or be damaged from any cause, it may be unscrewed and screwed in the reverse way, the point being a double one. The cap also can be renewed when requisite. The compass kettle is fitted with faces of plate glass, so that the card may be lighted from below or above it. These compasses can be fitted to any binnacles, and adapted to any locality of situation on board. When the horizontal position of the card is disturbed by any alteration of dip incidental to a change of latitude, it is to be corrected by moving the silver sliders on the needle.

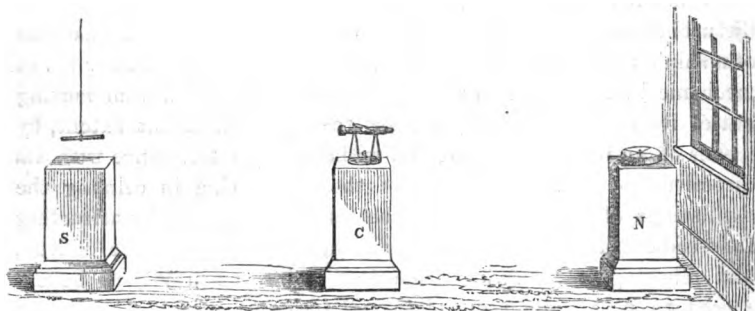
(870) This compass, which has now been in use for some years, appears to fulfil all the conditions requisite to the full practical conditions of the mariner's compass. In the heavy seas about Cape

* Sir William Harris has investigated the magnetic conditions of this phenomenon (*Phil. Trans.*, 1831), and has shown that the restraining force with a magnet of a given power, is as the quantity of the copper within the sphere of action directly, and as the squares of the distances from the magnetic polar extremity of the needle inversely.

Horn and the Cape of Good Hope, the card was not found to oscillate more than from $\frac{1}{4}$ to $\frac{1}{2}$ a point each way, and it has been found to be especially steady in steam ships fitted with the screw propeller.

(871) The following is the method of testing the compasses intended to be employed in H.M.'s ships, as adopted in the Observatory at Woolwich.*

Fig. 302.



Three pedestals, S N C. (Fig. 302), are firmly fixed in the room, quite independent of the floor, in the line of the magnetic meridian. The pedestal S carries a suspended magnet, which is observed by means of a transit telescope fixed on the centre pedestal, C; on the pedestal N is placed the compass to be examined. The collimating magnet S consists of a hollow steel cylinder $\frac{1}{4}$ an inch in diameter and about 6 inches in length, centrally suspended in an appropriate frame by a long silk fibre; a small lens is fixed in the N. end of the cylinder, and there is an extremely fine scale of 160 divisions traversing it horizontally and right across its centre. The transit on the central pillar C being duly adjusted and directed in the axis of the collimating magnet, its scale is observed to vibrate across fine filaments of spider's web fixed perpendicularly in the tube of the telescope. The magnetic meridian being found by these means, the transit is turned over and directed towards the N. upon a mark painted on a distant wall on a rising ground called Cox Mount; this mark corresponds to the line of the collimating magnet on pedestal S; we thus transfer over, as it were, the line of the magnetic meridian, as taken in the telescope, upon the compass to be examined, and which is placed on the pedestal N. The needle and card being removed, the compass is so adjusted in position by the appropriate apparatus on which it rests, as to bring the point of suspension of the needle in the line of the telescope, and so bisect it; this done,

* Harris's "Rudimentary Magnetism," Part III., p. 157.

the card is replaced, and its N. pole is made also to coincide with the line of the telescope.

For the adjustment of the azimuth compasses there is a set of graduated divisions painted on the distant wall, and the vertical line of the telescope is conveyed through the window so as to cut these divisions; the prism is now adjusted for the zero point of the card, the hair line of the sight vane being directed to the particular division on the wall cut by the vertical line of the telescope.

The pivots, caps, and gimbals, and the metal of the compass bowl, &c., are now carefully examined; also the magnetic power of the needles, which are tested by a standard magnetometer of deviation, so that errors liable to arise in any particular instrument are certain to be detected.

(872) *Local Attraction*.—From what has been said respecting the temporary magnetic condition of iron under the influence of terrestrial magnetic induction, it is obvious that the compasses in ships must be subject to derangements from the large masses of iron, guns, anchors, cables, &c., on board. These derangements amount sometimes to 15° or 20° , and have exposed the vessel to the most imminent perils; indeed, there can be little doubt but that some of the most dreadful shipwrecks which are to be found recorded in our naval annals are to be ascribed to this. The loss of H.M.'s ships *St. George*, of 98 guns; *Defiance*, 74; and *Hero*, 74, in the winter of 1811-12, are cases in point. The *Hero* sailed December 18th, 1811, from Wingo Sound in the Cattegat, and instead of standing well to the westward to compensate for the deviation of the compass and the action of a north-easterly wind, steered directly the *compass course* for the Downs, the consequence was that she struck the ground in a heavy squall of wind and sleet upon Haak Sand near the Texel Island, and soon went to pieces, all on board, with the exception of eight, perishing. The *St. George*, which had been dismasted in the Baltic, attempted together with the *Defiance* to perform the same passage, unfortunately both steering a direct compass course; both ships went on shore on the western coast of North Jutland; of the crew of the former only eleven, and of the latter only six men were saved. The number of persons who suffered in these three ships, including the whole of the officers on board, amounted to nearly 2,000, being a greater loss of life in British seamen than has occurred in some of the most splendid battles in which our fleets have been engaged. In iron ships the disturbance is far more serious than in vessels built of wood; it is sometimes indeed so great as to render the compass nearly useless. Messrs. Lilley, for instance, observed in the steam ship *Shanghai*, one of the vessels of the Peninsular and Oriental Company,

a deviation, with the ship's head to the S., amounting in the binnacle to $171^{\circ} 34' W.$, being more than 15 points.

(873) A subject of such serious, we may say of such national importance, has demanded the particular attention of scientific men, but although many useful investigations have been made, the problem of compensation for local attraction as regards iron ships is not as yet satisfactorily solved. We have already alluded to Professor Barlow's "neutralizing or correcting plate," and as this method of compensation has, for wooden vessels, proved in practice eminently successful, we will now give a more particular account of the instrument (*Encycl. Brit.*, Art. Magnetism). T is a rod of copper

Fig. 303.

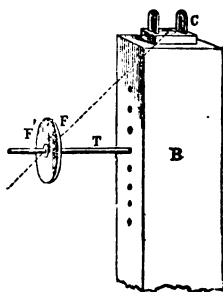
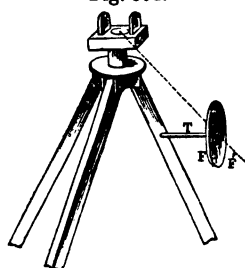


Fig. 304.



$1\frac{1}{2}$ inches in diameter, and FF' two plates of iron about 12 or 13 inches in diameter, and of such a thickness that a square foot of it will weigh about 3 lbs. avoirdupois; these plates are separated by a circular sheet of card, and pressed against each other at their centre by a screw on the end of the rod T, and at their margins by 3 small screws of iron. The compass C is placed on the top of a wooden box B, and the corrector T, is placed in one of the holes in the side of the box.

The adjustment of the plate is made when the ship is lying in a calm bay near the shore; an observer with a needle and theodolite is placed at some distance from the shore, from which he can perceive the ship while she is turning her head in different directions. The compass on board the ship is under the management of another observer, with the same apparatus. At a signal given, the observer determines the angle which his own needle makes with the axis of the telescopes (one being directed to the other), which is called the central line. But as the needle on shore experiences no disturbing action, it is evident that if the needle on ship-board also experience none, the two needles will be parallel, and will form the same angle with the central line. Hence the difference between these two

angles, when they are not the same, is that which is produced by the magnetic action of the iron in the vessel from its compass needle at the instant of observation. The vessel is now made to turn round completely, and a new observation is made at every azimuth of 10 or 12 degrees; the value of the deviation produced in all positions of the ship's head upon the compass needle is thus obtained. When this is done, the observer on shore takes away his compass, and replaces it with that of the ship, which he sets on the wooden cage (Fig. 303), having different holes for receiving the axis T of the plate F F'. As the box is turned round its axis, it carries along with it the compensator F F', which will affect the needle of the compass C differently in different azimuths; and by a few trials it may be adjusted by means of the holes of its axis T to produce the very same deviations in the compass as was produced upon it when in the ship by the action of the iron. When it is done, the position of the centres of the plate F F' with regard to the needle is completely marked, and when it is taken on board the ship, and placed in its proper position, the compensator is adjusted on the stand which carries the compass, so as to have exactly the same relative position as it had in the box D.

Now since the compensator produces the same effect as the iron on shipboard does, the deviation will be *doubled* in place of being corrected; but this furnishes the means of making the correction. If the variation is found to be 36° W. by the compass *without the compensator*, and afterwards 40° with the compensator, the difference $40^{\circ}-36^{\circ}=4^{\circ}$ shows that the compensator augments the variation 4° , and the iron on board the vessel as much. Hence the true variation will be $36^{\circ}-4^{\circ}=32^{\circ}$, or $40^{\circ}-4^{\circ}-4^{\circ}=32^{\circ}$. If the observations with the compensator had given a less result than without it, this would have shown that the action of the iron had diminished the declination, and the difference of the two observations must have been added to the first to have the true declination.*

(874) *Local Attraction in Iron Ships*.—It had been noticed by Captain Johnson that an iron ship operates on the compass needle in the same manner as a permanent magnet placed outside the vessel; this observation induced the Astronomer-Royal to direct his attention to the subject with a view to the discovery of some method of correcting the local attraction in iron vessels. The results of his inves-

* This method of correcting the compass for local attraction is not, we believe, now adopted in the Royal Navy. Either tables of errors are constructed for each ship, or the card is distorted so as to correspond with the true magnetic direction of the ship's head, the vessel being swung upon the different points of the compass.

tigations were communicated to the Royal Society, and are published in the Transactions for 1839. The experiments were made on board the iron steam ship *Rainbow*, and the iron sailing ship *Ironsides*. For the purpose of ascertaining the laws of the deviation of the compass, four stations were selected in the vessel, about 4 feet above the deck, and at these the deviations of the horizontal compasses were determined in various positions of the ship's head. All these stations were in the vertical plane, passing through the ship's keel, three being in the after part of the ship, and one near the bow. Observations were also made for determining the horizontal intensity at each of the stations. The deviations of dipping needles at three of these stations were also determined, when the plane of vibration coincided with that of the ship's keel, and also when at right angles to it. The most striking feature in the results as to the disturbance of the horizontal compass at the four stations, was the very great apparent change in the direction of the ship's head as indicated by the compass nearest the stern, corresponding to a small real change in one particular position; the former change being 97° , whereas the latter was only 23° ; and the small amount of disturbance indicated by the compass near the bow.

Any attempt to discuss Mr. Airy's elaborate mathematical investigation would be quite foreign to the object of this work.

(875) The fundamental supposition of the theory of induced Magnetism on which he rests his calculations is, that by the action of terrestrial Magnetism, every particle of iron is converted into a magnet, whose direction is parallel to that of the dipping needle, and whose intensity is proportional to that of terrestrial Magnetism; the upper end having the property of attracting the N. end of the needle, and the lower end that of repelling it. He deduces the following simple rule for the correction of a compass disturbed by the induced Magnetism only of the iron in a ship:—

1. Determine the position of Barlow's plate with regard to the compass, which will produce the same effect as the iron in the ship.

2. Fix Barlow's plate at the distance and depression determined by the last experiment, but in the opposite azimuth.

3. Mount another mass of iron at the same level as the compass, but on the starboard or larboard side, and determine its position so that the compass points correctly when the ship's head is N.E., S.E., S.W., or N.W.; then the compass will be correct in all positions of the ship's head, and in all magnetic latitudes.

When the disturbing iron of the ship is at the same level as the compass, the correction is stated to be much more simple, it being then only necessary to introduce a single mass of iron at the star-

board or larboard side, and at the same level as the compass; but in the construction of the ship, and in the fixing of correctors, no large mass of iron should be placed below the compass.

(876) In his experiments on the ship *Ironsides*, Mr. Airy corrected one of the compasses by a tentative process, which he considers likely to be of the highest value in the correction of compasses of iron ships in general. The ship's head being placed exactly N. as ascertained by a shore compass, a magnet was placed upon the beam from which the compass was suspended, with the direction of its length exactly transverse to the ship's keel; it was moved upon the beam to various distances, till the compass pointed correctly, and then it was fixed. Then the ship's head was placed exactly E. and another magnet, with its length parallel to the ship's keel, was placed upon the same beam, and moved to different distances till the compass pointed correctly, and then it was fixed. The correction for induced Magnetism was neglected, but there would have been no difficulty in adjusting it by the same process, placing the vessel's head in azimuth 45° , or 135° , or 225° , or 315° . The deviations of the compass are caused by two modifications of magnetic power; the one being the independent Magnetism of the ship which retains, in all positions of the ship, the same magnitude and the same direction relatively to the ship; the other being the induced Magnetism, of which the force varies in magnitude and direction when the ship's position is changed. In the cases investigated by Mr. Airy, the effect of the former force was found greatly to exceed that of the latter. The most remarkable result, in a scientific view, of Mr. Airy's investigation, is the great intensity of the permanent Magnetism of the malleable iron of which the ship is composed. It appears, however, that almost every plate of rolled iron is intensely magnetic.

(877) The Rev. Dr. Scoresby, whose unceasing labours in the service of practical magnetics we have had occasion repeatedly to refer to, has devoted much study to the variation of the compass in iron vessels.* He considers that the adjustment of the compasses of iron ships by fixed permanent magnets is not only delusive but dangerous. Iron becomes magnetic by virtue of the inductive influence of the earth, but its Magnetism might be controlled, altered, or destroyed, by mechanical action (859—861). Applying this to the case of iron ships, Dr. Scoresby considers that, in consequence of the percussive action to which the material is exposed while the ships are in course of construction, it becomes as intensely magnetic as it

* Vide "Magnetical Investigations," vol. ii.; also, Reports of the Proceedings of the British Association at Oxford in 1847, and at Liverpool in 1854.

is possible for malleable iron to do. This augmented Magnetism is not, however, permanent or fixed, but under different circumstances as to the relative deviation of the ship's Magnetism and that of the earth, is easily changeable, and liable necessarily to be changed. Experiments on rolled iron plates of the same kind as those of which ships are generally built, showed that in them the Magnetism was changeable and controllable like that in bar iron under the requisite change of position, by vibratory or percussive action. Dr. Scoresby likewise made experiments on a portion of a plate cut out of the side of a ship recently built, and the results of his observations was to establish the fact that, besides the two denominations of Magnetism ordinarily received, that of simple terrestrial induction, and that of permanent independent Magnetism, there was another denomination corresponding with neither, not being absolutely controllable, like the former, by terrestrial influences, nor capable, like the latter, of resisting all kinds and modes of mechanical violence. To this denomination he gives the name of *retentive* Magnetism. The vibration of a ship in a heavy sea is sufficient to change the original Magnetism developed and augmented in the course of her construction. A great deal will depend on the position in which the ship has been built. If, for instance, she has been built with her head to the N.E., she will have a certain magnetic distribution, but when she begins to strain with her head to the S.W., that distribution will become changed, and the first effect will be to alter the compasses adjusted by fixed magnets. All attempts, therefore, to adjust a transient influence by a permanent one, only aggravate the error which it is sought to overcome, and captains of ships should lose no opportunity of correcting and verifying their compasses whenever the sun or a star is in sight. A compass should likewise be kept aloft, as far as possible from the iron of a ship, as a standard for reference. Another objection that has been raised to the Astronomer-Royal's system is, that the magnetic poles of the compensating magnets are liable to change or vary in their intensity.

The Magnetism of iron ships is thus changeable in all its qualities, the most enduring being of a description changeable under severe straining and mechanical violence; this Scoresby calls "*retentive Magnetism*." His suggestions are:—

1°. A standard azimuth compass to be placed on a high pedestal where (on the Admiralty plan) a position of small deviation may be found.

2°. A compass at the mast-head for reference will be best of all.

3°. The wheel compass required for ships engaged in the home trade, or traversing mainly parallels of latitude, not southward of the

Mediterranean, if adjusted with magnets and pieces of iron, may not then be unsafe, where reference may always be had to the standard for verification.

4°. No standard compass in great distances.

5°. Care in selection of compasses to have ample directive force. His improvement had trebled the directive force weight for weight of the compasses used in the Navy up to 1849 or 1850.

6°. Captains should be made to take observations for verifying their compasses by azimuth compasses, stars, position of land, &c.

7°. Captains should have a special knowledge for the charge of iron ships; for here, in addition to the ordinary dangers of navigation, is a new source of error and misguidance, as to which it is most important he should never be thrown off his guard.*

* A most lamentable instance of the loss of an iron ship in consequence of changes in the action of her compasses, occurred in the early part of the year 1854. The circumstances were as follow: The ship, *Tayleur*, a new vessel bound to Australia, sailed from Liverpool on Thursday, 19th January; she was 1,979 tons burden new measurement, and she had on board 458 passengers—the crew and passengers together making a total of 528 persons. She left the Mersey about noon, and the pilot left her between seven and eight o'clock in the evening in a position between Point Lynas and the Skerries. On Friday she encountered very heavy weather, and about eight o'clock on the following morning it was for the first time ascertained that there was any material difference between her compasses. One was near the helmsman, and was the one by which he was steering; the other was near the mizen mast. Both of these compasses had been adjusted by permanent magnets, so that if the principle of adjustment had been correct, they should not either have changed or differed from each other. Trusting to the compass near the helmsman, the captain had the idea firmly impressed upon his mind that he was sailing fairly down almost mid-channel; at all events, in a good position for navigating the Irish channel. The other compass indicated a difference of about two points; the captain, however, judging from certain indications which he had noticed previously, assumed that the wheel compass was the correct one. In the course of a few hours—about half-past eleven o'clock on the same morning—the wind having increased and a heavy sea setting up the channel, the ship made rather a rapid progress, when they came suddenly in sight of land on the lee beam in such a position that there was necessarily a great difficulty—in this case (according to the measures pursued), an insurmountable difficulty—in avoiding the land. An attempt was made to wear the ship round; this failed, and then an attempt was made to use the anchors to bring her up. Both the cables snapped on the occasion, and the ship was thus left helpless, driving broadside upon the rocks of Lambay Island. The result was the fearful catastrophe of the loss of about 290 lives! Inquiries were instituted by the Board of Trade in two departments; one by means of Captain Walker of the Navy, who ascribed the loss of the vessel to the captain's supposition that the compass by the helm was correct; the other by means of the Marine Board of Liverpool, who reported that although the captain had given very great attention to the ascertaining of the correctness of his compasses, yet the *Tayleur* was

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(878) To these observations of Dr. Scoresby, Mr. Airy has made a reply (*Athenæum*, Oct. 28, 1854) to the following effect: He objects to the term "retentive" or "retained" Magnetism, as representing the characteristics of the Magnetism of wrought iron plates, which appears to him to differ very little from the Magnetism of hard steel bars. Both are magnetized by induction, and both are liable to have their Magnetism weakened or reversed; but as in practice the Magnetism of an iron ship is slightly more liable to change than that of a carefully preserved steel bar, he would call it "sub-permanent polar." He thinks it likely that the striking character of Dr. Scoresby's experiments, produces an impression of the extent of their applicability to iron ships, far greater than is warranted by careful consideration. We may speak poetically of the shocks which a ship receives from the waves, but, in reality, the plates of iron of which a ship is composed sustain no such shocks. The direct effect of the most violent sea upon them is this: that in the course of two or three seconds of time, the plate is plunged 5 or 6 feet deeper in the water, and sustains the corresponding hydrostatic pressure. This is very different indeed from the raps or slaps in Dr. Scoresby's experiments, in which it is essential that the blow be of the nature of *impact*, occupying a very small fraction of a second of time. Probably the strain of extension to which the plates are subjected may produce a greater effect; on this, however, experiments are wanting. But even here the change in the state of extension is not sudden, but gradual. The tremor produced by steam power is more likely to affect the plates in some parts of the ship. It is evident that there are causes in action tending to produce effects like those exhibited in Dr. Scoresby's experiments; and it is equally evident that the action of those causes must be exceedingly slow. The change to be expected in a ship's sub-permanent Magnetism in sailing from England to the Cape of Good Hope, does *not* essentially depend on her passing into another magnetic hemisphere. It *does* depend mainly on this circumstance: that supposing her to have been built with her head to the north, or in the line of *boreal* Magnetism, she is then turned with her head to the south, or in the line of *austral* Magnetism, and is so kept exposed to slight tremors for one or more months. If she had been moored off the coast of Portugal for the same time, in the same position, and exposed to the same tremors, Mr. Airy believes that her Magnetism would have undergone nearly the same change

brought into the dangerous position in which the wreck took place, through the deviation of the compasses—the cause of which, they (the Marine Board) had been unable to determine.—*Report of the Twenty-fourth Meeting of the British Association, Liverpool—Athenæum.*

(as regards horizontal deviation of the compass) as in the voyage to the Cape of Good Hope.

(879) Mr. Airy adverts to the following two sources of error to which his method of correcting compasses may be liable, if due care is not exercised. The first is, that captains are hardly aware that a very trifling disturbance in the position of the compass (for instance, a change of a quarter of an inch in the height) may very greatly disturb the neutralizing influence of the magnets. The second is, that the artists who correct the compasses are too much inclined to place the correcting magnets in the position called "end on." In this position the magnet exerts greater deflective power, but it also introduces a force perpendicular to the ship's deck; and this force, when the ship reels, produces an uncorrected horizontal disturbance. While the building in iron was principally confined to paddle steam ships, this was not important; but now, when so many screw steam ships and sailing ships are built of iron, this arrangement ought never to be used.

(880) To the important question—What (under all circumstances) is it best to do now? Mr. Airy answers by asserting, in the first place, that the source of local disturbance and its laws are perfectly well known; that the disturbance can be neutralized by well known means to the greatest exactness; and that this neutralization is perfect during change of time and change of place, until the ship herself undergoes an organic change. In the next place, he protests strongly against the system now generally in use in the Royal Navy, of using a table of errors, and thus constantly making numerical corrections, instead of at once making a mechanical correction. 1°. It is baffling to the mariner. 2°. It is liable to exactly the same errors, in the event of a change in the ship's sub-permanent Magnetism, as the system relying on the mechanical correction. 3°. It is liable to errors peculiar to itself, which would be entirely avoided by the use of mechanical correction. 4°. In extreme cases it cannot be used at all; thus, in the Greenland seas the compasses would sometimes turn round with the ship; whereas, there are in the Greenland seas several iron ships with correcting magnets effecting their purpose successfully. 5°. In cases not so extreme, the inconvenience is intolerable; thus, in one instance which came under Mr. Airy's own eyes, the compass changed 100° with a very small motion of the ship; and the directive intensity in one position was only $\frac{1}{16}$ th of what it was in another position: these inconveniences are entirely remedied by the correcting magnets.

(881) After a due consideration of the whole matter, Mr. Airy has come to the following conclusions: For voyages of moderate

duration, as, for instance, not farther than to the Mediterranean, or to the northern parts of N. America, no improvement can be made in the existing system, except in the details above alluded to. The "end on" position of the magnets ought to be forbidden, and some attention ought to be given to the ship's sub-permanent Magnetism in the direction perpendicular to the deck. For voyages of greater duration, as to the Plata, the Cape of Good Hope, &c., he thinks it desirable that means should be provided for enabling the captain to make the small changes which may be required in the correcting magnets, and he undertakes to point out a practical course by which this can be effected. He thinks that some general supervision should be exercised by the Board of Trade over the correction of the compasses in iron ships, and that the Marine Board of Liverpool should interest themselves in the matter. He volunteers his assistance, and expresses his conviction that with the sanction of one liberal ship-owner, the aid of one intelligent captain, and the command of one ship for a few days, he could arrange everything with good hope of complete success. The above remarks are intended to apply to *iron*-built ships only, in which the sensible part of the disturbance of the compass is produced almost entirely by the ship's sub-permanent Magnetism. In wood-built ships, in which the *induced* Magnetism is the principal disturbing power, the rules of correction are necessarily different; here, however, Mr. Airy also disapproves of the use of a table of errors, and prefers that of mechanical correction; the nature of which, as applicable to the neutralization of induced Magnetism, is perfectly understood.*

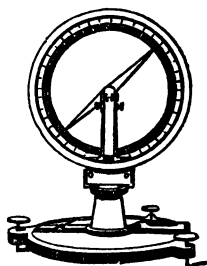
(882) *The Dipping Needle*.—The important fact that a magnetized needle when allowed perfect freedom of motion endeavours to place itself in the plane of the magnetic meridian in a direction more or less inclined to the horizon, was discovered about the year 1756, by Robert Norman, an optician, of London; but many years elapsed before it was known that this inclination of the needle was subject to a variation; this interesting fact has, however, been well ascer-

* Dr. Scoresby has undertaken a voyage to Australia with an express view of performing experiments in the southern hemisphere; the directors of the Liverpool and Australian Navigation Company having granted him the use of a state cabin in their splendid screw steamer *The Royal Charter*, a vessel well adapted for investigations of this nature. The masts are of wood. The compasses are so arranged as to check each other. The wheels are, it is said, not likely to influence even delicate experiments. Dr. Scoresby sailed in January (1856).

Mr. Hyde, of the Cumberland Iron Works, Bristol, is reported (*Times*, Tuesday, December 11th, 1855) to have solved the difficulty of the variation of the compass in iron ships, by placing the compass in a neutral position in the vessel where the Magnetism of the iron in the afterpart is exactly balanced.

tained, and various instruments, called *dipping needles*, have been constructed, with a view of ascertaining the amount of the *dip* in different places at the same time, or in the same place at different times; but it was not until the latter end of the last century that sufficient accuracy could be carried into their construction to render them fully competent to the delicate task they were intended to perform. A simple form of the dipping needle is shown in Fig. 305. It consists of a brass plate supported on a flat stand by 3 screws; on this plate is placed a spirit-level for adjusting the plate horizontally; a stout hollow brass pillar rising from the centre of the plate carries a circular box, forming the case of the dipping needle, which turns freely on two finely polished planes of agate.

Fig. 305.



(883) It is very rarely, however, that a needle can be so nicely balanced as to give the exact dip at a single observation. The usual mode of proceeding is, therefore, as follows: Having taken eight or ten observations, turn the needle completely round; viz., if in the first instance the face was towards E., turn it now to W.; if it was before W., turn it to E.; this is very easily effected by the graduations on the lower limb of the instrument. Here, again, the same number of observations are to be taken, in the same manner as above, which, from slight defects of construction, may not agree precisely with the former; let, however, the mean in both cases be preserved by dividing the sum of each set of observations by the number of them. The needle is now to be removed from the box, and its poles inverted by any of the usual methods of magnetizing; so that when replaced on its axis, that end which was before below the horizon will now be above it, and if the needle be correctly balanced, by exactly the same quantity; but if not, as is most likely to happen, we must get two other means, as above, and the general mean of the four will be very nearly, or exactly, the true dip.

(884) It is easy to see how the least possible defect in the axis, or the interposition of the smallest particle of dust will be sufficient to stop the motion of the needle, and lead to inaccuracy in the results; for if we examine the nature of the force by which the needle is brought into its direction, we shall see that it varies as the *sine of the angle* between its true position and that in which it is actually found at any time, and therefore when the needle is, say 15° of its natural position, the lever by which the power is communicated to the needle is only equal to the sine of 15° , or the power of the

terrestrial Magnetism on the needle in this position is to the same when the latter is at right angles to the dip, as radius to sine $15'$, or as $1 : \cdot 0043$. (*Barlow.*)*

(885) *The Variation Compass.*—This instrument being only intended for measuring small changes in the declination of the magnetic needle, either annual or diurnal, is more limited in its arc of vibration, and is generally longer than the needle used for common purposes; it is also furnished with conveniences for reading closer than the ordinary compass; otherwise any needle so mounted and furnished as to be very sensible and capable of being read off to minute divisions, might be used as a variation compass. In general, however, needles intended for this purpose are constructed in a particular manner, having only a very small part of the circle graduated, and the means of distinguishing small changes better suited to the eye than they generally are in common horizontal needles. The place in which the instrument is fixed is required to be particularly firm and steady, and in short, every precaution is necessary to be had recourse to in order to avoid small irregularities, because the changes to be observed are in themselves so small that without the greatest accuracy they may be either overlooked, or the irregularities of the instrument may so combine them, that every attempt to deduce laws from them would be unavailing.†

(886) *The Declination Magnet.*—This instrument as constructed by Professor Gauss, of Göttingen, consists of a prismatic magnetic bar, suspended by untwisted threads of raw silk. To the S. or N. end of the bar a plane mirror is fixed, and it is enclosed in a wooden cylindrical box, which besides the small aperture in the lid for the passage of the thread, has a larger one in the side, which is rather higher and wider than the mirror. Opposite the mirror a theodolite is placed, the vertical axis of which is in the same magnetic meridian with the line of suspension, and at a distance from it of about 16 Parisian feet. To the stand of the theodolite is fixed a horizontal scale of 4 feet in length, divided into single millimetres: it makes a right angle with the magnetic meridian. That point of the scale which is situated in the same vertical plane with the optical axis of the telescope, and which may be called the zero point, is marked out by a fine thread of gold depending from the middle of the object glass, and charged with a

* For a description of a beautiful dipping-needle deflector invented and used by Mr. Fox for measuring the variation and dip of the needle, and the magnetic intensity, see the *Report of the Royal Cornwall Polytechnic Society for 1835*.

† The most perfect variation compass is, probably, that employed by Colonel Beaufoy, for a description of which see *Annals of Philosophy*, 1813.

weight. The scale is fixed at such a height that the image of a portion of it is seen in the mirror through the telescope, the eye-glass of which is adjusted accordingly. At the opposite side from the needle, in the same vertical plane, and at a distance from the telescope equal to that of the image, a mark is fixed serving every instant to ascertain the unchanged position of the theodolite. It is obvious that if all these conditions be fulfilled, the image of the zero point on the scale will appear exactly on the optical axis of the telescope, and that so far as an object of known azimuth is visible at the place of the theodolite, we may by means of this instrument immediately find the absolute magnetic declination. If, on the other hand, these conditions are only partially fulfilled, then generally speaking, the image not of the zero point, but that of another point of the scale, will appear on the optical axis; and if the horizontal distance of the scale from the mirror, have been measured with exactness, it will be easy to reduce the amount of the divisions of the scale to the corresponding angle, and thus to correct the result first obtained. By turning the needle in the stirrup so that the upper surface becomes the lower, the amount of the error of collimation of the mirror may be ascertained with great ease and precision. By this mode of operating the direction of the needle and its variations are determined with the greatest possible precision.

(887) *The Horizontal Force Magnetometer*.—In this instrument, which is intended to measure the changes which occur in the directive force of the needle, the magnetic bar is suspended by two parallel bundles of unspun silk fibres, by twisting which the bar is forced into a position perpendicular to the magnetic meridian, and maintained in *equilibrium* by the opposition of two equal forces; the reactive force of the suspension tending to untwist the silk, and the magnetic force of the bar by which it seeks to recover its normal position. Now, as the first of these forces is constant, it is evident that any change of the latter will give rise to small movements in the position of the bar; these movements are read off by a telescope directed towards a mirror attached to the centre of the bar, and variations in the horizontal magnetic force are thus determined.

(888) *The Vertical Force Magnetometer*.—The object of this instrument is the measurement of the vertical component of the magnetic force and its momentary changes, without knowing which it is impossible to conclude anything as to the real nature, amount, and direction of the perturbative forces. It is a species of magnetic balance in which a needle or magnetized bar placed in the magnetic meridian, is coerced by the action of small weights from its natural

direction to a horizontal one. This condition renders it possible to rest it by knife-edges invariably fixed in, and forming a part of it, on planes of agate, and thus to secure for it in all geographical positions, the same delicacy, sensibility, and freedom of motion which belong to the ordinary balance. Thus coerced, adjusted, and counterpoised, whatever movements take place in it, are referable directly to changes in the amount of the vertical magnetic force which opposes, and in its mean situation neutralizes, the action of the weights. The bar carries over and across its axis a small mirror, and the movement being read off by a microscope and subjected to calculation, affords a measure of the amount of those changes. This beautiful instrument is considered by its inventor, Mr. Lloyd, to be capable of detecting a change to the extent $\frac{1}{100000}$ th of the total magnetic intensity.*

* The labour of registering magnetical observations has been lately relieved by photography—perhaps the most valuable application of that beautiful art. Two methods are in use: that of Mr. Brooke, for a description of which see Bird and Brooke's "*Elements of Natural Philosophy*," p. 271; and that of Mr. Ronalds, for which see *Phil. Trans.*, 1847, p. 111.

CHAPTER XVII.

MAGNETISM—(CONTINUED).

Magnetical observations—Humboldt's researches—The declination of the horizontal needle—Isogonic lines—Periodic variations—Sabine's researches—The inclination of the needle—The magnetic equator—Terrestrial magnetic intensity—Magnetic storms—Theory of terrestrial Magnetism.

(889) In April, 1836, Baron Alexander Von Humboldt addressed a letter to His Royal Highness the Duke of Sussex, President of the Royal Society of London, to solicit the co-operation of that body towards the advancement of the knowledge of terrestrial Magnetism, by the establishment of magnetic stations and corresponding observations, and soliciting it to extend, in the colonies of Great Britain, the line of simultaneous observations; these stations he proposed to be established, either in the tropical regions on each side of the magnetic equator, or in the high latitudes of the southern hemisphere and Canada.

This distinguished traveller had been for many years much occupied with the phenomena of the intensity of the magnetic forces, and the inclination and declination of the magnetic needle. During the years 1806 and 1807, particularly at the periods of the equinoxes and solstices, he measured the angular alterations of the magnetic meridian, at intervals of an hour, often of half an hour, without interruption, during four, five, and six days, and as many nights, in a large garden at Berlin. The instrument he employed was a magnetic telescope (*lunette aimantée*) of Prony, capable of being reversed upon its axis, suspended according to the method of Coulomb, placed in a glass frame, and directed towards a very distant meridian mark, the divisions of which, illuminated during the night, indicated even six or seven seconds of *horary* variation. In verifying the habitual regularity of a *nocturnal period*, he was struck with the frequency of the perturbations, especially of oscillations, the amplitude of which extended beyond all the divisions of the scale, and which occurred repeatedly at the same hours before sunrise, the violent and accelerated movements of which could not be attributed to any acci-

dental mechanical cause. These vagaries of the needle, the almost periodical return of which were subsequently confirmed by M. Kupffer, appeared to Humboldt the effect of a reaction of the interior of the earth towards the surface of *magnetic storms*, which indicate a rapid change of tension. From that time, he says, he has been anxious to establish on the E. and W. of the meridian of Berlin apparatus similar to his own, in order to obtain corresponding observations, made at great distances, and at the same hours.

(890) In 1827, Baron Humboldt renewed these observations at Berlin, and endeavoured at the same time to generalize the means of simultaneous observations, the accidental employment of which had produced such important results. One of Gambey's compasses was placed in the *magnetic pavilion*, in which no portion of iron was introduced, which had been erected in the middle of a garden. At his request, the Imperial Academy and the curator of the University of Cazan, erected *magnetic houses* at St. Petersburg and at Cazan, and the Imperial Department for Mines having concurred in the same object, *magnetic stations* were successively established at Moscow, Barnaoul, and at Nertschinsk. The Academy of St. Petersburg did still more, and sent a courageous and clever astronomer, M. George Fuss, the brother of its perpetual secretary, to Peking, and procured the erection there of a *magnetic pavilion* in the convent garden of the monks of the Greek church. Subsequent to the return of M. Fuss, M. Kowanko continued the observations of horary declination, corresponding to those of Germany, St. Petersburg, Cazan, and Nicolajeff in the Crimea, where Admiral Greigh had established one of Gambey's compasses, the care of which was confided to the director of the observatory, Mr. Knorre. A magnetic apparatus was also established at the depth of 35 fathoms, in an adit in the mines of Freiberg, in Saxony, where M. Reich, to whom we are indebted for valuable experiments and observations upon the mean temperature of the earth at different depths, made observations at regulated intervals. Observations of horary declination, made at Marmato, in the province of Antioquia, in South America, in N. latitude $5^{\circ} 27'$, in a place where, as at Cazan, and Barnaoul in Asia, the declination is E., have been transmitted by M. Boussingault; while on the N.W. coasts of the new continent, at Sitka in the Russian settlements, Baron Von Wrangal, also provided with one of Gambey's compasses, took part in the simultaneous observations made at the time of the solstices and equinoxes. Magnetic apparatus were also sent by Baron Humboldt to Havannah and Cuba; and M. Arago erected a compass, at his own expense, in the interior of Mexico, where the soil is elevated 6,000 feet above the level of the sea. A magnetic station in Iceland has also been established.

(891) The suggestions of Baron Humboldt received from the Royal Society the attention which they merited; and a committee was appointed for carrying his recommendations into effect. Conformably with the report made by this committee, the ten following places were fixed on by the council as being the most eligible for carrying on magnetic observations according to the plan recommended by Baron Von Humboldt: Gibraltar, Corfu, Ceylon, Hobart Town, Jamaica, Barbadoes, Newfoundland, Toronto, Bagdad, and the Cape of Good Hope; these places being permanent stations, where officers of engineers and clerks are always to be found. The council also determined that for the present the observations of Magnetism may be limited to those of the direction of the magnetic needle. "I could hardly," says Humboldt ("Cosmos," Sabine's Transl., vol. i., p. 419) "entertain the hope when I first proposed to establish a system of observatories, that I should live to see the time when, thanks to the united activity of excellent physicists and astronomers, and especially to the munificent and persevering support of two governments, the Russian and British, both hemispheres should be covered with magnetic observatories. From Toronto, in Canada, to the Cape of Good Hope and Van Diemen's Land, and from Paris to Peking, since 1828, the globe has been covered by magnetic observatories, in which every movement or manifestation, regular and irregular, of the earth's magnetic force is watched by uninterrupted and simultaneous observation. A variation of $\frac{1}{100000}$ of the magnetic intensity is measured. At certain epochs, observations are taken at intervals of $2\frac{1}{2}$ minutes, and are continued during 24 consecutive hours. A great English astronomer and physical philosopher has computed that the mass of observations to be discussed amounted in three years to 1,958,000. Never before has an effort so grand and so worthy of admiration, been made to investigate the *quantitative* in the laws of one of the great phenomena of nature. . . . I need not dwell on how deeply science is indebted to the great and zealous exertions, on this occasion of Herschel, Sabine, Airy, and Lloyd, and to the powerful support of the British Association for the Advancement of Science at its meeting at Newcastle in 1838. In June, 1839, the Magnetic Antarctic Expedition was determined on, and placed under the command of Captain James Clark Ross. It returned crowned with success and honour; having enriched science with most important geographical discoveries in the vicinity of the Southern pole, with simultaneous observations on eight or ten magnetic term days, and with a determination of the lines of equal declination, equal inclination, and equal force for three-

fourths of the accessible portion of the high latitudes of the Southern hemisphere.”*

(892) The magnetic apparatus with which each station is provided, consists of the three magnetometers above described. Each day is, in the first place, supposed to be divided into 12 equal portions of 2 hours each, commencing at all the stations at the same instants of absolute time, which may be called the magnetic hours, viz., 0 h. 0 m. 0 s., 2 h. 0 m. 0 s., 3 h., &c., of *mean time at Göttingen*, without any regard to the apparent *times of the day at the stations themselves*, which will, of course, differ by their differences of longitude, so that the first magnetic hour which at Göttingen commences at noon will at Dublin (1 h. 5 m. 8 s. *west* of Göttingen) commence at 10 h. 54 m. 52 s.; at Madras (4 h. 41 m. 42 s. *east* of it) at 4 h. 41 m. 42 s. p.m. The magnetometers are read off at the commencement of every magnetic hour, day and night, Sundays excepted; and to multiply opportunities for observing remarkable coincidences, the observation at 2 h. p.m. Göttingen mean time, is in all cases, a triple one, the magnetic readings being thrice repeated in a given order, at intervals of 5 minutes.

(893) The magnetical observatory erected in Dublin under the superintendence of Professor Lloyd, is situated in an open space in the gardens of Trinity College, and sufficiently remote from all disturbing influences. The building is 40 feet in length, by 30 in depth. It is constructed of the dark-coloured argillaceous limestone, which abounds in the valley of Dublin, and which has been ascertained to be perfectly devoid of any influence on the needle. This is faced with Portland stone; and within, the walls are *studded*, to protect from cold and damp. No iron whatever is used

* The following summary of the magnetic observatories co-operating in the proposed plan in 1840, will serve to show the spirit with which the subject was taken up—and many more stations have since been added:—

British Stations.—Dublin, Toronto, St. Helena, Cape of Good Hope, Van Diemen's Land, Madras, Simla, Singapore, Aden, with each ship of the naval expedition under Captain Ross.

Russian.—Boulowa, Helsingfors, Petersburg, Sitka, Catherineberg, Cazan, Bar-naoul, Nertschinsk, Nicolajeff, Tiflis, Peking.

Austrian.—Prague, Milan.

Bavarian.—Munich.

United States.—Philadelphia, Cambridge.

Belgian.—Brussels.

French.—Algiers.

Egyptian.—Cairo.

Prussian.—Breslau.

Hindustan.—Trevandrum.

Russia has ever taken a warm interest in the advance of terrestrial Magnetism: as early as 1829, Humboldt succeeded in procuring the establishment of observatories at most of the above-named places, which have existed ever since.

throughout the building. With reference to the materials, Professor Lloyd mentions, that in the course of the arrangements for the erection of a magnetical observatory at Greenwich, Mr. Airy had rejected bricks in the construction of the building, finding that they were in all cases magnetic, and sometimes even *polar*. Mr. Lloyd has since confirmed this observation, by the examination of specimens of bricks from various localities; and though there appeared to be great diversity in the amount of their action on the needle, he met with none entirely free from such influence.

The building consists of one principal room, and two smaller rooms, one of which serves as a vestibule. The principal room is 36 feet in length, by 16 feet in breadth, and has projections in its longer sides which increase the breadth of the central part to 20 feet. This room contains four principal instruments, suitably supported on stone pillars: viz., a transit instrument, a theodolite, a variation instrument, and a dipping circle. The transit instrument (4 feet in focal length), is stationed close to the southern window of the room. In this position it serves for the determination of the time; and a small trap-door in the ceiling enables the observer to adjust it to the meridian. The theodolite is situated towards the other end of the room, and its centre is on the meridian line of the transit. The limit of the theodolite is 12 inches in diameter, and is read off by 3 verniers to 10 seconds. Its telescope has a focal length of 20 inches, and is furnished with a micrometer reading to a single second, for the purpose of observing the *diurnal variation*.

The variation instrument is placed in the magnetic meridian with respect to the theodolite; the distance between these instruments being about 7 feet. The needle is a rectangular bar, 12 inches long, suspended by parallel silk fibres, and enclosed in a box to protect it from the agitation of the air. The magnetic bar is furnished with an achromatic lens at one end, and a cross of wires at the other, after the principle of the collimator. This is observed with the telescope of the theodolite in the usual manner; and the deviation of the line of collimation of the collimator from the magnetic axis, is ascertained by reversal. The direction of the *magnetic meridian* being thus found, that of the true meridian is given by the transit. It is only necessary to turn over the transit telescope, and using it also as a collimator, to make a similar reading of its central wire by the telescope of the theodolite; the angle read off on the limb of the theodolite is obviously the supplement of the variation. The use of the transit was suggested by Dr. Robinson; and it was anticipated that much advantage would result from the circumstance, that the two extremities of the arc are observed by precisely the

same instrumental means. With this apparatus observations of the *absolute variation* are made twice each day, as is done in the observatory of Professor Gauss, at Göttingen, the course of the *diurnal variation*, and the hours of maxima and minima, having been ascertained by a series of preliminary observations with the same instrument.

A dipping circle, constructed by Gambey, is placed on a pillar at the remote end of the room; and is furnished with a needle, whose axis is formed into a knife edge, for the purpose of observing the diurnal variations of the dip. Gauss's large apparatus is also set up in the same room, and is used occasionally, especially in observations of the *absolute intensity* made according to the method proposed by that distinguished philosopher.

The bars are too large to be employed in conjunction with other magnetical apparatus.

(894) The magnetic force of the earth exhibits itself at the surface in three classes of phenomena: 1st. In a variation in direction shown by the *declination* of the horizontal needle; 2nd. By a variation in the inclination of the needle in a vertical plane; 3rd. By a variation in the intensity of the force. Lines of equal declination are called *isogonic* lines; lines of equal dip, *isoclinical*; and lines of equal force, *isodynamic* lines. The absolute and relative positions of these lines are undergoing continual changes, so irregular and complicated, that a few years suffices to alter their form and position.

(895) *The Declination.* — Measures of the variation of the needle have been taken by navigators and travellers in all parts of the globe. In some places the magnetic and terrestrial meridians exactly correspond; in these situations the needle points to the true N. and S.; but in most parts of the earth's surface its direction deviates, sometimes to the E., and sometimes to the W. We are indebted to Professor Hansteen for the first satisfactory collection of observations on the variation of the needle, and for the first philosophical generalization of them. He has published a variation chart for 1787, in which it is shown how irregular are the causes on which terrestrial Magnetism depends, by the total want of symmetry, and the irregularities and inflexions of the magnetic curves. He makes the *western line of no variation*, or that which passes through all the places on the globe where the needle points to the true N., to begin in latitude 60° to the W. of Hudson's Bay, proceeding in a S.E. direction through the North American Lake, passing the Antilles and Cape St. Roque, till it reaches the South Atlantic Ocean, where it cuts the meridian of Greenwich at about 65° of S. latitude. This line of no variation is extremely regular, being

almost straight till it bends round the eastern part of South America, a little S. of the equator. On the other hand, his chart shows that the *eastern line of no variation* is extremely irregular, being full of loops and inflexions of the most extraordinary kind, indicating the action of local magnetic forces. It begins in latitude 60° S., below New Holland, crosses that immense island through its centre, extends through the Indian Archipelago with a double sinuosity, so as to cross the equator three times; first passing N. of it to the E. of Borneo, then returning to it and passing S. through Sumatra and Borneo, and then crossing it again beneath Ceylon, from which it passes to the E. through the Yellow Sea. It then stretches along the coast of China, making a semicircular sweep to the W. till it reaches the latitude of 70° , where it descends again to the S., and returns northward with a great semicircular bend, which terminates in the White Sea.

These lines of no variation—*agonic* lines as they are called—are accompanied through all their windings by other lines where the variation is 5° , 10° , 15° , &c.; these lines becoming more irregular as they recede from those of no variation. Their position is not stable, being sensibly altered after the lapse of considerable periods of time.

(896) In 1833, Professor Barlow constructed a new variation chart, in which he has inserted the magnetic observations of Commander Ross; and he remarks, that the very spot where this officer found the needle perpendicular, “that is, the pole itself, is precisely that point in my globe and chart in which, by supposing all the lines to meet, the several curves would best preserve their unity of character, both separately and conjointly as a system.”

(897) Hansteen is of opinion, that there are *four points of convergency* in each hemisphere; and that these points are to be considered as the *four magnetic poles of the globe*. He concludes that they have a regular motion round the globe; the two northern ones from W. to E., in an oblique direction; and the southern ones from E. to W., also obliquely. The following are the calculated periods of their revolution:—

The strongest *north* pole in 1740 years.

The strongest *south* pole in 4609 years.

The weakest *north* pole in 860 years.

The weakest *south* pole in 1304 years.

Hansteen considers the four poles as originating in *two* magnetic axes, the two strongest being the termination of one axis, and the two weakest of the other; and he conceives that they may have been produced, either along with the earth itself, or at a later epoch. Accord-

ing to the first supposition, it is not easy to account for their change of position; but according to the last, they must have originated either from the earth alone, or from some external cause. If they originated in the earth, their change of position is still unsusceptible of explanation; and hence Hansteen conceives that they have their origin from the action of the sun heating and illuminating the earth, and producing a magnetic tension as it produces electrical phenomena.

(898) The following table exhibits the progressive changes in the variation of the needle, which have taken place in London from 1576 to 1831, and in Paris from 1541 to 1829, and in Brussels from 1827 to 1849:—

Years.	Observers.	Variations.
London:—		
1576	Norman	11° 15' Easterly.
1580	Burroughs	11 17 Maximum.
1622	Gunter	6 12 "
1634	Gellibrand	4 5 "
1657 } 1662 }		0 0 No variation.
1666		0 34 Westerly.
1670		2 6 "
1672		2 30 "
1700		9 40 "
1720		13 0 "
1740		16 10 "
1760		19 30 "
1774		22 20 "
1778	Phil. Trans.	22 11 "
1790		23 39 "
1800		24 36 "
1806	Phil. Trans.	24 8 "
1813	Col. Beaufoy	24 20 17" "
1815	Ditto	24 27 18 Maximum.
1816		24 17 9 "
1820		24 11 7 "
1823		24 9 40 "
1831		24 0 0 "

Paris:—

1541		7 0 Easterly.
1550		8 0 "
1580		11 30 Maximum.

Years.		Variations.
1603		8° 45' "
1618		8 0 "
1630		4 30 "
1640		3 0 "
1659		2 0 "
1664		0 40 "
1667		0 0 No variation.
1669		0 15 Westerly.
1670		1 30 "
1683		3 50 "
1700		7 40 "
1750		17 15 "
1767		19 16 "
1780		20 35 "
1785		22 0 "
1800		22 12 "
1807		22 34 "
1814		22 54 maximum.
1819		22 39 "
1824		22 33 "
1829		22 12 5" "

—Arago.

Brussels :—

1827	October		22 28 8 Westerly.
1830	End of March		22 25 6 "
1832			22 18 0 "
1833			22 13 5 "
1834	April		22 15 2 "
1835	End of March		22 6 2 "
1836			22 7 6 "
1837			22 4 1 "
1838			22 3 7 "
1839			21 53 6 "
1840			21 46 1 "
1841			21 38 2 "
1842			21 35 5 "
1843			21 26 2 "
1844			21 17 4 "
1845			21 11 6 "
1846			21 41 7 "
1847			20 56 8 "

Years.	Variations.
1848	20° 49' 2" „
1849	20 39 2 „

The declination has thus diminished 2° since 1827.

—*Quetelet.*

The westerly variation of the needle at the observatory at Paris, on the 30th November, 1849, 1 h. 25 m., was 20° 34' 18". The needle began to have a westerly variation in London from 1662. Between 1657 and 1662 the needle pointed due N. and S. at Paris, notwithstanding the small distance between the two capitals; the variation was easterly till 1669, when the needle pointed due N. and S.; since this time the variation has been westerly; it reached its maximum westerly variation about the year 1819, since which time it has been retrograding, and is now moving eastward at the rate (according to Dr. Lloyd) of about 5' annually: the period of the westerly movement is thus about 160 years, and the limit of the angular variation about 24° 27'. At the present time the whole of Europe, with the exception of a small part of Russia, has a W. declination. In Eastern Russia, to the E. of the mouth of the Volga of Saralow, Nishni-Nowgorod, and Archangel, the easterly declination of Asia, is advancing towards us. There are particular parts of the earth's surface, as in the western part of the Antilles, and in Spitzbergen, where the mean declination of the needle has scarcely undergone any sensible change in the course of the last hundred years. Since 1660, the compass has been permanent in Jamaica. "The whole mass of West India property," remarks Sir J. Herschel,* "has been saved from the bottomless pit of endless litigation, by the invariability of the magnetic declination in Jamaica and the surrounding Archipelago, during the whole of the last century all surveys of property there having been conducted solely by the compass.

(899) The variation of the magnetic force, when viewed generally in its operation over the whole globe, does not present the character of an oscillation round a mean value, but appears as a continuously progressive change, and has hence received the name of "*Secular Change.*" Colonel Sabine, whose unceasing labours for the last twenty-five years have thrown so much light on the intricate science of terrestrial Magnetism, has lately (May 18, 1854) presented to the Royal Society a memoir, in which he has at great length discussed the observations of the magnetic declination at the observatory of St. Helena during a period of five years; the following very brief and general abstract of this valuable paper (*Phil. Mag.*) will be read

* "Cosmos." Sabine's Translation, vol. i. p. 410.

with interest, as showing the progress made in unravelling a most obscure subject.

(900) It is possible that the Magnetism of the earth may have its periods; that the phenomena existing at one and the same epoch over the whole surface of the globe, may be identically reproduced at a subsequent epoch; and that, what has been called the *Secular Change* of each of the magnetic elements, which we perceive to be in progress at any particular point of the surface, St. Helena for example, may be part of a succession of changes which operate in a cycle, of which the duration, vast as it may be, may hereafter be found calculable; but as far as our knowledge has as yet gone, it is insufficient to justify the assumption of even approximate periodical laws of this variation of the terrestrial Magnetism, and we must continue to regard it, therefore, for the present, as a secular change of which the period or periods are unknown.

(901) The average rate at which the *Secular change*, as regards *declination*, is taking place at St. Helena, was found by taking the successive differences between the monthly means of all the hourly observations in the first and second month of their continuance; then between the second and third months; and then between the third and fourth, and so on. In this way sixty differences occurred in the five years of hourly observation, by which it was found that the monthly increase of W. declination, during five years amounted on the average to 0.657m., or to an annual increase of 7.88m. A comparison of eight years, gave an average monthly increase of monthly declination of 0.661m., equal to an annual increase of 7.93m. in a solar year. During these eight years, therefore, the horizontal magnetic direction had changed at St. Helena rather more than *one degree*. By comparing eleven of the best determinations of the *declination*, all made at the same spot (the anchorage at St. Helena) by various trustworthy observers from 1610 to 1846, a period of 236 years, the rate of annual increase was found to be 8.05m. and this affords a striking example of the magnitude and character of the change wrought at a particular station, by this very remarkable feature of the earth's magnetic force. In less than *two centuries and a half* the horizontal direction which a magnet takes at St. Helena, by virtue of the terrestrial magnetic force, has been found to have changed more than 30° or more than a *twelfth part of the whole circle*, and this by a steady, equable, and uniform progression throughout the whole period.

(902) The St. Helena observations further show, that the average annual change takes place by certain aliquot portions in each month of the year, and the same features of regularity and uniformity are manifested by comparing together the fortnightly means; the whole

showing the magnitude, the regularity, and the systematic character of the changes, called *Secular*, which are thus produced by forces which are in constant operation at the surface of our planet. In our entire inability to connect these changes with any other of the phenomena of nature, either cosmical or terrestrial, we appear to have no other alternative, than to view them as a constituent feature of the terrestrial magnetic force itself, and as one of its most remarkable characteristics, not to be overlooked by those who would seek to explain the phenomena of that force by means of a physical theory. The attempts which have sometimes been made to explain them by a supposed connexion of the terrestrial magnetic phenomena with the distribution of heat on that surface, or by electrical currents excited by the rotation of the earth on its axis, contain no provision to meet a systematic variation of this nature, and break down altogether when the facts of the secular change are duly apprehended. The phenomena must find a place in any physical theory, which professes to explain the phenomena of the earth's Magnetism. It is indispensable towards the acquisition of a knowledge of the laws of terrestrial Magnetism that the complex phenomena of the secular magnetic change, should be traced out; (and this can only be done by collecting observations similar to those made at St. Helena, at a great number of stations distributed over the earth's surface), and that these should be studied separately and together; in this way order will doubtless be recognized amidst apparent irregularity, and system amidst incessant variation.

(903) By a comparison of the *isogonic* lines (lines of equal magnetic declination), corresponding to different epochs, we perceive that a secular change of the declination, almost identical with that of St. Helena, has prevailed at the same time over the greater part of the Southern Atlantic; and that from the form of the isogonic lines in that quarter of the globe (which has undergone very little variation in the last 200 years), the regularity of its progression, and its persistence in the same direction, is in accordance with that general progressive motion from E. to W., which Magneticians have long since recognized as distinguishing the general systematic change in the southern hemisphere from that in the northern, which takes place in the opposite direction; whilst from the form of the isogonic lines in that quarter we may further anticipate that at St. Helena the secular change in the *declination* will continue to take place in the same direction as at present until a line drawn through the conical summits of the isogonic curves shall in its western progress pass the geographical meridian of that station.

(904) *Periodic Variations*.—The horizontal needle is subject to

annual variations, depending on the position of the sun in reference to the equinoctial and solstitial points, and to *horary* variations corresponding to changes of temperature from the diurnal rotation of the earth.

Between the months of January and April, the magnetic needle recedes from the N. pole of the globe, so that its western declination increases.

From April to the beginning of July, that is, from the vernal equinox to the summer solstice, the declination diminishes, or the needle approaches the N. pole of the globe.

From the summer solstice to the vernal equinox, the needle receding from the N. pole, returns to the W., so that in October it has nearly the same position as in May; and between October and March, the western motion is smaller than in the three preceding months. Hence it follows that during the three months between the vernal equinox and the summer solstice, the needle retrogrades towards E.; and during the following *nine* months its general motion is towards W.

(905) There is also a daily change in the variation of the needle; this was first observed in 1724, by Mr. Graham, and has been confirmed with the most accurate instruments in almost every part of the world. When it was first discovered, the needle was supposed to have only two changes in its movements during the day. About 7 A.M. its N. end began to deviate to the W.; and about 2 P.M. it reached its maximum westerly deviation; it then returned eastward to its first position, and remained stationary till it again resumed its westerly course in the following morning. It was afterwards found that the diurnal motion commences much earlier than 7 A.M., but its motion is E. At $7\frac{1}{2}$ A.M. it reaches its greatest easterly deviation, and then begins its movement W. till 2 P.M. It then returns to the eastward till evening, when it has again a slight westerly motion; and in the course of the night, or early in the morning, it reaches the point from which it set out twenty-four hours before.

(906) The following are the general results of a series of observations taken every two hours, day and night, for between two and three years, at the Dublin Observatory, under Professor Lloyd (*Brit. Assoc. Rep.*, 1843). The mean daily curve of the changes of declination for the entire year exhibits a small easterly movement of the N. end of the magnet during the morning hours, which reaches its maximum about 7 A.M.; after that hour the N. end moves rapidly westward, and reaches its extreme westerly position at 1h. 10m. P.M. It then returns to the eastward, but less rapidly, the easterly deviation becoming a maximum about 10 P.M.; the mean daily range

being equal to 9·8m. During the summer months the morning maximum at 7 A.M. is more marked; the evening maximum, on the contrary, disappears, there being a slow and regular movement of the N. end to the eastward from 7 P.M. until 7 A.M. In winter, on the other hand, the evening maximum is well defined, and the morning maximum disappears, there being a slow and regular westerly movement until 9 A.M., after which, the movement becomes more rapid in the same direction. The epoch of the extreme westerly position of the magnet is nearly the same throughout the year; the greatest daily range in summer is about 13·7m.; the least range in winter about 7·2m.

At Paris, the needle is nearly stationary during the night. At sunrise its N. extremity moves westward, as if it were avoiding the solar influence. Towards noon, or more generally from noon to 3 P.M., it attains its maximum westerly deviation, and then it returns eastward till 9, 10, or 11, P.M.; having reached its original position, it remains stationary during the night. The amount of this daily variation is, for April, May, June, July, August, and September, from 13m. to 15m.; and for the other six months of the year, from 8m. to 10m.: on some days it rises to 25m., and on others it does not exceed 5m. or 6m.

(907) Colonel Sabine has arranged and presented together (*Phil. Trans.*, 1851) the annual variations which the declination undergoes at every hour of the day at the four colonial observatories established by the British Government; at Toronto, from three years' observation; Hobarton, from five years' observation; at the Cape of Good Hope, from five years' observation; and St. Helena from three years' observation. The range of variation at all the four stations is considerably greater during the hours of the day than during those of the night, and a great similarity, though not a perfect identity, is observed at all the stations in the relative amount of the range at different hours. It further appears, that the amount does not progressively enlarge to a maximum at or about noon when the sun's altitude is greatest, or at the early hours of the afternoon when the temperature is greatest, but that at all the stations the increase of the range is most rapid in the first or second hour after sunrise, and that its extent at the hours from 7 to 9 A.M. is not exceeded at any subsequent hour at Hobarton, the Cape, and St. Helena, whilst at Toronto the great enlargement takes place even earlier, the hours of 6, 7, and 8 A.M. being exceeded by none, though they are equalled by a second increase at noon and the two following hours. The second enlargement is perceptible at the same hour at Hobarton and St. Helena.

(908) It was also observed with reference to the relative positions of the several months, at the different hours, that certain months which are found congregated at one extremity of the range during the early hours of the morning, undergo a transfer towards the opposite extremity at a subsequent period of the day. Thus, the months June, July, August, wholly occupy one extremity of the range, and November, December, January, the other extremity in the morning hours, and until from 8 to 10 A.M., when each of the two groups is respectively transferred towards the opposite extremity to that which it previously occupied. The period at which this transfer takes place is somewhat earlier at Toronto and St. Helena than at the Cape of Good Hope or Hobarton. The comportment of the two equinoctial months, March and September, at the Cape of Good Hope and St. Helena, presents a remarkable contrast to that of the two solstitial groups that have been described, and at the same time a still more remarkable contrast to each other; March being at almost all the hours on the W., and September on the E. of the mean time.

(909) Colonel Sabine returns to this most curious subject in his last memoir (*Phil. Trans.*, 1854) while discussing the annual variation at each of the hours at the observatory at St. Helena. Taking the hour of 7 A.M., the order and succession of the several months are as follows: in April, the mean declination is about $\frac{1}{2}$ a minute E. of the mean declination in the year; in May, about 2' E; in June, about 2 $\frac{1}{2}$ ' E.; in July and August, when the sequence is slightly irregular, respectively 2' 1" and 2' 6" E.; in September, the declination is again approaching the mean line, being less than 1 $\frac{1}{2}$ ' E.; in October, it has passed the mean line, being about 1 $\frac{1}{2}$ ' west of it; November, December, January, and February, are congregated near the western extremity of the annual range, whilst in March we perceive that the declination is again approaching the mean line, and in April it has passed to the east of it. We have here, then, in the successive changes in the declination in the course of the year, the general fact of the existence of an annual variation, of which, at the solar hour of 7 A.M., selected as an example, or when the sun is five hours east of the meridian, the phenomena are such as have been thus cursorily described; were there no annual variation of that hour, the different months would all have the same mean declination. The annual variation, however, differs considerably at different hours; but it is a general feature amongst them, that the months on either side of the one solstice are either congregated together towards one extremity of the annual range at the same hour, whilst the months on either side of the opposite solstice are similarly congregated at the opposite

extremity ; or the months of both solstices are contemporaneously in pretty rapid transition from the one extremity to the other.

(910) By projecting in a straight line the *mean* diurnal march in the year, the two *semi-annual* groups formed by grouping together the monthly means of each period of six months separated by the equinoxes, are found to assume a peculiar figure round that line, and what is particularly interesting and remarkable, the figure is so nearly the same at Toronto and Hobarton, that there can be no doubt that they all represent substantially the same phenomenon. During the hours when the sun is above the horizon, and the effects are greatest, the correspondence of the phenomena at the three stations is most striking, and there is no inversion of the phenomena in the opposite hemispheres, in both, as well as at St. Helena, in the tropics, the declination is easterly of the mean in the forenoon, and westerly in the afternoon, when the sun is N. of the equator, and reverse when he is S. The effects are the same at the three stations, though in the one hemisphere the sun being N. of the equator corresponds to summer, and in the other hemisphere to winter. There can be no doubt that this annual variation is attributable primarily to the earth's revolution round the sun in a period of the same duration, and in an orbit inclined to the equator. The similarity of effect amounting almost, indeed, to identity, at the hours when the sun is above the horizon at the station, taking place at stations where both the climatic and the terrestrial magnetic conditions are so dissimilar, seems, (observes Sabine) to remove it altogether from those physical connexions which have so often and in so many various ways, been referred to as affording possible explanations of the magnetic variations. It is evident that the epochs of the sun's passage of the equator have a very marked influence on the phenomena, and the influence is the same, and produces similar effects, whether the station itself be N. or S. of the equator, and however diverse may be its climatic or magnetic conditions.

(911) *The Inclination of the Needle*.—The dip of the needle, like the variation, undergoes a continual change, increasing in some parts of the world, and diminishing in others. The following tables show the changes of the dip at London, since 1720 ; at Paris, from 1671 to 1829 ; and at Brussels, from 1827 to 1849.

London :—

Year.	Observed.	Observer.	Computed.
1720 . . .	74°42' . . .	Graham . . .	76°27'
1773 . . .	72 19 . . .	Heberden . . .	73 40
1780 . . .	72 8 . . .	Gilpin . . .	73 18

Year.	Observed.	Observer.	Computed.
1790 . . .	71°53'	Gilpin . . .	72°39'
1800 . . .	70 35 . . .	ditto . . .	71 58
1810 . . .			71 15
1818 . . .	70 34 . . .	Kater. . . .	70 34
1821 . . .	70 3 . . .	Sabine . . .	. . .
1828 . . .	69 47 . . .	ditto . . .	69 43
1830 . . .	69 38 . . .	ditto . . .	. . .
1833 . . .			69 21

Paris:—

Year.	Dip.	Year.	Dip.
1671 . . .	75° 0'	1818 . . .	68°35'
1754 . . .	72 15	1819 . . .	68 25
1776 . . .	72 25	1820 . . .	68 20
1780 . . .	71 48	1821 . . .	68 14
1791 . . .	70 52	1822 . . .	68 11
1798 . . .	69 51	1823 . . .	68 8
1806 . . .	69 12	1824 . . .	68 7
1810 . . .	68 50	1825 . . .	68 0
1814 . . .	68 36	1826 . . .	68 0
1816 . . .	68 40	1829 . . .	67 41
1817 . . .	68 38		—Arago.

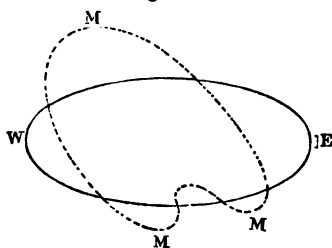
Brussels:—

1827	68° 56' 5"
1830	68 51 7
1832	68 49 1
1833	68 42 8
1834	69 38 4
1835	68 35 0
1836	68 32 2
1837	68 28 8
1838	68 26 1
1839	68 22 4
1840	68 21 4
1841	68 16 2
1842	68 15 4
1843	68 10 9
1844	68 9 2
1845	68 6 3
1846	68 3 4
1847	68 1 9
1848	68 0 4
1849	67 56 8—Quetelet

The magnetic dip reached its maximum in London, in 1720, it being then $74^{\circ} 42'$; it is now, according to observations made at Greenwich, about $68^{\circ} 30'$, so that, during the last 134 years, it has lost $6^{\circ} 12'$, being at the rate of nearly $3'$ each year. The horary variation of the dip is small; according to Hansteen, it is $4'$ greater in the morning than in the afternoon. At Toronto, the inclination on 1st March, 1847, was $75^{\circ} 16' \cdot 09$ with an annual increase of $0' 89$.

—(Sabine.)

(912) *The Magnetic Equator*.—This is an irregular line crossing the terrestrial equator at *four* points, as shown in Fig. (306) where the black line WE, may be supposed to represent the real equator, and the dotted line M M M, the magnetic equator, crossing the former at *four* points instead of two, and showing the evident existence of some great disturbing cause.



(913) MM. Morlet and Hansteen have determined the true form of the magnetic equator with great care; they have traced it over the whole globe, and have found that its motion is from E. to W. in so far as can be determined by direct observations on the position of its nodes. They both place the magnetic equator wholly to the S. of the terrestrial equator, between Africa and America; its greatest southern latitude being at 25° . One node is in Africa, in about 22° of E. longitude, or in 18° according to Morlet. In setting out towards the E. from this node, which is nearly in the centre of that part of the African continent, the magnetic equator advances rapidly to the N. of the terrestrial equator, quits Africa a little to the S. of Cape Guardafui, and in the Arabian Sea it attains its most northerly latitude of about 12° , in 62° of E. longitude; between this meridian and 174° E. the magnetic equator is constantly to the N. of the equinoctial line. It cuts the Indian Peninsula a little to the N. of Cape Cormorin, traverses the Gulf of Bengal, making a slight advance to the equinoctial, from which it is only 8° distant at the entry of the Gulf of Siam. It then reascends a little to the N. almost touches the N. point of Borneo, traverses the Isle of Paragua, the strait which separates the most southern of the Philippines from the Isle of Mindanao, and under the meridian of Naigiou, it again reaches the N. latitude of 9° . From this point it traverses the Archipelago of the Caroline Islands, and descends rapidly to the equinoctial line, which it cuts, according to Morlet in 174° , and according to Hansteen in 187° E. longitude.

There is much less uncertainty respecting the position of a second node, also situated in the Pacific Ocean. Its W. longitude ought to be about 120° ; but while M. Morlet's inquiries lead him to conclude that the magnetic equator merely touches the equinoctial at that point, and then bends again to the south, M. Hansteen makes it cross the line into the northern hemisphere, and continue there through an extent of 15° of longitude, and then return southward, and cross the equinoctial again in about 108° of W. longitude, or 23° from the W. coast of America. This discrepancy between the results of Morley and Hansteen is, after all, very trivial; for in the case just mentioned, the magnetic equator does not go more than $1\frac{1}{2}^{\circ}$ to the equinoctial; and in general the magnetic equator of Morlet differs in no part so much at 2° in latitude from that of Hansteen.

(914) The observations of Captain Duperrey, made on board the *Coquille*, in the years 1822-25, have contributed considerably to our stock of knowledge on the subject of terrestrial Magnetism, and particularly on the form and motion of the magnetic equator. This vessel crossed the magnetic meridian six times, and M. Duperrey was enabled to determine directly two of its points, situated in the Atlantic Ocean. On the chart of Morlet, and in that of Hansteen, the latitudes of those parts, which correspond to the same longitudes, are greater by $1^{\circ} 43'$ and $1^{\circ} 50'$; and hence M. Arago has concluded that the magnetic equator has approached the terrestrial equator by the same quantities. In the South Sea, near the coast of America, Duperrey has determined two points of the magnetic equator. On the charts of Morlet and Hansteen, the latitudes of these points are about a degree smaller, but the difference is in a direction contrary to that which was found in the Atlantic Ocean; from which it follows, that near the coast of Peru, the magnetic equator has removed from the equinoctial line.

(915) In a chart of the equatorial regions, which M. Duperrey has drawn up and published in the *Annales de Chimie*, for 1830, these results are laid down: "That the magnetic equator will meet the equinoctial line only in two points, which are diametrically opposite, the one situated in the Atlantic Ocean, and the other in the great ocean, nearly in the plane of the meridian of Paris. When this equator meets only some scattered islands, it recedes only a little from the equinoctial line; when the islands are more numerous, it recedes farther; and it reaches its maximum deviation in both hemispheres, only in the two great continents which it traverses. He found also, that between the northern and southern halves of the

magnetic equator, there is a symmetry very remarkable, and much more perfect than had previously been believed.

"The dip of the needle increases on each side of the magnetic equator; and Hansteen has projected lines of equal dip in his chart. These lines are nearly parallel to the magnetic equator, till we reach 60° of N. latitude; they then begin to bend round the American magnetic pole which Sir James Clark Ross found to be situated in N. latitude $70^\circ 5' 17''$, and W. longitude $96^\circ 45' 48''$, the needle having at this point in Boothia Felix lost wholly its directive power, and the dip being $89^\circ 59'$ within *one* minute of 90° or vertical. Had we inferred the position of the needle from the form of the magnetic equator, we should have placed it in 25° of W. longitude, viz., the meridian on which the magnetic equator advances farthest to the S., or about $13\frac{1}{2}^\circ$, and $76\frac{1}{2}^\circ$ of N. latitude, or $90^\circ - 13\frac{1}{2}^\circ$. This, however, as all arctic observations prove, is not the case, and we are led by the phenomena of the dip, as well as by those of the variation in different parts of the globe, to conclude that every place has its own magnetic axis, with its own pole, and its own equator, as stated by Mr. Barlow."

(916) *Terrestrial Magnetic Intensity*. — It has become a most important practical problem, connected with the physical condition of the globe, to determine the intensity of its Magnetism at different points on its surface, and the changes which it undergoes at different seasons of the year, and at different times of the day.

Mr. Graham first suggested a method of determining this, by the number of oscillations of the magnetic needle; and this plan has been since much improved by Coulomb, Humboldt, and others.

If a needle, whose axis of suspension passes through its centre of gravity, and which has its N. and S. polar Magnetism equal and similarly distributed, be made to vibrate, by turning it from its position, and allowing it to recover that position by a series of oscillations, it is evident that the Magnetism of the earth will act with equal force on each half, and that the needle will be drawn into the magnetic meridian by the combined action of both forces. The greater the magnetic force, the more quickly will the needle oscillate, and recover its primitive position. The needle is, in short, in the same circumstances as a pendulum, oscillating by the action of gravity; and as in this case, the forces are as the squares of the number of oscillations made in the same time.

Suppose the dipping needle be made to oscillate in the plane of the magnetic meridian, round the line of the dip, and that when an experiment is made at the equator, the number of oscillations in a second is 24, while in another place it is 25; then the intensity of

the magnetic force at these places, is as 25^2 to 24^2 , or as 625 to 576, or as 1.085 to 1.000. By carrying the same needle to different parts of the earth, the magnetic intensity at these places will be found from the number of its oscillations.

(917) In the application of this method there are various practical difficulties, particularly the necessity of the needle resting on knobs, edges of steel, or agate, during its oscillations; these difficulties are avoided by suspending it by a fibre of silk, and allowing it to oscillate horizontally. This method is therefore the one adopted, though a little calculation is necessary to obtain the intensity of terrestrial Magnetism, from the number of oscillations that are performed.*

Hansteen has drawn up a table, which is too long for insertion here, exhibiting the magnetic intensity in almost every part of the world, from observations made principally by himself and his friends. He has projected, on a map of the globe, the lines passing through all the places in which the intensity has the same value. These lines he calls *isodynamic lines*, or those of equal force; and they are, generally speaking, nearly parallel to each other, and to the lines of equal dip.

(918) The same indefatigable philosopher, not satisfied with the many valuable observations which were made during the various arctic expeditions which were sent out by the British government, and being exceedingly anxious to establish, by direct observations of his own, the existence of the secondary magnetic pole, which he believed existed in Siberia, undertook a journey at the expense of the Norwegian Storting, and with every encouragement and assistance from the Russian government. The results of his expedition were highly satisfactory; and in consequence, the Russian Academy of Sciences were induced to take a new interest in the subject of terrestrial Magnetism, which exhibits such important features throughout the Russian empire; and the Russian government has established regular observatories in various parts of its vast dominions for making magnetic experiments. The Russian empire is actually traversed by *two* lines of no variation, and it is proposed to determine with great precision, every ten years, the exact position of these two lines. Near the first of them, which traverses European Russia, Petersburg, Moscow, and Cazan are situated; and near the second, which passes through Siberia, are situated Kiachta and Nizni Oudinsk. Observations are yet wanting to determine in what manner the inten-

* See Harris's Magnetometer of Oscillation, *Edin. Phil. Trans.*, vol. xiii., part I. Trans. Roy. Soc., 1831.

sity varies with the height. Humboldt is of opinion that it decreases, confirming the deductions of Kupffer.

By combining all the observations of intensity from 179° to 183° , M. Hansteen has drawn the conclusion, *that the total magnetic intensity is smaller in the southern than in the northern hemisphere*. M. Duperrey has confirmed this result.

(919) The magnetic intensity, like the variation and dip of the needle, undergoes monthly and diurnal changes. Hansteen found by means of the vibrations of a needle delicately suspended, that the *minimum* of daily change of intensity is between 10 and 11 A.M., and the *maximum* between 4 and 7 P.M. in May, and about 7 P.M. in June. The intensity is a maximum in December, and a minimum in June. The greatest monthly change in the intensity is a maximum in the months of December and June, about the time when the earth is in its perihelion and aphelion. It is a minimum near the equinoxes, or when the earth is at its mean distance from the sun. The greatest daily change is least in the winter, and greatest in the summer. The greatest difference of the annual intensity is 0.0859. M. Hansteen likewise found that the magnetic intensity is diminishing in Europe, and that the decrease is greater in the northern and eastern, than in the southern and western parts—an effect which he conceives to be produced by the motion of the Siberian pole towards the E. At Port Bowen, Captain Parry observed an augmentation of the magnetic intensity to take place from the morning till the afternoon, and a diminution of it from the afternoon till the morning. These results of M. Hansteen have been confirmed by Mr. Christie,* who has shown that the terrestrial magnetic intensity is a minimum between 10 and 11 A.M.; the time nearly when the sun is in the magnetic meridian; that it increases from this time until between 9 and 10 A.M., after which it decreases, and continues decreasing during the morning, till it reaches its minimum between 10 and 11 A.M. These results were deduced from observations made in May, *within doors*, to determine the positions of the points of equilibrium at which a magnetic needle was retained, at different hours during the day, by the joint action of two bar magnets, and by terrestrial Magnetism, reduced to their true positions at the standard temperature 60° of the magnet.

Mr. Christie repeated his observations *in the open air* in June, and from these it appears that the minimum intensity happened nearly at the time the sun passed the magnetic meridian, and rather later than in May, which was also the case with the time of the sun's passage

* *Philosophical Transactions*, 1825, pp. 49—51.

over the meridian. The intensity increased till about six o'clock in the afternoon, after which it appears to have decreased during the evening. The following table shows the results of the observations of Mr. Christie, compared with those of M. Hansteen:—

Intensity deduced from Hansteen's Observations in 1820.			Intensity deduced from Mr. Christie's Observations in 1823.		
TIME.	MAY.	JUNE.	TIME.	MAY.	JUNE.
8 h 0m. A.M.	1·00034	1·00010	7 h 30m.	1·00114	1·00061
10 30	1·00000	1·00000	10 30	1·00000	1·00000
4 0 P.M.	1·00299	1·00251	4 30	1·00175	1·00223
7 0	1·00294	1·00304	7 30	1·00220	1·00339
10 30	1·00191	1·00267	9 30	1·00231	1·00209

The principal difference between these results is, that in Mr. Christie's observations the intensity seems to diminish more rapidly in the morning, and increase more slowly in the afternoon, than it does in those of Hansteen.

(920) The philosopher who has contributed more largely than any other to our knowledge of the magnetic intensity and its laws, is Colonel Sabine, who, since the year 1819, has made this a subject of unceasing study. It appears that there are two foci or points of maximum force in each hemisphere round which the isodynamic lines circulate in an ovate form; these foci are not of equal force in either hemisphere: the focus of greater intensity in the northern hemisphere is in North America, in the vicinity of the S.W. shores of Hudson's Bay in 52° of latitude; the weaker focus is in the North of Siberia, about 120° of E. longitude from Greenwich. The corresponding phenomena of the southern hemisphere are not yet determined with an equal precision. The two major foci, one in the northern and the other in the southern, are not at opposite points of the globe to each other, neither are the two minor foci. At both the foci of the northern hemisphere the predominance is of the forces which attract the N. end of the needle and repel the S., and at both the foci of the southern hemisphere the converse is the case. The ratio of the magnetic force at the major focus in North America as determined by Captain Lefroy, is 13·9; at the minor focus in Siberia from the observations of Hansteen and Duc, 13·3; at St. Helena, which is at the weakest part of the line of least intensity, its value is 6·4. The approximate value of the force of the major focus in the southern hemisphere is 15·6; that of the minor about 14·9. The unit of force in this scale is that amount of magnetic force which acting on the unit of mass through the unit of time, generates in it the unit of

velocity, and the units are taken respectively as a grain, a second, and a foot in British measure. (“Cosmos,” note by Colonel Sabine, vol. i., p. 416.) According to Sabine’s observations at Toronto, the horizontal force from January to April, 1845, possessed there a mean value of 3·53043, with a mean annual decrease of 0·0042. At Toronto and at Hobart Town (Van Dieman’s Land), two magnetic stations which are nearly at opposite points of the earth’s surface, the total magnetic force from October to April inclusive, is greater than from April to August inclusive, and the inclination needle in both places stands more nearly perpendicular during the former period than during the latter.

(921) From Lloyd’s observations at the magnetic observatory at Dublin, it appears that the mean daily course of the horizontal force for the entire year has two maxima and two minima. The first minimum occurs between 1 A.M. and 3 A.M., or a little after. These fluctuations are small. A second and principal minimum takes place at 10h. 10m. A.M., and a second and principal maximum about 6 P.M., the mean daily course being 0·0024 of the whole intensity. In the smaller months, the smaller maximum and minimum disappear, the intensity decreasing continually throughout the night, but slowly till 5 or 6 A.M., after which the decrease becomes rapid. There is consequently but one maximum and one minimum in the mean daily curve, which nearly correspond in epoch with the principal maximum and minimum of the curve for the entire year. In the winter months, on the other hand, there are three maxima and three minima, the evening maximum appearing to break into two. The epoch of the morning maximum moves forward as the line approaches the winter solstice, appearing to depend upon the hour of sunrise, which it precedes by a short interval. The epoch of the principal minimum is nearly constant throughout the year. The daily range is greatest in the month of July, when it is about 0·0045 of the whole intensity; it is least in the month of January, being then about 0·0008 of the whole. The total intensity appears to vary very little throughout the day: it seems to be least about 9 A.M., and then to increase, attaining a double maximum in the afternoon; the total range is, however, very small. From a review of the facts, Professor Lloyd concludes that the diurnal changes in the direction of the magnetic force are connected with the diurnal movement of the sun, and its times of rising and setting; but that the changes of the intensity appear to be influenced, in addition, by some other cause.

(922) *Magnetic Storms.*—This term was applied by Humboldt to certain fitful agitations of the needle, which he was the first to notice, at Berlin, in 1806. The phenomenon has since engaged the

attention of all philosophers occupied with the subject of terrestrial Magnetism. These unaccountable commotions of the needle occur at irregular intervals, are of short duration, but of immense extent. In 1818, a magnetic storm, shown by a violent agitation of the needle, took place simultaneously over 47° of longitude, extending through all the countries from Paris to Cazan; and on the 25th of September, 1841, one of these storms was simultaneously observed at Toronto, in North America, at the Cape of Good Hope, Prague, in Europe, and Macao, in China; and there is reason to believe that it extended to Van Diemen's Land. Similar storms have happened simultaneously in Sicily, and at Upsala, in Sweden (Mrs. Somerville's "Physical Geography.") "When the ordinary horary movement of the needle," says Humboldt (*Cosmos*), "is interrupted by a magnetic storm, the perturbation manifests itself often simultaneously, in the strictest sense of the word, over land and sea, over hundreds and thousands of miles, or propagates itself gradually, in short intervals of time, in every direction over the surface of the earth." When this sudden interruption or disturbance of the horary movement of the needle announces the presence of a magnetic storm, we are unable to determine the seat of the perturbing cause, whether it be in the crust of the earth or in the upper regions of the atmosphere, nor are we able to attribute it to any known cause. The aurora is now, on all hands, recognized as a magnetic phenomenon; its appearance is foretold by an irregularity in the diurnal march of the needle, indicating a disturbance in the equilibrium of the distribution of the earth's Magnetism. "When the disturbance has reached a great degree of intensity the equilibrium is restored by a discharge, accompanied by an evolution of light. The aurora is not, therefore, to be itself regarded as a cause of the perturbation, but as a result of a state of stellar activity excited to the production of luminous phenomena: an activity which manifests itself, on the one hand, by the fluctuations of the needle, and on the other, by the appearance of the brilliant auroral light. The magnificent phenomenon of coloured polar light is the act of discharge—the termination of a magnetic storm." (*Cosmos*.)

(923) The magnetic character of the aurora is clearly shown by Sabine in his "Observations on Days of unusual Magnetic Disturbance made at the British Colonial Magnetic Observatories." On examining the meteorological registers at the Toronto observatory, with reference to the appearance of these meteors, on the twenty-four days of principal magnetic disturbance at that station, it was found that on thirteen days of the twenty-four, the aurora was visible, and that on the remaining eleven days the sky was either

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densely overcast, or heavily-clouded, so that the aurora, though it might exist, could not be seen. It is to be observed, however, that the days on which magnetic disturbance and auroræ occurred together at Toronto, were days of disturbance also at Prague and Van Diemen's Land; so that we may view the occurrence of auroræ at Toronto on these occasions as local manifestations connected with magnetic effect, which, whatever may have been their origin, probably prevailed on the same day over the whole surface of the globe.

(924) *Theory of Terrestrial Magnetism*.—Little that is satisfactory can be said on this head. Actively as the study of terrestrial magnetic phenomena is now proceeding, much remains to be done, before anything approaching to a solution of its wondrous and complex phenomena can be hoped for. It may not, however, be amiss to conclude this portion of our subject with a brief notice of the speculations of Hansteen, and of Mr. Barlow's experimental application of the electro-magnetic hypothesis, first advanced by Sir David Brewster.

(925) The Magnetism of the earth cannot be explained by the action of two magnetic poles at a distance from each other; on the contrary, Biot has observed, that the nearer the poles were taken to each other, the greater was the agreement between the computed and the observed result.

"For these reasons," says Hansteen (in his work on the Magnetism of the earth) "it appears most natural to seek their origin in the sun, the source of all living activity; and our conjecture gains probability from the preceding remarks on the daily oscillations of the needle. Upon this principle the sun may be conceived as possessing one or more magnetic axes, which by distributing the force, occasion a magnetic difference in the earth, in the moon, and in all those planets whose internal structure admits of such a difference. Yet allowing all this, the main difficulty seems not to be overcome, but merely removed from the eyes to a greater distance; for the question may still be asked with equal justice, *whence did the sun acquire its magnetic force?* And if from the sun we have recourse to a central sun, and from that again to a general magnetic direction throughout the universe, having the Milky Way for its equator, we but lengthen an unrestricted chain, every link of which hangs on the preceding link, no one of them on a point of support. All things considered, the following mode of considering the subject seems to me the most plausible. If a single globe were left alone to move freely in the immensity of space, the opposite forces existing in its material structure would soon arrive at an equilibrium conformable to their nature, if they were not so at first, and all activity would soon come to an end. But

if we imagine another globe to be introduced, a mutual relation will arise between the two ; and one of its results will be a reciprocal tendency to unite, which is designated and sometimes thought to be explained, by the merely descriptive word *attraction*. Now, would this tendency be the only consequence of that relation ? Is it not more likely that the fundamental forces, being driven from their state of indifference or rest, would exhibit their energy in all possible directions, giving rise to all kinds of contrary action ? The electric force is excited not by friction alone, but also by contact, and probably also, although in smaller degrees, by the mutual action of two bodies at a distance ; for contact is nothing but the smallest possible distance, and that moreover only for a few small particles. Is it not conceivable that magnetic force may likewise originate in a similar manner ? When the natural philosopher and the mathematician pay regard to no other effect of the reciprocal relation between two bodies at a distance, except the tendency to unite, they proceed logically, if their investigations require nothing more than a moving power ; but should it be maintained that no other energy *can* be developed between two such bodies, the assertion will need proof, and the proof will be hard to find.

"I reckon it possible, therefore, that by means of the mutual relation subsisting between the sun and all the planets, as well as between the latter and their satellites, a magnetic action may be excited in every one of those globes, whose material structure admits of it, in a direction depending on the position of the rotatory axis with regard to the plane of the orbit. Each of the planets may thus give rise to a particular magnetic axis in the sun ; but as their orbits make only small angles with the sun's equator and each other, these magnetic axes would perhaps, on the whole, correspond with the several rotatory axes. Such planets as have no moons, would, on this principle, have but one magnetic axis ; the rest would in all cases have one axis more than they have moons, if those different axes, by reason of the small angles which the orbits of their several moons form with each other, did not combine into a single axis. The conical motions by which the rotatory axes of the planets are carried round the pole of the ecliptic (the precession in the earth), joined to the revolving motion of the orbits about the sun's equator (which occasions the present diminution in the obliquity of the ecliptic), might perhaps, in this case, account for the change of position in the magnetic axis. It would greatly strengthen this hypothesis, if the above great magnetic period, after the lapse of which both axes again assume the same position, should in fact be found to coincide with the period of the precession, which, however, seems a little doubtful."

(926) Such were the speculations of Hansteen. But Sir David

Brewster has proved, from an immense number of meteorological observations, that there were in our northern hemisphere two poles of maximum cold; that these poles coincided with the magnetic poles; that the circle of maximum heat, like the magnetic equator, did not coincide with the equinoctial line; that the isothermal lines, and that the lines of equal magnetic intensity, had the same general form, surrounding and enclosing the magnetic poles and those of maximum cold; and that by the same formula, *mutatis mutandis*, we could calculate the temperature and the magnetic intensity of any point of the globe; thus there can be no doubt that there is a close connexion between the phenomena of temperature and Magnetism; and since the discovery of Dr. Seebeck, that the mere application of heat to a circuit of two metals is capable of developing magnetic effects, we may consider that we have arrived a step nearer to an explanation of the earth's Magnetism, by referring to the sun as the great agent of all these phenomena; but we have yet to discover the metallic thermo-magnetic apparatus by which they are produced.

(927) The electro-magnetic hypothesis was first advanced by Sir David Brewster; and Mr. Barlow has, by a beautiful experiment, shown its application. It occurred to him that if he could distribute over the surface of an artificial globe a series of galvanic currents, in such a way that their tangential power should everywhere give a corresponding direction to the needle, this globe would exhibit, while under electrical induction, all the magnetic phenomena of the earth upon a needle freely suspended above it. The following is an account of the experiment:—

“I procured a wooden globe, 16 inches in diameter, which was made hollow for the purpose of reducing its weight, and while still in the lathe, grooves were cut to represent an equator and parallels of latitude, at every $4\frac{1}{2}^{\circ}$ each way from the equator to the poles; these grooves were about $\frac{1}{4}$ th of an inch deep and broad; and, lastly, a groove of the same breadth, but of double the depth, was cut like a meridian from pole to pole half round. These grooves were for the purpose of laying in the wire, which was effected thus: the middle of a copper wire nearly 90 feet long, and $\frac{1}{8}$ th of an inch in diameter, was applied to the equatorial groove, so as to meet in the transverse meridian; it was then made to pass round this parallel, returned again along the meridian to the next parallel, and then passed round this again, and so on, till the wire was thus led in continuation from pole to pole.

“The length of wire still remaining at each pole was bound with varnished silk, to prevent contact, and then returned from each pole along the meridian groove to the equator. At this point, each wire

being fastened down with small staples, the wires for the remaining 5 feet were bound together to near their common extremity, where they opened to form two points for connecting the poles of a powerful compound voltaic battery.

"When this connexion was made the wire became, of course, an electric conductor, and the whole surface of the globe was put into a state of transient magnetic induction; and consequently, agreeably to the laws of action above described, a neutralized needle freely suspended above such a globe, would arrange itself in a plane passing from pole to pole through the centre, and take different angles of inclination, according to its situation between the equator and either pole.

"In order to render the experiment more strongly representative of the actual state of the earth, the globe in the state above described, was covered by the gores of a common globe, which were laid on so as to bring the poles of this wire arrangement into the situation of the earth's magnetic poles, according to the best observations we have for this determination; I therefore placed them in latitude 72° N., and 72° S., and on the meridian corresponding with 76° W., by which means the magnetic and true equators cut one another at about 14° E. and 166° W. longitude.

"The globe being thus completed, a delicate needle must be suspended above it, neutralized from the effect of the earth's Magnetism, according to the principle I employed in my observations on the daily variation, and described in the *Philosophical Transactions* for 1823; by which means it will become entirely under the superficial galvanic arrangement just described. Conceive the globe now to be placed so as to bring London into the zenith, then the two ends of the conducting wire being connected with the poles of a powerful battery, it will be seen immediately that the needle, which was before indifferent to any direction, will have its N. end depressed about 70° , as nearly as the eye can judge, *which is the actual dip in London*. If now we turn the globe about on its support, so as to bring to the zenith places equally distant with England from the magnetic pole, we shall find the dip remains the same; but the variation will continually change, being first zero, and then gradually increasing eastward as happens on the earth. If again we turn the globe so as to make the pole approach the zenith, the dip will increase, till at the pole itself the needle will become perfectly vertical. Making now this pole recede, the dip will decrease, till at the equator it vanishes, the needle becoming horizontal; continuing the motion, and approaching the S. pole, the S. end of the needle will be found to dip, the degree of inclination increasing continually from the equator

to the pole, where it becomes again vertical, but reversed as regards its verticality at the N. pole."

(928) But although a sphere thus arranged may be made to exhibit the phenomena of terrestrial Magnetism without the aid of any magnetic body, we have yet to learn how such a system of electrical currents can have existence in the earth, unless we refer them to the action of the sun on a metallic thermo-electric apparatus distributed over the earth. It would still, however, remain to be shown what this thermo-electric apparatus is, and where and how it is distributed.

Whether we seek for a cause of terrestrial Magnetism in electrical currents, induced on the earth's surface, or whether we refer it to Magnetism induced on the ferruginous matter it contains, or in its atmosphere, we are limited to the *Sun*, if not as a primary cause, at least as an agent, to which magnetic phenomena have a distinct reference; future investigation must decide whether it acts by its heat, or by its light, or by specific rays, or influences of a magnetic nature.

CHAPTER XVIII.

ELECTRO-MAGNETISM.

Oersted's discovery—Affections of the needle and electrified wire—Mutual actions and reactions—De la Rive's floating ring—Mutual actions of parallel electrical currents—Laws of angular currents—Sinuous currents, solenoids—Galvanometers—Faraday's researches—Electro-magnetic rotations—Electro-magnets and electro-magnetic engines.

(929) THE disturbance produced in the magnetic needle by the aurora borealis and lightning, had long suggested to philosophers that the agencies of Electricity and Magnetism must be connected by some close and intimate relation. For nearly half a century the discovery of this relation was a favourite subject of speculation; and it is curious to compare the various opinions which were maintained by different experimentalists. Magnetic properties were easily communicated to bars of steel, by passing strong electrical shocks through them, but no general law could be traced as governing the polarity thereby imparted. D'Abilard imagined, that he had proved that the electric discharge imparts a northern polarity to that point of a steel bar at which it enters, and a southern polarity to that at which it makes its exit; and this quite independently of the position of the needle, with respect to the magnetic poles of the earth. Wilke, on the other hand, was equally satisfied that an invariable connexion exists between the negative Electricity and the northern polarity.

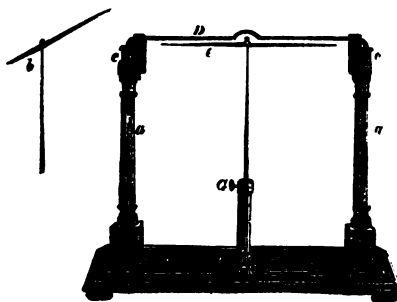
(930) In one of the essays (which received a prize) on the question proposed by the Electoral Academy of Bavaria, in 1774: "Is there a real and physical analogy between electric and magnetic forces; and if such analogy exists, in what manner do these forces act on the animal body?" Professor Van Swinden, of Franeker, after a long and elaborate discussion of the subject, arrived at the conclusion, that the similarity between Electricity and Magnetism amounts merely to an *apparent* resemblance, and does not constitute a true physical analogy; whence he infers that these two powers are essentially different and distinct from each other. On the other hand, Professors Steiglehner and Hubner, maintained that both classes of phenomena are referable to the *same* agent, varying only in consequence of a diversity of circumstances. In this unsettled state, the subject remained till some years after the discovery of Galvanism, by which a fresh field of inquiry was opened, and a means of maintaining a

large and continuous current of Electricity obtained. The first approach to a solution of the question, was the publication of Ritter; he asserted, "that a needle, composed of silver and zinc, arranged itself in the magnetic meridian, and was slightly attracted and repelled by the poles of a magnet;" he also stated, "that by placing a gold coin in the voltaic circuit, he had succeeded in giving to it positive and negative electric poles; and that the polarity so communicated, was retained by the gold, after it had been in contact with other metals, and appeared therefore to partake of the nature of Magnetism; that a gold needle, under similar circumstances, acquired still more decided magnetic properties;" and, "that a metallic wire, after being exposed to the voltaic current, took a direction N.E. and S.W."

(981) In consequence of the vague and loose manner in which Ritter advanced his speculations, but little notice was taken of them, and no satisfactory results were obtained till the year 1819, when Professor Oersted, of Copenhagen, made his famous discovery, which forms the basis of the science of Electro-magnetism. The fact observed by Oersted was, that when a magnetic needle is brought near the connecting medium (whether a metallic wire or charcoal, or even saline fluids of a closed voltaic circle), it is immediately deflected from its natural position, and takes up a new one, depending on the relative positions of the needle and wire. If the connecting medium be placed horizontally *over* the needle, that pole of the latter which is nearest to the *negative* end of the battery, always moves *westward*; if it be placed *under*, the same pole moves to the *east*. If the connecting wire be placed parallel with the needle, that is, brought into the same horizontal plane in which the needle is moving, then no motion of the needle in that plane takes place; but a tendency is exhibited in it to move in a vertical circle, the pole nearest the *negative* side of the battery being depressed, when the wire is to the *west* of it, and elevated when it is placed on the *eastern* side.

Fig. 307 represents a convenient arrangement for exhibiting

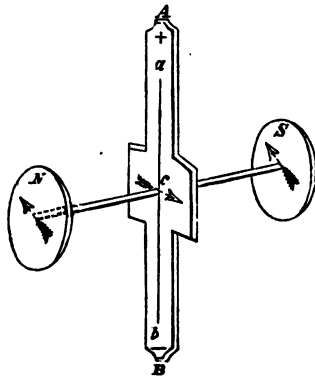
Fig. 307.



the action of a wire conducting a current of Electricity on the magnetic needle. *a a*, two turned wooden pillars screwed into a base board *B*, and surmounted by two mercury cups *c c*. *D*, a copper wire, the ends of which dip into the mercury, as do also the wires connected with

the opposite extremities of a simple voltaic battery. A current of Electricity can thus be made to pass in either direction along the wire D : e is the magnetic needle nicely poised on a wire, which by means of the screw G may be elevated or depressed, and the needle thus set either above or below the wire D , or it may be removed and replaced by the dipping needle b . The needle is likewise affected when suspended over the battery itself, but its movements are the reverse of those which take place when it is suspended over the connecting wire. As in all electro-magnetic researches it is necessary to bear in mind these affections of the needle and electrified wire, several contrivances have been made to assist the memory respecting the details. Fig. 308 represents the plan of Dr. Roget. AB is a slip of card, on each side of which a line $a b$ is drawn along the middle of its length, the end a being marked $+$, the end b —, and the centre c being crossed by an arrow, at right angles to it, directed as in the figure. Through the centre, and at right angles to the plane of the slip of card, there is made to pass a slender stem of wood, at the two ends of which are fixed in planes, parallel to the slip of card AB , the circular discs of cards marked respectively with the letters N and S , and with arrows parallel to, but pointing in a

Fig. 308.



contrary direction to the one at c . The same marks must be put on the reverse of each of the three pieces of card, so that when held in different situations they may be seen without turning the instrument.

(932) If the line ab , be supposed to represent the connecting wire (the direction of the current of Electricity being denoted by the signs $+$ and $-$ at the ends of the line), the arrow at the centre will point out the direction in which it tends to move, when under the influence of the N . pole of a magnet, situated at N ; or of a S . pole situated on the other side, as at S ; and *vice versa* the arrows N and S , will indicate the directions in which the N . and S . pole respectively tends to revolve round the connecting wire in its vicinity, with relation to the direction of the current of Electricity that is passing through it. It must be observed that the poles NS are not considered as in connexion with each other, or as forming parts of one magnet; their operations are exhibited singly and quite independently of each other. The advantage of the instrument consists in its being capable of being held in any situation, and thus easily adapted

to the circumstances of any fact or experiment of which we may wish to examine the theory.

(933) A useful help to the memory has also been suggested by Ampère. Let the observer regard himself as the conductor or connecting wire, and imagine a positive electric current to pass from his head towards his feet in a direction parallel to the magnet; then its N. pole in front of him will move to his right side, and its S. pole to his left. The plane in which the magnet moves is always parallel to the plane in which the observer supposes himself to be placed. If the plane of his chest be horizontal, the plane of the magnet's motion will be horizontal; but if he lie on either side of the horizontally suspended magnet, his face being towards it, the plane of his chest will be vertical, and the magnet will tend to move in a vertical plane. Figs. 309 and 310 represent the direction of the circulating current of Magnetism.

Fig. 309.

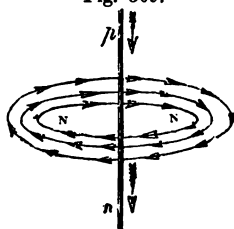
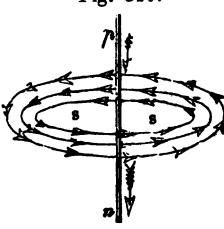


Fig. 310.



relating current of Magnetism. In Fig. 309 the connecting wire is placed vertically, the electric current descending it from p to n ; the arrows denote the direction in

which the N. pole of a magnet will have a tendency to move round it; *i. e.* from left to right, or in the direction of the hands of a watch. Fig. 310 shows the motion impressed on the S. pole by a similar current; when the direction of the electricity is reversed, the wire still preserving its vertical position, the direction of the action is also reversed. From the manner in which the needle is affected when placed parallel to either side of the current it was inferred that a *current of Magnetism* is set in motion at right angles to the latter. This was termed by Dr. Wollaston *Vertiginous Magnetism*; and by Mr. Barlow, the magnetic force was said to exert a *tangential* action.

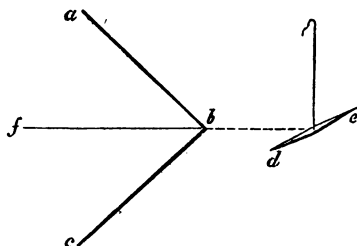
(934) The extent of the declination of the magnetic needle depends entirely on the *quantity of Electricity* passing along the connecting wire, and has nothing to do with the *tension* of that Electricity, nor is it increased by increasing the intensity of the current; hence the employment of galvanic batteries for the exhibition of the effects of Electro-magnetism: we see here also the reason why the first inquirers were foiled in their attempts to elicit these effects.

(935) The force exerted by the electric current on the magnetized needle diminishes in intensity in proportion as the distance between the current and the needle increases. The law, in accordance with which this diminution is regulated, was determined by MM. Biot and

Savary. When the current is rectilinear, and the length of the wire considerable, so that in relation to that of the needle it may be regarded as infinite, the intensity of the electro-magnetic force is *in inverse ratio to the simple distance of the magnetized needle from the current*. But it is only under these conditions that the law is true, for Laplace has shown that the elementary electro-magnetic force, that is, the elementary action of a simple section of the current upon the needle, is like all other known forces in the inverse ratio of the *square of the distance*, and proportional to the sine of the angle formed by the direction of the current, and by the line drawn through the centre of the section to the centre of the needle. In fact, by calculating according to this principle, the sum of all the elementary actions that are exercised on a small needle by an indefinite rectilinear current, it is found that the intensity of this resultant should be, as experiment proves it really is, in the inverse ratio of the simple distance.

Fig. 311.

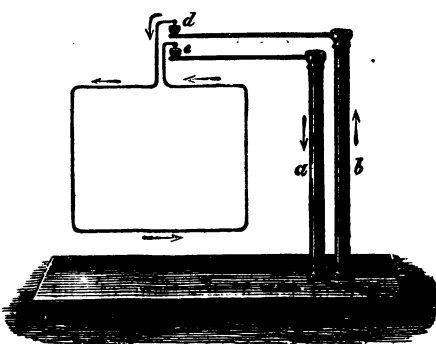
From the same law of the elementary force it follows, that the intensity of the action of an indefinite angular current, abc , (Fig. 311) on a small needle, de , is in the inverse ratio of the distance, bd , like that of the rectangular current, but it is moreover proportional to the tangent of half the angle, abf .



(936) The action of the electric current on the magnet is attended with a corresponding and equal reaction of the magnetic poles on the current.

Fig. 312 exhibits the apparatus contrived by Ampère for showing the action of a fixed magnet on a moveable rectangular wire. Two metallic uprights, a , b , provided at their lower extremities with cups to hold mercury, are fixed on a base board, c ; from the tops of

Fig. 312.

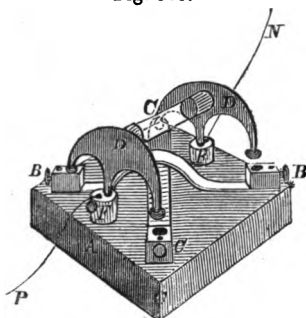


these vertical rods proceed long horizontal arms, carrying at their ends brass mercury cups. The moveable conductor consists of a rectangular copper wire, its two extremities being brought back near each other, so that their points may dip into the mercury capsules,

d, e; one of the poles of the voltaic battery is made to communicate with the lower extremity of one of the fixed conductors, and the other with the corresponding extremity of the second pillar. Supposing the connexions to be made in the manner indicated in the figure, then the current will circulate through the system in the direction pointed out by the arrows, and on placing a magnetized bar below and very near to the lower part of the wire, the latter immediately moves and sets itself transversely to the magnet. On altering the direction of the current, or on turning the fixed magnet round, the wire again moves and describes an angle of 180° in order to take up a position the reverse of that which it previously occupied, and which is in strict accordance with Ampère's formula in the case of a fixed current and moveable magnet.

(937) In making electro-magnetic experiments, it is convenient to be provided with an apparatus for reversing the direction of the electrical current without disturbing the conducting wires. Fig. 313 shows the contrivance of Magnus for this purpose.

Fig. 313.



AA is a block of wood on which are fixed the two brass bands, *BB, CC*, terminated at their extremities by square blocks of brass with binding screws and cup-shaped holes. *DD*, two flat pieces of brass connected and insulated by the glass rod, *E*. These are the break pieces, and move on joints at *FF*, where they are connected by the wires, *PN*, with the battery.

The other binding screws at the termination of the brass bands serve to connect the arrangement through which the currents are to pass.

(938) The rectangular wire when traversed by a powerful voltaic current, and when its diameter is from 18 inches to 2 feet, is acted upon sensibly by terrestrial Magnetism; it sets itself, in fact, transversely, or perpendicularly, to the magnetic meridian, the earth acting like a magnet whose N. pole would be on the S., and whose S. pole would be on the N. of the earth. Under the influence of the Magnetism of the globe, therefore, the moveable conductor moves in a direction the reverse of that to which it would tend when influenced by a magnet alone; the two motions tend to counteract each other, and this complication Ampère obviated by making the system *astatic*, that is, by so arranging it that there shall be equal and similar horizontal currents running in contrary directions, and equal and similar vertical currents running in the

same direction, as shown in Fig. 314, where the two rectangles are represented as situated each on a different side of the axis of rotation, but on the same plane; the current traversing the two associated rectangles in different directions, as shown by the arrows. The action of the earth's Magnetism on this system is null, because it gives to one of the rectangles a tendency to move in a direction the reverse of the other.

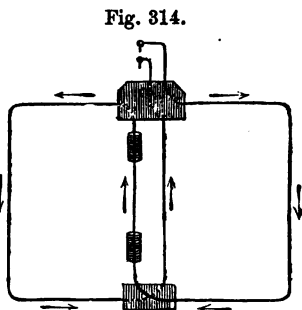
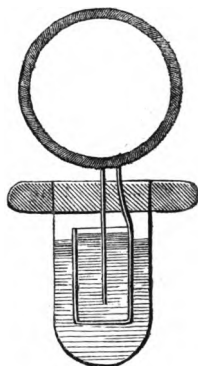


Fig. 314.

(939) In order to give the moveable conductor perfect freedom of motion, which in Ampère's arrangement it could not have, because of the horizontal arms of the vertical supports, M. De la Rive

contrived the ingenious little apparatus shown in Fig (315). It consists of a cylindrical glass vessel, having a cork float attached to its upper end. Into this vessel is inserted a small voltaic combination, formed on Dr. Wollaston's plan, and consisting of a plate of zinc surrounded by a copper plate, the zinc plate being insulated upon its edges. A copper wire affixed by soldering to both these plates, is made into the form of a ring, consisting of several coils of the wire, which is besides insulated, by being wrapped round with silk thread: upon pouring diluted acid into the glass vessel, and placing the plates in it, voltaic action commences, and is mani-

Fig. 315.



fest by placing the apparatus afloat in water, when the coil will have a tendency to take a position in the plane of the magnetic meridian, and will exhibit all the effects of the attractive and repulsive tendencies which have been described above, when a strong bar magnet is brought near it on either side. If the magnet be sufficiently slender to pass through the ring, the following curious phenomenon will be observed: If the pole be presented to it on the side where attraction takes place, the ring will move towards it till it arrives at the pole, and then proceed onwards in the same course, the magnet being held in the axis of the ring, till it reaches the middle of the magnet, but there it seems inclined to stop; and then, after a few oscillations, it settles as in a position of equilibrium; for, if purposely displaced, by bringing it forwards towards the other pole, it returns with a force which shows that it is repelled from that other pole. Let the magnet now be withdrawn, and turning it half round,

so that its poles are in directions the reverse of what they were at first, and holding the ring in one hand, let the magnet be again introduced into it with the other hand, until it is half way through. Under these circumstances, it is just possible that it may have been brought into such a situation as that the ring may again be in equilibrium, undetermined in what direction to move; but the slightest change in this position, causes it to move with an accelerated velocity towards that pole which is nearest to it; and getting entirely clear of the magnet, it is projected to a considerable distance from it. At length, however, it stops, and, gradually turning round, presents the opposite face to the magnet; attraction now takes place, and the ring returns to the magnet with a force equal to that with which it had before fled from it; and passing again over its pole, finally rests in its position of equilibrium, encircling the middle, or what may be termed the equator, of the magnet. In the former position it was equally attracted by the two poles of the magnet, in the latter it is equally repelled; and accordingly, the first was an unstable and the last a stable equilibrium. There are few experiments better calcu-

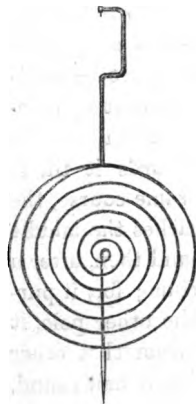
Fig. 316. lated to exhibit to a class in a lecture-room the mutual affections of a magnet and an electrified wire than this: the motions of the floating coil are less impeded by setting it afloat in a small thin varnished wooden dish as shown in Fig. 316, where the voltaic pair is represented as being placed in a horizontal position in a little bowl;



the whole is then set afloat in a large basin or trough of water, and on pouring a little dilute sulphuric acid into the bowl, the coil will be found to be surprisingly sensible to the influence of a magnet, and will be attracted and repelled at the distance of several inches.

(940) The directive tendency of an electrified wire may also be

Fig. 317.

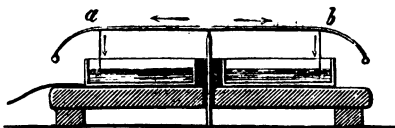


strikingly exhibited by bending it into the form of a spiral, and either connecting it with the floating galvanic arrangement, or suspending it delicately by a hook as in Fig. 317, and passing the voltaic current through it; the plane of the spiral will be found to place itself E. and W., the positive current ascending on the W. side, and descending on the E., taking the same course as the hands of a watch when it is held on edge with the plane of the dial lying E. and W. facing S. That side of the spiral which is towards the N. acts as the N. pole, and the S. side has an opposite polarity. Each side powerfully attracts iron filings.

(941) The rotation of horizontal currents by the influence of the Magnetism of the earth is demonstrated by the apparatus shown in Fig. 318. It consists of a cop-

per dish filled with dilute sulphuric acid, in the centre of which the horizontal wire, *a b*, terminated with two balls, is balanced on a fine point; from

Fig. 318.



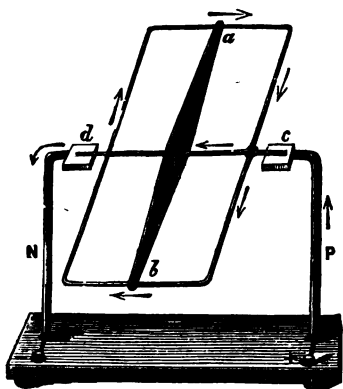
near the ends of this wire two short wires drop vertically into the acid; on causing the voltaic current to pass in a contrary direction through the two halves of the wire, as indicated by the arrow heads in the figure, a continuous rotatory movement is established. The rotation is from E. to W. when the current passes from the centre to the circumference, and from W. to E. when it moves from the circumference to the centre of the wire. If the N. pole of a magnet be held underneath the apparatus, a great increase in the velocity of the rotation takes place; but if the same pole be presented above, the velocity is diminished, the magnet in the first instance co-operating with, and in the second instance contending against, the action induced by the earth; the reverse effects are produced by the S. pole. If the magnetic pole be held in the same horizontal plane as the wire *a b*, its action is altogether null.

(942) The following curious phenomena were observed by Sir H. Davy. He plunged the two poles of a powerful battery vertically at about an equal distance from the centre and circumference into mercury contained in a shallow dish and covered with acidulated water; no particular appearance was observed till one of the poles of a powerful magnet was brought near, when the mercury became agitated, and began to revolve with rapid rotation round each wire, the direction of the motion being determined by that of the current; and by the position and nature of the magnetic pole. The rotation was most rapid when the two opposite magnetic poles were brought into action, one being held above and the other below the mercury. Two thick copper wires covered with wax, but with their ends clean, were passed through the bottom of a glass dish about 3 inches apart, and projecting about 1 inch from the bottom of the dish, which was then filled with mercury to the depth of about a line above the tops of the wires. On passing a powerful current through the wires, the mercury became violently agitated, its surface above each wire rose in the form of small cones, which fell in little waves in all directions, the only quiescent spot being where the waves met at the centre of the mercury between the two wires. On approaching gradually one of the poles of a powerful magnet to the summit of one of the cones,

it gradually fell, and, as the magnet advanced, a funnel-shaped cavity was formed in the mercury, the apex of which descended nearly to the top of the wire. Fused tin exhibited the same phenomena.

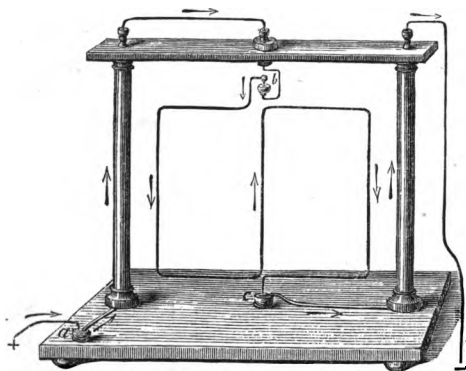
(943) By the apparatus shown in Fig. (319) Ampère demonstrated that a rectangular wire, if arranged so as to be moveable

Fig. 319.



round a horizontal axis, and in perfect equilibrium, in all its positions round this axis, will, if placed with its axis of motion at right angles to the magnetic meridian, place itself steadily in the plane of the magnetic equator, that is, in a plane perpendicular to the line of the dip, when traversed by a voltaic current. The rectangular frame of copper wire is fixed at right angles to a tube of wood, which serves as an axis, and in the same plane, a lozenge-shaped bar of wood, *a b*, is placed. The current ascending the pillar, *P*, enters the rectangle through a steel pivot, resting on the metallic plate *c*.; it traverses the wire in the direction of the arrows, and finally descends through the plate *d*, down the metallic pillar, *N*. The moment the electric current is established through the wire, it begins to oscillate, and finally takes up a position in the plane of the magnetic equator. On reversing the direction of the current, the magnetic polarity of the wire becomes reversed, and the rectangle turns round, so as still to place itself in the same plane as before, but with its faces turned in the opposite directions.

Fig. 320.



wires, there is a mutual attraction; when they move in a contrary

(944) *Mutual Action of two Parallel Electrical Currents.* — When two metallic wires are traversed simultaneously by an electrical current, the wires are either attracted towards, or repelled from each other, according to the relative directions of the two currents; when they move in the same direction through the

direction there is a mutual repulsion set up between the conductors. These phenomena, as well as the development of the mathematical laws which govern them, were discovered by Ampère, and may be illustrated by means of the apparatus shown in Figs. 320 and 321.

Two copper columns are fixed vertically on a wooden base. The positive electrode of a battery of 5 or 6 pairs is made to communicate with the left hand pillar through the mercury cup *a*; the voltaic current ascends this pillar, and enters the moveable rectangular copper wire through the mercury cup *b*, leaves it through the cup *c*, and ascending the right hand column completes the circuit through a wire communicating with the negative electrode.

By observing the direction of the arrow heads, it will be perceived that the voltaic current is moving in different directions through the fixed pillars, and through those portions of the moveable conductor adjacent to them; the rectangle is, therefore, repelled in accordance with Ampère's law; but by arranging the wire as shown in Fig. 321. the current is caused to move in the same direction through the pillars and the adjacent parts of the moveable conductor, and attraction consequently results. The intensity of these attractions and repulsions is in proportion to the length of the vertical sides of the rectangles, and to the square of the intensity of the current in circulation, it would be also in the inverse ratio of the simple distance, if the fixed columns could be considered as having a length infinite in relation to that of the moveable conductors.

(945) *Laws of Angular Currents.*—Two rectilinear currents which diverge from, or converge to a common point, mutually attract. If one converges and

the other diverges, mutual repulsion ensues. Thus let *ab* and *cd* (Fig. 322) be two currents crossing at the point *r*, there will be attraction

between the two parts *ar*, *cr*, because the currents are both converging towards *r*, and also between *br*, *dr*, because they both are diverging from that point; but there will be repulsion between *ar* and *r*, *d*, and also between *cr* and *r*, *b*, because, while *ar* and *cr* are

Fig. 321.

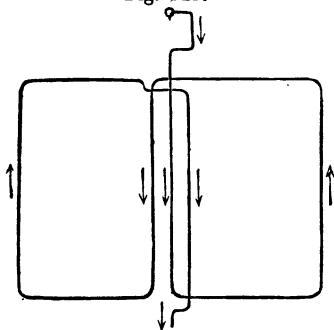
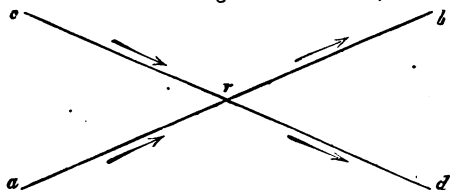


Fig. 322.

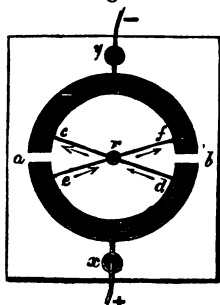


approaching the point r , $r b$ and $r d$ are receding from it. These

Fig. 323.

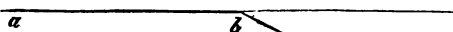


Fig. 324.



The needles being in the position $c d, e f$, repulsion takes place, but attraction ensues when they are placed in any other position whatever, such that the angle $c r f$, shall be less than a right angle. From this it follows that an angular current $a b c$, tends to become straight;

Fig. 325.



the parts $a b$ and $b c$ exercising a mutual repulsion. This repulsion not only tends to bend back $b c$ into a prolongation

of $a b$, but it is still exercised when this condition is fulfilled; in other words, *the contiguous portions of the same rectilinear currents repel each other*. By means of the apparatus (Fig. 326) this consequence so important to his theory was demonstrated by Ampère. A hollow

Fig. 326.



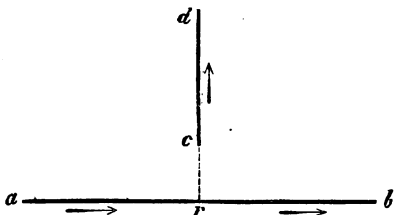
cut out of a block of wood, is divided into two compartments by the non-conducting division $a b$; a silk covered copper wire is so bent that in each compartment it shall present

a horizontal branch parallel to the division; these branches or arms are covered with wax, except at their extreme ends, where they are bent so as to touch the mercury. On passing a strong current through the wire it immediately recedes, showing an apparent repulsion between the current passing through the mercury, and that traversing the wire. Pouillet ("Elements de Physique" tome i, p. 562), does not think that this experiment demonstrates the fact in a manner completely satisfactory, because we have not sufficient knowledge of the mode in which a voltaic current passes from a liquid to

a solid; if for instance, one portion of the current should pass obliquely to the wire, the phenomenon of repulsion would be equally exhibited.

(946) *Rotation of a Current by the Action of a Current.*—If we imagine a fixed indefinite current moving in the direction, $a b$, Fig. 327, and another current, $c d$, moving in a direction parallel to itself, the point of crossing being at r , there will be attraction about the angle $b r d$, between the parts $r b$ and $c d$, because in both the current

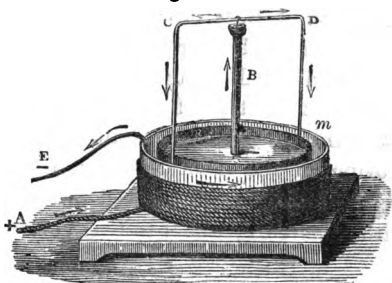
Fig. 327.



is moving from the summit of the angle, or from the point of crossing; there will, on the contrary, be repulsion about the angle $a r d$, because on one side, $a r$, the current is approaching to, while on the other side, $c d$, it is receding from the point of intersection. These two forces give rise to a resultant parallel, $a b$, which tends to urge incessantly the current $c d$ from a towards b . If the fixed current, $a b$, is formed into a circle, it is evident that $c d$ should revolve indefinitely; and that it actually does so may be proved by the little apparatus

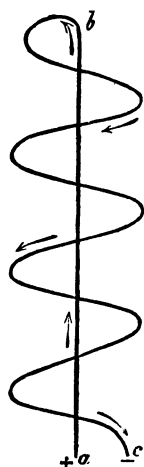
Fig. 328.

shown in Fig. 328. It consists of a glass vessel, containing acidulated water, round which is wound a silk-covered copper wire, through which a voltaic current is caused to circulate. In the centre of this vessel there is fixed a copper pillar, B, surmounted by a small capsule for containing mercury; in this is plunged an iron point supporting a copper wire, $D C$, bent at a right angle at either end, and carrying the copper ring, m , which dips into the acidulated water. The voltaic current entering at A, after having made several circuits round the glass vessel, passes up the pillar B, from the cup of which it proceeds in both directions along the copper wire and reaching the copper ring is transferred to the acidulated water, into which is plunged the negative electrode, E, of the pile; the moment the circuit is complete, the whole moveable system begins to revolve in a direction contrary to that of the fixed current.



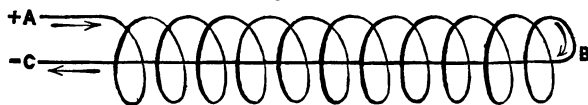
(947) *Sinusoidal Currents; Solenoids.*—If a current, instead of

Fig. 329.



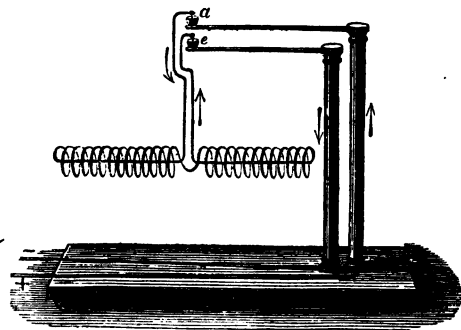
following a rectilinear course, deviate alternately to the right and to the left, its action is the same with that of a rectilinear current of the same extension. This may be proved by passing a current through a wire, $a b c$, partly rectilinear and partly sinuous or zig-zag, and bringing it near to a mobile conductor (Fig. 329); the latter will be neither attracted nor repelled, proving that the sinuous portion, $c b$, is in exact equilibrium with the rectilinear portion, $a b$. The combination of a rectilinear with a sinuous current is called a *solenoid*. It is a system of circular currents, equal and parallel, formed by twisting a silk-covered copper wire, corkscrew-fashion, back upon itself; but to make it perfect, the straight part of the wire must be as exactly as possible in the centre of the helix. Thus arranged, when the circuit is traversed by a current, the action of the solenoid in the direction of

Fig. 330.



its length, $A B$, is destroyed by that of the rectilinear current $B C$, and the only effect produced is due to the system of circular currents, equal and parallel, moving in a direction perpendicular to its axis. Now, as the action of fixed currents on moveable ones is to bring them into a position parallel to themselves, with their currents moving in the same direction, a solenoid freely suspended on a vertical axis should, when acted on by a rectilinear current, range itself with its circles parallel to that current. It is accordingly found that

Fig. 331.



itself across that current taking up a position with its circles

on passing a strong voltaic current through a solenoid suspended from two mercury cups, as shown in Fig. 331, so as to allow it perfect freedom of motion round a vertical axis, and passing at the same time underneath, and parallel to its axis, a rectilinear current, the solenoid turns

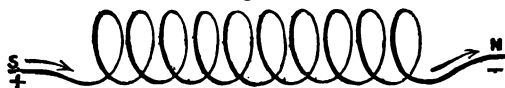
parallel to it. If instead of passing the rectilinear current *horizontally* underneath the solenoid, it be passed *vertically* and near one end, the latter is either attracted or repelled according as the currents are passing in the same or in opposite directions, through the wire and through the contiguous parts of the solenoid. Two solenoids exhibit towards each other the phenomena of attraction and repulsion in a manner precisely similar to two magnets, and a solenoid is influenced by a magnetic bar precisely as another magnet would be. In short, a solenoid has all the properties of a magnet, and when suspended, as shown in Fig. 331, and traversed by a strong electric current, it will range itself with its axis parallel to the direction of the declination needle. If the solenoid be a *right*

Fig. 332.



handed helix, its wire being turned from left to right, then the extremity at which the current enters has the magnetic properties of a N. pole, and the extremity at which it leaves the helix those of a S. pole. If the helix be left-handed, its wire turning from right

Fig. 333.



to left, then the extremity at which the current enters has the properties of a S. pole, and that at which it leaves the helix has those of a N. pole. When a magnetic bar is broken across, each fragment is itself a perfect magnet, the two fractured ends having an opposite polarity ; it is precisely the same with a solenoid : suppose, for example, A B to represent a solenoid extending indefinitely on either side of the point *m*, and traversed by a current in the direction of the arrows, the extremity A is a S. pole, because on looking at the face of this terminal circle the ascending current is observed to be moving from left to right ; suppose now the solenoid to be cut in two at *m*, the *a* end will be a S. pole, and the end *b* a N. pole, because on looking at the face of the terminal circle of the latter, the ascending current is seen to be moving from right to left. It is evident, therefore, that there will be attrac-

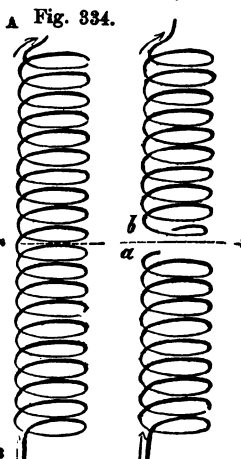


Fig. 334.

tion between a and b , and it may be proved moreover that this attraction is, as in the case of magnets, inversely as the square of the distance between a and b .

(948) A beautiful exemplification of the mutual attraction of conducting wires carrying voltaic currents moving in the same direction, is afforded by Roget's spiral (Fig. 335). It consists of a

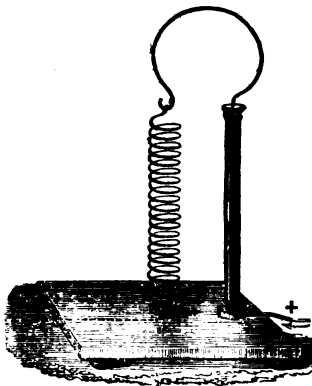


Fig. 335.

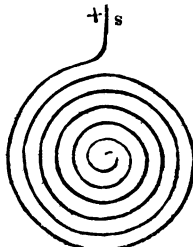
loose coil of copper wire, the upper end being either held by a binding screw or suspended by a fibre of silk, and the lower end (which should be amalgamated) just touching the surface of some mercury in a little eup, communicating with the negative electrode of a pretty strong voltaic battery. On making a contact between the upper extremity of the spiral and the positive electrode, the coils being all traversed by a current in the same direction, will mutually attract each other; the entire spiral being hereby shortened, the lower

end leaves the mercury, and the contact with the battery is broken; the weight of the wire thus causes it again to fall into the mercury, and the passage of the current is restored; in this way a rapid series of longitudinal vibrations is produced, accompanied by a snapping noise, and a succession of bright sparks. Again, suspend from a horizontal rod two similar compound spirals, each consisting of several layers of insulated copper wire superposed, and send a strong current through each in the same direction; they will attract each other powerfully, even at a distance of several inches; now reverse the direction of the current in one of the spirals, upon which a repulsion equally powerful will be set up between them. It must be borne in mind that in flat spirals as well as in helices, the nature of the magnetic poles is determined by the direction of the *spirals* as well as by the direction of the *current*. In the right-hand spiral (Fig.

Fig. 336.



Fig. 337.

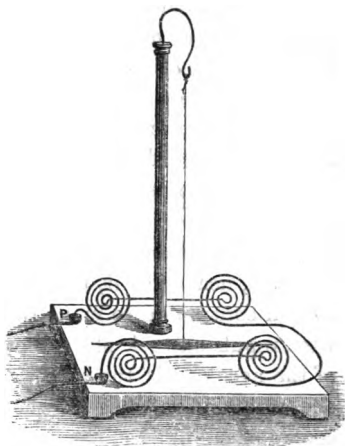


836.) the end at which the current enters has the magnetic properties of a N. pole and in the left-hand helix (Fig. 337), the end at which the current enters has the properties of a S. pole.

(949) *Galvanometers*.—We have already described the construction of the various forms of this valuable instrument (426 *et seq.*), and the preceding considerations render it probably unnecessary to add anything with reference to the principles on which their action depends.

In Fig. 338, is shown the vertical spiral coil, galvanometer described by Dr. Roget (*Library of Useful Knowledge*, Electro-magnetism, No. 44). The needle is suspended from its centre by a fine thread between four vertical spiral coils, the centres of which are brought very near to the poles of the needle. The same current is made to circulate through all the four spirals, the turns of which are directed so as to produce repulsion

Fig. 338.

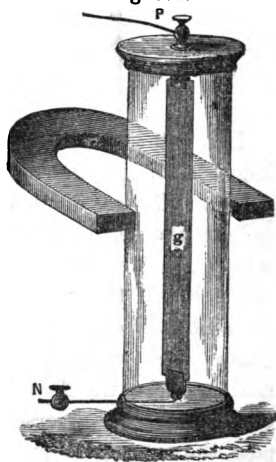


of the contiguous pole on the one side, and attraction of the same pole on the other side. In each disc the force acting perpendicularly to the plane of the discs is multiplied in proportion to the number of the circumvolutions of the wire, and the spiral turns being made in the same directions in all the discs, their actions will concur in producing in the needle a deviation in the same direction, and the total force will be four times that of a single disc.

(950) The action of a magnet on a moveable conductor has also been made available as an extremely delicate test of a weak galvanic current. (*Cumming's Electro Dynamics*.)

A slip of gold leaf *g* (Fig. 339) is retained loosely between two forceps, each terminating in a mercury cup or binding screw, for establishing the communications by which the current is transmitted through the leaf. The whole is enclosed in a cylindrical glass case, the middle of which is placed between the poles of a powerful horse-shoe magnet, so that the gold leaf may be nearly equidistant from them when the circuit is complete. The latter is attracted or repelled laterally by the poles of the magnet according as the current is ascending or descending; the broad surface of the leaf becoming convex towards

Fig. 339.



the magnet in the one case, and concave in the other. This principle has been adopted by Highton in one of his patented electric telegraphs.

(951) Mr. Faraday, whilst making experiments to ascertain the position of the magnetic needle relative to the connecting wire, was led (*Quart. Jour. of Science*, xii., p. 74) to some new views of electro-magnetic action. On placing the wire perpendicularly, and bringing the needle towards it to ascertain the attractive and repulsive positions with regard to the wire, he found them to be *eight*—2 attractive and 2 repulsive for each pole. Thus, allowing the needle to take its natural position across the wire, and then drawing the support away from the wire slowly so as to bring the N. pole, for instance, nearer to it, there was attraction, as was to be expected; but on continuing to make the end of the needle come nearer to the wire, repulsion took place, though the wire still was on the same side of the needle. If the wire was on the other side of the same pole of the needle, it repelled it when opposite to most parts between the centre of motion and the end; but there was a small portion at the end where it attracted it.

Fig. 340.

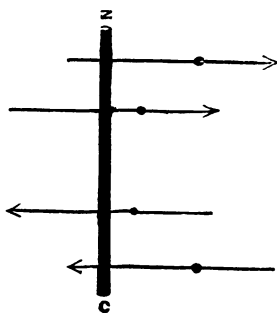


Fig. 341.

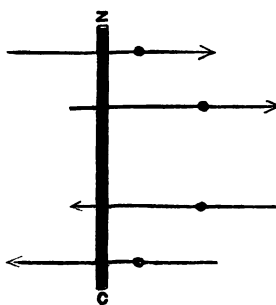


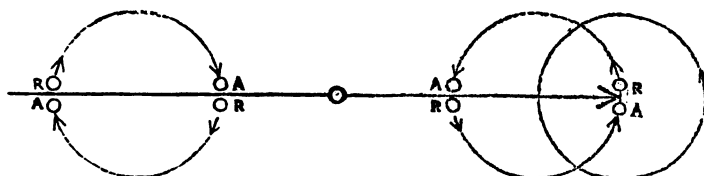
Fig. 340 shows the positions of attraction for the N. and S. poles. Fig. 341 the positions of repulsion.

(952) On making the wire approach perpendicularly towards one pole of the needle, the pole passed off on one side in that direction which the attraction and repulsion at the extreme point of the pole gave; but if the wire were continually made to approach the centre of motion by either the one or the other side of the needle, the tendency to move in the former direction diminished; it thus became null, and the needle was quite indifferent to the wire, ultimately the motion was reversed, and the needle powerfully endeavoured to pass the opposite way. From this it was evident that the centre of

the active portion of either limb of the needle, or the true pole as it may be called, *is not at the extremity* of the needle, but may be represented by a point generally in the axis of the needle at some little distance from the end. It was evident also that this point had a tendency to revolve round the wire, and necessarily, therefore, the wire round the point; and as the same effects in the opposite direction took place with the other pole, it was evident that each pole had the power of acting on the wire by itself, and not as any part of the needle, or as connected with the opposite pole.

In Fig. 342, sections of the wire in its different positions to the needle are represented—the active poles by two dots; and the arrow heads show the tendency of the wire in its positions to go round these poles.

Fig. 342.



From these facts it follows that both attraction and repulsion of conducting wires are compound actions; that there is no attraction between the wire and either pole of the magnet, and that the wire ought to revolve round the magnetic pole, and the magnetic pole round the wire. By the following ingenious apparatus Faraday proved this to be really the case.

Into the centre of the bottom of a cup, as in the vertical section, Fig. 343, a copper wire cD , was inserted; a cylindrical magnet ns , was attached by a thread to the copper wire, c , and the cup was nearly filled with mercury, so that only the N. pole of the magnet projected. A conductor, ab , was then fixed in the mercury, perpendicularly over c . On connecting the conducting wires with the opposite ends of the battery, a current was transmitted from one wire through the mercury to the other. If the positive current descended, the N. pole of this magnet immediately began to rotate round the wire ab , passing from E. through the S. to W., *i. e.*, in the direction of the hands of a watch; but if the current ascended, the line of rotation was reversed. Conversely, a magnet was fixed in a vessel of mercury, and the conducting wire hung from a hook above it, the end just dipping into

Fig. 343.

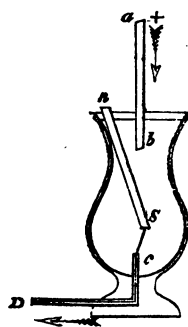
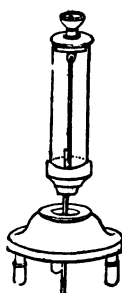


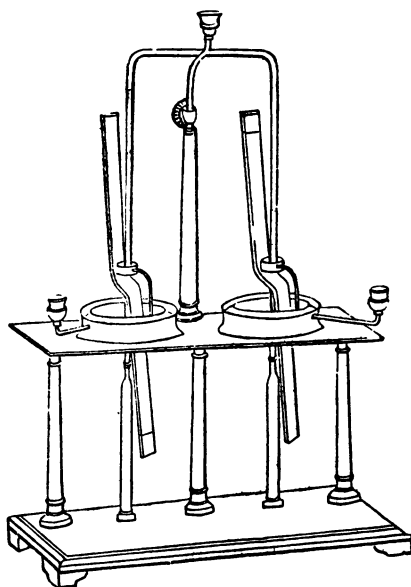
Fig. 344.



the fluid; the electric current being then transmitted through the moveable conductor, Faraday found that the free extremity instantly began to revolve round the pole of the magnet, in a direction similar to the last. A good contrivance for exhibiting this, is shown in Fig. 344.

(953) In order to obviate the necessity of employing so much quicksilver, which, by the resistance which it offers to the revolution of the magnet, greatly diminishes the velocity of the rotation, the apparatus in Fig. 345, was devised by Mr. Watkins. It exhibits the contrary poles of two magnets rotating about two electrified wires. Two flat bar magnets, doubly bent in the middle, and having agate cups fixed at the under part of the bend, by which they are supported upon upright pointed wires, are affixed in the basis of the apparatus, upon which they turn round as upon an axis. Above the agate cups, on the upper part of the bend, small cisterns to hold mercury are also formed. Two circular troughs to contain mercury, are supported

Fig. 345.



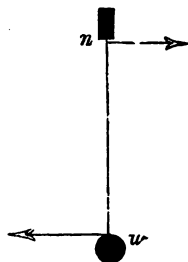
upon a stage, affixed to the basis, having holes in their centres, to allow the magnets to pass through them. A bent pointed wire is affixed into the cisterns of each magnet, the ends of which dip into the mercury contained in the troughs upon the stage; and through the sides of the trough, wires are passed, entering into the mercury contained in the troughs, and bearing at their ends other cups to hold mercury. To steady the motion of the magnets, wire loops are affixed to them, which embrace the upright

pointed wires on which the magnets rest. A hollow pillar is firmly affixed to the stage, in which a bent wire supporting another cross wire is inserted, and is capable of being raised or lowered, and secured

at any required height by a binding screw. The two ends of the cross wire are bent downwards and pointed, and made to enter the two small cisterns affixed upon the magnets. A third cup to contain mercury is also provided at the top of the cross wire, and a communication being made with the battery by means of uniting wires dipping into the mercury in the cups, the wire from the positive end of the battery being placed in the upper cup, and the wire from the negative end in each of the lower cups, the magnets will begin to rotate in opposite directions, and those directions may be reversed, by changing the situations of the uniting wires. Two batteries should here be employed, in order to make both the magnets revolve with the desired velocity; and attention must be paid, when using two batteries, that the currents of Electricity flow in the same direction; otherwise, the phenomena of the revolutions of the magnets in contrary directions will not take place, but they will both revolve in the same direction. (*Popular Sketch of Electro-magnetism*, by Francis Watkins.)

(954) Thus it will be seen that the direction of the rotation imparted by a fixed current to a moveable pole, will be the same as that which the same pole imparts to the same current. Suppose w (Fig. 346) to represent a section of a conducting wire, along which a positive current is descending, and n the N. pole of a magnet; the influence of w on n will be to impel it in the direction of the arrow; but n will also react on w , and tend to produce in it motion in an opposite direction, as exhibited by the arrow attached to w . Each is supposed to describe a circle round the other, moving in the same direction as the hands of a watch; and if w and n were at liberty equally to move, they would have a tendency to rotate round the line between them.

Fig. 346.



(955) Ampère first succeeded in effecting the rotation of a magnet round its own axis. In his original experiment the magnet was allowed to float, without a support, in a vessel of mercury, being kept in a vertical position by a weight of platinum attached to its lower end. The object was to make the electrical current pass through one half of the magnet itself, and then to divert it from its course, and make it pass away in such a direction as that it should not affect the other half. The reason of this is evident: suppose a positive current be made to descend a magnet placed vertically, its N. pole being uppermost, it would tend to urge that pole round from left to

right, but its influence on the S. pole would [be just the reverse, tending to urge it from right to left; or if two electrical currents be supposed, corresponding to the vitreous and resinous electricities, the tendencies would be the same; and here it may be as well to mention, that in describing the phenomena of Electro-magnetism, we shall, to avoid tediousness, adopt the language of a single fluid, and suppose, that in the connecting wire of a voltaic battery, the electrical current is passing in one stream from the positive to the negative end.

(956) In Ampère's experiment, the electric current, after traversing the upper half of the magnet, passes into the mercury, and being diffused through it, acts in no sensible degree on the lower half, and does not interfere with the rotation produced by its influence on the upper pole.

It is, however, better to carry off the current by a different channel, and this is effected by adopting the form of apparatus, shown in

Fig. 347.

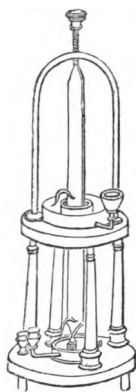


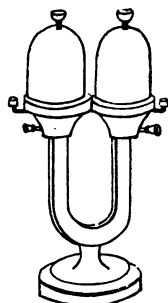
Fig. 347. It is thus constructed by Mr. Watkins. A flat bar magnet is supported in a vertical position by an upright metal wire, affixed in the basis of the apparatus, and having a hole in its centre, containing an agate cup, to receive the lower pointed end of the magnet; its upper end turns in another hole, made in a vertical screw, with a milled head to turn it by, which is passed through a screw hole, made in an arched piece of wire, affixed to the upper part of the basis. Around the first mentioned vertical wire a cistern to contain mercury is provided; and another, having a hole in its centre, to allow the magnet to pass through, and revolve within it, near the middle of the magnet. These cisterns have metal wires projecting into them, through their sides, to support cups

which contain mercury, to effect the communication with the voltaic battery by means of uniting wires. Into the magnet two small bent and pointed wires are affixed, the ends of which dip into the mercury contained in the cisterns. When the voltaic circuit is complete, the magnet begins to rotate within the Electricity, which it conducts itself, as it in fact forms part of the circuit; the rapidity of the revolutions of the magnet depending upon the delicacy of the sustaining point, the strength of the magnet, and the power of the battery employed. If it be desired to actuate a large magnet, it is necessary that an addition to the apparatus should be made, by providing a cup, affixed to the vertical screw, to contain mercury, by which contrivance, and by employing an additional battery, a current of Electricity can be

passed from the top of the magnet to its equator; and, as in the first mentioned case, an opposite current can be passed from its lower end to the equator, an additional force is obtained. The current from the second battery must, of course, be sent along the upper half of the magnet, in a direction contrary to that which passes through the lower pole; but since the rotatory force is proportional to the power of the voltaic battery employed, it is probable that the second battery would be equally efficacious, if it were employed in increasing the strength of the first by being joined to it. The ends of the wires should be amalgamated, by rubbing them first with nitrate of mercury and then dipping them into the clean metal.

(957) Fig. 348 represents an apparatus to exhibit the rotation of a conducting body round its own axis, and is exactly the converse of the last experiment. In the former case, the electric current was applied in the interior of the magnet, but here means have been devised for procuring the action of the magnet, from the interior of the conducting body. In the place of the wire, therefore, a hollow metallic cylinder is employed, in the axis of which the influencing magnet can be placed.

Fig. 348.



Mr. Barlow devised this instrument, and the figure shows the arrangement on a horse-shoe magnet by Mr. Watkins. A horse-shoe magnet is supported vertically upon a stand, having holes formed in the centres of its ends. Two wooden circular troughs are secured by binding screws upon the arms of the magnet, to contain mercury. Into the holes in the centres of the ends of the magnet, two conical pointed wires are inserted, which are affixed in the middle of two hemispherical cups, united to cylinders, the rims of which are formed into points, which are dipped into the mercury contained in the circular troughs. Upon the top of each hemisphere is placed a small platinum cup to contain mercury. Other cups for holding mercury are supported on the external ends of bent wires, which pass through the sides of the circular troughs into the mercury contained therein. When a stream of voltaic Electricity is passed through this apparatus by means of connecting wires, placed in the mercury contained in the upper and lower cup, the cylinders commence revolving in opposite directions, that cylinder on the N. pole, and down which the current is descending, moving from left to right; but if the two upper cups be united by a wire, and the lower cups connected with the positive and negative extremities of the voltaic battery, the same stream will traverse both sides of the apparatus, passing upwards in one cylinder, and downwards in the other; and the rotations

will now, from the contrary influences of the two poles, be in the same direction in both cylinders.

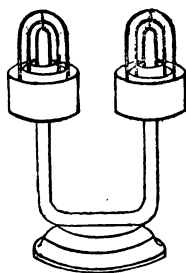
(958) Faraday has shown, that the results in this last experiment, are the same when the magnet and conductor are united together; for on fixing a thin piece of wood on the upper end of a magnet, loaded at its lower extremity with a platinum weight, floating in a vessel of quicksilver, and attaching to the wood an arch of strong wire, the whole apparatus commenced revolving on the transmission of the electric current through it; on the other hand, when a hollow cylinder of metal was balanced on a vertical axis of wood, and acted on by the poles of a magnet placed *outside*, the rotatory force was very feeble. This affords us means of explaining the circumstances of the rotation of a magnet about its own axis, for the explanation of that experiment will very much depend on the course which the current of Electricity is supposed to take in its passage through the magnet. If it be supposed to pass through the interior, along the axis of the magnet, it would then occasion rotation by its influence on the parts of the magnet that are situated nearer the surface; but if the course of the current be supposed to be along the surface, it will itself be influenced by the polarity of those portions of the magnet which lie near the axis, and the rotatory tendency impressed upon it will produce the rotation of the magnet, which will, of course, be carried along with it. This, it will be seen, corresponds with the rotation of a conducting body round its own axis, a magnet being in the centre; and it has been shown above, that the circumstance of the magnet and conductor being immoveably joined makes no difference in the results.

(959) Another fact is made apparent by this last experiment, which is, that the electro-magnetic influence of the conductor takes place equally when the electrical current is diffused over a considerable surface, as when it is concentrated in a single wire; in the cylinder, every filament of which it is composed may be supposed to conduct its share of the current, and thus contribute towards the general effect.

(960) A magnetic needle is found to be influenced by the current of Electricity that is passing through the voltaic battery from its *positive* to its *negative* pole, as well as by the wire that completes the circuit, or in other words, every part of the circuit exhibits the same electro-magnetic properties; and as action always implies an equal and corresponding re-action, the magnet may be supposed to have a tendency to move the battery, equal to that which the battery has to move it. This tendency was first actually exhibited by a very ingenious contrivance of Ampère, and which Mr. Watkins

has applied to each of the poles of a horse-shoe magnet, as shown in Fig. 349. It consists of a horse-shoe magnet, firmly fixed to a stand at its bent part; its two ends being made round, and having a small hole in the centre of each, at the bottom of which hole, an agate cup is placed, in which pointed wires fixed to the parts presently to be described are made to revolve. A double cylindrical copper vessel, having a bent metal wire fixed to the top of its innermost cylinder, with a vertical wire pointed at both ends fixed in the middle of that bent wire, is hung upon the upper end of each pole of the magnet, the lower points of the vertical wires of each vessel entering the holes, formed as above described, in the magnet for that purpose. Two hollow cylinders of zinc, each furnished with similar bent wires, having holes made in the under sides of each, are then placed within the double copper vessels; the holes in the bent wires being hung upon the uppermost pointed ends of the vertical wires before mentioned. Diluted acid being then poured into the space between the copper cylinders, the voltaic action commences, and presents the phenomena of the whole four cylinders revolving upon their axes, the copper vessels revolving in opposite and contrary directions, and the zinc cylinders turning in opposite directions to them: the rapidity of their revolutions depending upon the strength of the acid and the delicacy of their suspension.*

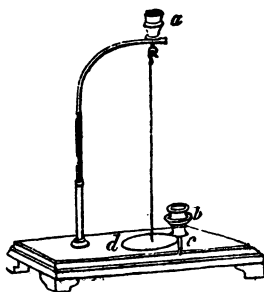
Fig. 349.



(961) Numerous amusing experiments have been devised for exhibiting the vibratory tendencies of electrified wires when under the influence of magnets. Fig. 350 represents an arrangement by Mr. Marsh.

Fig. 350.

It consists of a slender wire, suspended from a loop and capable of free motion; its lower end is amalgamated, and dips into a small cistern of mercury; the cups *a* and *b* are filled also with mercury, and through them the electrical current is passed down the loose wire; no motion of this wire is perceptible until a horse-shoe magnet is placed in a horizontal position on the basis, with its poles enclosing the wire, when it is instantly urged either forwards towards *c*, or backwards towards *d*,

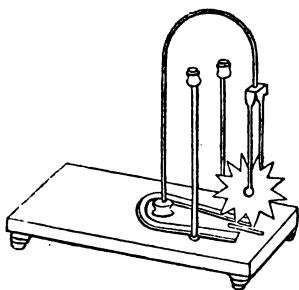


* The zinc cylinders revolve with great rapidity, but from the superior weight of the copper cylinders when filled with the exciting liquor, it is rarely that a rapid rotation can be exhibited in them.

according to the position of the poles, and the direction of the current. In either case it is thrown out of the mercury, and the circuit being thus broken, the effect ceases, until the wire falls back again by its own weight into the mercury; when the current being re-established, the same influence is again exerted, the phenomenon is repeated, and the wire exhibits a quick succession of vibratory motions.

(962) This vibratory motion is easily converted into one of rotation by employing a spur wheel, as in Fig. 351. The radii of the

Fig. 351.

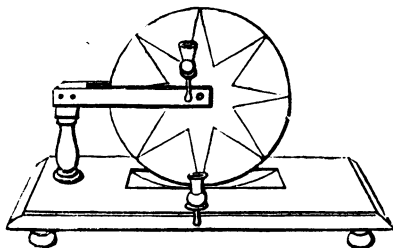


wheel must be so arranged that each ray shall touch the surface of the mercury before the preceding ray shall have quitted it. The direction of the motion depends of course on the same circumstances as were before mentioned.

This forms a very brilliant experiment when a powerful battery and a strong magnet are employed. The wheel revolves with immense velocity, and streams of sparks of a green colour, arising from the combustion of the copper points of the radii of the wheel, are thrown sometimes over the cups of the instrument.

Mr. Sturgeon found that the division of the wheel into rays was not necessary, and that if a circular metallic disc be substituted for the spur wheel, as shown in Fig. 352, it will revolve equally well. In

Fig. 352.



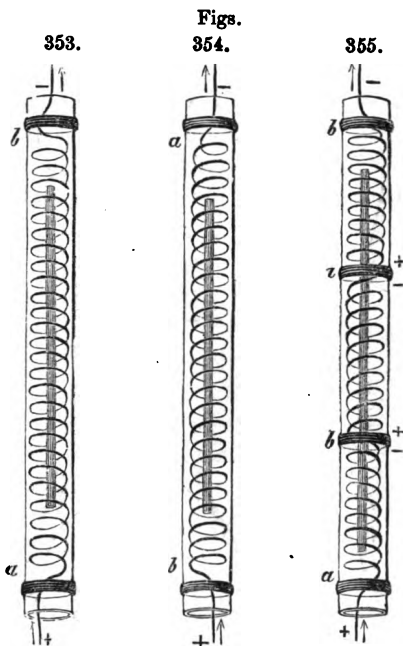
all these experiments it is important that the ends of the wires and surface of the metals which touch the mercury should be well amalgamated in order to ensure perfect contact.

By altering the direction of the electrical current all the vibrations and rotations that have been just described are reversed.

(963) *Magnetizing Properties of the Voltaic Current.*—If the wire which connects the two extremities of a voltaic battery be plunged into fine iron filings, a considerable portion will be attracted and will remain attached to the wire as long as the current continues to circulate through it; on breaking the circuit, the filings will immediately drop off. If small steel needles be laid across the wire, they

will also be attracted, and on removing them they will be found to be permanently magnetized. The voltaic current is thus seen to possess the power of decomposing the natural Magnetism of magnetic bodies, in a manner precisely similar to magnets themselves. From what has been already said, it will appear evident that in order to give the current its full efficiency, it should be allowed to pass transversely round the iron or steel; it should surround it in the form of a helix. Here again we

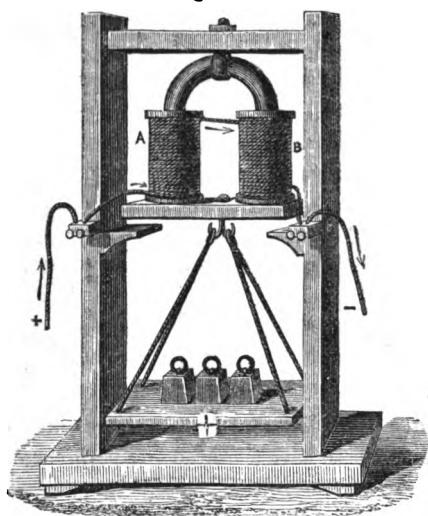
find the polarity given to the needle to depend on the direction of the turns of the helix. If it be a right-handed spiral (Fig. 353), the N. pole is always formed at the end at which the current enters, that is, on the positive side; if it be a left-handed helix (Fig. 354), the bar acquires at this end, a southern polarity. If the wire be twisted round the tube in such a manner as to form reverse contrary helices following one another, then the needle is magnetized with "consecutive poles" (807) at the junctions of the helices, each helix acting as if it were alone. If the helix be constructed in such a manner that it turns alternately from the right to the left, the needle will not be found to have acquired any permanent polarity. The magnetizing power of the voltaic current is exerted instantaneously, the steel bars acquiring the utmost Magnetism they are capable of receiving the moment the circuit is completed. This instantaneous breaking down of the resistance offered by the coercitive force of the bar is a phenomenon of a very remarkable character. We have in a previous chapter (828) described the application of the helix to the magnetizing of large steel bars by Elias of Haarlem. This method has been compared by Frick (*Annual Report of the Progress of Chemistry*, 1849), with that of the touch (819), an electro-magnet being used; on the whole he prefers the latter. By employing, however, the band spiral (828) recommended by Böttger, a 6-lb. bar of very hard cast steel was magnetized to satu-



ration as completely as it could have been by any known process of communicating permanent Magnetism, merely by passing the spiral once backwards and forwards along the bar.

(964) *Electro-Magnets*.—When bars of soft iron are submitted to the influence of the voltaic current, they acquire a very high degree of Magnetism, but the *coercitive* force, that is, the force in a magnetic substance which opposes the separation of the two magnetic fluids, and their recombination when separated, being, in iron, almost inappreciable, the Magnetism is only temporary, the bar returning nearly to its normal state the moment the current ceases to pass through the enveloping helix; we say *nearly* to its normal state, because if the iron be not perfectly pure it always retains a certain amount of Magnetism. Fig. 356 shows the ordinary arrangement of the horse-shoe electro-magnet. The copper wire,

Fig. 356.



which for large bars should be very stout and well covered with silk, is wound a great number of times round the two arms, so as to form two bobbins, A and B. It must turn in the same direction round each bobbin, in order that the two extremities of the bar should acquire opposite polarities; the S. pole being formed on the side at which the current enters, and the N. pole on the opposite side. The power of the electro-magnet varies with the size of the iron cylinder,

with the intensity of the current, and with the length and thickness of the copper wire. With regard to the thickness of the iron bar, the power of the electro-magnet to deflect a magnetic needle, has been found by Dub to be proportional to the square root of the diameter of the cylinder, and its lifting power in proportion to its simple diameter. Instead of coiling the wire round the bobbins in one continuous length, which is known to diminish considerably the influence of the current, it is better that the total length of wire intended to be used should be cut into several portions, each of which, covered with silk or cotton, should be coiled separately on the iron; the ends of all the wires are then collected into two separate parcels,

and made to communicate with the battery, care being taken that the current shall pass along each wire in the same direction. A powerful bar electro-magnet was constructed some years ago under the direction of Mr. Faraday, for the magnetic observatory at Woolwich. The helix was 27 inches long by $2\frac{3}{4}$ inches internal diameter; it had 4 coils of No. 7 copper wire covered with tape; their lengths being 108 feet 10 inches, 120 feet, 129 feet 7 inches, and 143 feet; in all 501 feet 5 inches; and they were arranged with bars and clamps so as to admit of using one or more of the helices variously combined. The soft iron core was 28 inches long by $2\frac{3}{4}$ inches in diameter, and there were 2 other cores, each $12\frac{1}{2}$ inches by $2\frac{3}{4}$ inches, for magnetizing a steel bar placed in the coil between them. A horse-shoe electro-magnet of extraordinary power was constructed in the year 1830, for the Faculty of Sciences, at Paris, by M. Pouillet. It consisted of two horse-shoes, the ends of the branches of which were presented to each other, the bands being turned in contrary directions. The superior horse-shoe was fixed in the frame of the apparatus, the inferior being attached to a cross piece which slid in vertical grooves formed in the sides of the frame. To this cross piece a platform was suspended in which weights were placed, by the effect of which the attraction which united the two horse-shoes was at length overcome. Each horse-shoe was wrapped with 10,000 feet of copper wire, and they were so arranged that the poles of contrary names should be in contact. With a current of moderate intensity, this apparatus supported a weight of many tons.

(965) In *Sturgeon's Annals of Electricity*, vol. vi., the three following electro-magnets are described. The first is the contrivance of Mr. Richard Roberts; its peculiarity consists in the great extent of the area of the face, on the surface of which a series of grooves are formed, into which the conducting wire is coiled. The magnet is $2\frac{1}{8}$ inches thick, and $6\frac{1}{2}$ inches square on its face, into which are planed (at equal distances from each other across its surface) 4 grooves, $1\frac{1}{4}$ inch deep, and nearly $\frac{2}{3}$ of an inch broad. Into these grooves was coiled, three-fold deep, a bundle of 36 copper wires (No. 18), wrapped with cotton tape, to prevent contact with the iron, the wires having no insulation from each other. The magnet, with the conducting wire, weighed 35lbs. The armature was $1\frac{1}{2}$ inch thick, and the same size as the magnet on the face; its weight was 23lbs. The upper side of the iron, which constituted the magnet, was formed into an eye or bow, by which the whole was suspended; and a similar bow was formed on the back of the armature, to which the weight scale was attached. This electro-magnet,

x x 2

when excited by a battery of 8 pairs of Sturgeon's cast iron jars, is reported to have sustained the enormous weight of 2950 lbs. (*Sturgeon's Annals*, vol. vi. p. 168), which is nearly double the weight which the author's large magnet, the weight of which is about 112lbs., will sustain with any battery that has been tried.

The second is that of Mr. Joseph Radford. Its peculiarities consist in the convoluted figure of its face, and in the unusual arrangement of its poles, both of which are on the same convoluted strip of iron, one pole occupying the whole length on one edge, and the other the whole length of the opposite edge. Its diameter is 9 inches, and it weighs, with its copper coil, 18 lbs. 4 oz. The keeper, or armature, weighs 14 lbs. 4½ oz. The depth of the convoluted groove, or recess, is ⅔ of an inch, and ¼ of an inch wide. The width or breadth of the metal between the grooves is ½ an inch; the thickness of the magnet is 1 inch at the outside edge, and about ⅔ in the centre. When excited by a battery of 12 of Sturgeon's jars, this electro-magnet is stated to have sustained 2500 lbs. avoirdupois; it is, therefore, in proportion to its weight, much more powerful than Mr. Roberts's magnet.

The third electro-magnet alluded to (vol. vi. p. 231.) is that of Mr. J. P. Joule, and is shown in Fig. 357. *BB* are two rings of brass, each

Fig. 357.



12 inches in exterior diameter, 2 inches in breadth, and 1 inch in thickness; to each of these, pieces of iron are affixed, by means of the bolt-headed screws, *s s*, &c.: 24 of these are *grooved*, and fastened to the upper ring; 24 are plain, and affixed to the lower ring. A bundle, *WW*, consisting of 16

Fig. 358.



copper wires (each of which was 16 feet long, and ⅛th of an inch thick), covered with a double fold of thick cotton tape, was bent in a zig-zag direction about the grooved pieces. Fig. 358 represents the method adopted for giving the electro-magnetic ring a firm and equable suspension: *a a* are hoops of wrought iron, to each of which 4 bars of the same metal are riveted, and welded together at the other end into a very strong hook. The hoops are bound down to the brass rings by means of copper wires. The weight of the pieces of grooved iron was 7·25 lbs., and that of the plain pieces 4·550 lbs; and when excited by 16 pairs of the cast-iron battery, arranged into a series of 4, a weight of 2710 lbs. was suspended from the armature, without separating it from the electro-

magnet; and Mr. Joule thinks, that by the use of some precautions, which have occurred to him since making his first experiments, the actual power will be very considerably augmented.

It has been mentioned that when very soft iron is employed in the construction of the electro-magnet, its Magnetism nearly disappears, when the voltaic current ceases to flow through the helix surrounding it. It was, however, discovered by the late Dr. Ritchie, that there are other circumstances which modify the retaining power; the most remarkable of which is the *length of the magnetic circuit*. When the electro-magnet is very short, and the poles near each other, the retaining power is exceedingly small; when the magnet is very long, the retaining power is very great, the reason of which appeared to Dr. Ritchie to be this (*L. & E. Phil. Mag.* vol. iii. p. 123.) the molecules of the electric fluid, acting on each other with the same force, will obviously return to their natural position most rapidly when the length of the circuit through which the action takes place is diminished. If it be diminished till the coercitive force of the iron be overbalanced by the tendency of the molecules to return to their natural state of equilibrium, from which they have been forced by the action of the conducting wire, the electro-magnet will lose all its retaining power.

Another singular fact discovered by Dr. Ritchie was, that a *short* electro-magnet; though its lifting power be very considerable, is incapable of inducing permanent Magnetism on an unmagnetized horse-shoe of tempered steel; while an electro-magnet of 4 feet in length, though of no greater lifting power than the small one, is capable of inducing a very considerable permanent effect. It was likewise found by Dr. Ritchie that a bar electro-magnet, 4 feet long, which scarcely retained any power when its connexion with the battery was broken, on being *re-connected* with it, in the *same* direction as before, was *rapidly* converted into a powerful magnet; but after being removed, and its wires now connected with the opposite poles, it required a long time to convert it into a magnet of much inferior power, as if the atoms of Electricity, having been first put in motion in one direction, are afterwards more easily turned in that direction than in the contrary.

(966) It was first noticed by Professor Page, of Philadelphia, (*Silliman's Journal*, 1837), that during the act of sudden magnetization of a bar of iron, a peculiar sound is elicited. This phenomenon has since been studied by Marrian, Joule, Grove, Beatson, and other electricians. The sound is best observed by resting the end of a long iron bar, surrounded with a coil of covered copper wire, on a sounding board; it thus becomes a musical note, and is distinctly

audible throughout a large room. It is heard both on magnetizing and demagnetizing the iron, that is, on making and on breaking contact between the coil and the battery; but it is louder in the latter case than in the former. By suspending an iron bar so that it could vibrate freely, and circulating the voltaic current by a wire so as not to touch the bar, and breaking and renewing battery contact rapidly, Mr. Beatson elicited sounds as loud and distinct as those from a small bell; he found, moreover, that similar though feeble tones were produced by passing an intermitting current from a set of 10 of Smee's battery, through a brass wire $\frac{1}{16}$ th of an inch in diameter, stretched across a sounding board, and from an iron wire simply suspended without any tension, with each end dipping into a mercury cup. Professor Page succeeded in producing the *various notes in the scale* by carefully suspending steel bars within a series of coils, and breaking the galvanic current at the rate of five or six thousand times per minute by a revolving apparatus placed in an adjoining room. These effects are caused by a molecular disturbance of the particles of the metal by the action of the galvanic current, as has been well shown by M. Wertheim (*Comptes Rendus*, July 22nd, 1844). It is strikingly illustrated by an experiment arranged by Mr. Grove, in which a glass tube, open at both ends, but protected along its length with a copper jacket, is filled with water, in which is suspended powdered magnetic oxide of iron. On looking through the tube at distant objects, a considerable portion of the light is intercepted by the heterogeneous arrangement of the particles of the oxide; but on passing a current through a coil placed round the tube, these particles assume a symmetrical character, and much more light is transmitted. Mr. Beatson has shown (*Elect. Mag.* vol. ii, p. 295) that, at the moment the sound is produced, the metal undergoes a sudden expansion; in the case of an unannealed iron wire, amounting to about $\frac{1}{1000}$ th of an inch, and on interrupting the circuit a similar sudden contraction takes place; this expansion and contraction is independent of that produced by the heating power of the current, as was proved by the fact of its taking place *after* the current had developed the total expansion which its heating power was capable of producing. Mr. Beatson also succeeded in eliciting distinct intonations from an iron wire by means of the discharge of a Leyden Jar; and we have frequently successfully repeated the same experiment.

(967) An ingenious piece of apparatus was invented by the late Dr. Ritchie for illustrating the induction of Magnetism on soft iron. It is shown in Fig. 359, where a bar of iron is represented covered with a helix of insulated copper wire and mounted horizontally on

a wire, the extremity of which is finely pointed, so as to allow the bar to rotate freely. The two ends of the helix are bent downwards so as just to dip into a small channel of mercury divided into two parts by a diaphragm of wood; one end of the wire dips into each division of the trough, and a sufficient quantity of mercury is poured into the trough to fill it, without however allowing the two portions to become united; the mercury in each division will be found to rise a little above the level of the partition by capillary repulsion. It will thus be immediately seen that on connecting the two cells of mercury with the two plates of a battery the current must pass through the helix enclosing the iron bar before the circuit can be completed, and that the iron will consequently become for the time magnetic. Now, suppose each end of the iron bar to be opposed to the pole of a powerful steel bar magnet, an opposite pole on each side, and suppose the connexions with the battery to be made so that the N. pole of the iron bar is formed opposite to the N. pole of the steel bar, then as a necessary consequence, the opposite end of the iron bar will be a *south* pole, and will be opposed to the S. pole of the steel bar; *repulsion* will accordingly take place on each side, and the iron bar will move through half a revolution. Here the wires of the helix surrounding it pass over the wooden partition, and dipping into the opposite cells of mercury, the polarity of the bar becomes reversed and so on, the bar soon revolving with great rapidity in consequence of its polarity being reversed twice during each revolution. Sometimes the bar is arranged to rotate vertically as shown in Fig. (360.)

(968) In all these pieces of apparatus the employment of mercury is essential. Messrs. Knight have, however, devised a method of arranging the rotating magnet whereby the use of the fluid metal is dispensed with. A round plate of brass is divided by 2 small strips of ivory and the wires of the helix are terminated by 2 small metallic rollers which thus pass easily over the brass surface, contact being broken at the proper place by the ivory strips. Fig. 361 exhibits this useful modification of Ritchie's rotating magnet.

(969) In Fig. 362 a horse-shoe magnet is represented supported

Fig. 359.

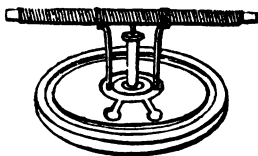


Fig. 360.

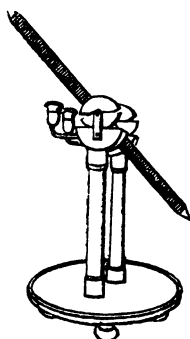
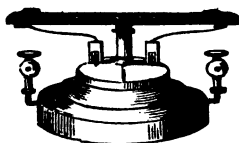
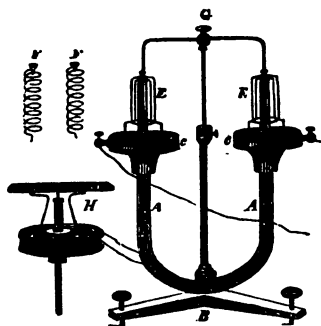


Fig. 361.



on a tripod stand with levelling screws, in which state it is well

Fig. 362.



adapted for exhibiting the rotation of coils, wires, helices, &c. *A A* is the magnet, *B* the tripod stand, *C C* two circular wooden cisterns for holding mercury, and capable of being adjusted at any required height by binding screws, *E E* are two light wire frames, *F F* two helices, *H* a Ritchie's rotating magnet; on the tops of the wire frames and helices are small cups to contain a drop of mercury, *G* is a piece of brass wire bent twice at right angles

and terminated at each end by a fine point to dip into the globules of mercury: it can be raised or depressed without disturbing the general arrangement of the apparatus, as a simple inspection of the figure will show.

When the rotating magnet is set in action in this apparatus a loud humming noise and sometimes a loud musical sound is excited by the rapid vibratory motion assumed by the fixed magnet during the rapid revolution of the electro-magnet. This musical sound is best observed when the levelling screws of the tripod are placed on a mahogany table in the middle of a large room. For the electro-magnet *H* a simple coil of wire may be substituted, the rotation of which will be exceedingly rapid, its faces becoming alternately attracted and repelled by the poles of the magnet.

(970) In *Sturgeon's Annals of Electricity*, vol. iii., p. 426, will be found a description and engraving of an ingenious apparatus for exhibiting the simultaneous rotation in opposite directions of the permanent magnet and the electro-magnet. The current from the voltaic battery instead of going directly to the mercury flood in connexion with the electro-magnet, is made to enter two concentric troughs containing mercury, placed immediately under the former, communication between the upper and lower cups being established by means of wires; the electro and permanent magnet may thus be placed on one spindle, and the former being put in motion, it was found that the permanent magnet immediately commenced rotating in an opposite direction. This instrument was the contrivance of Mr. C. W. Collins.

(971) *Electro-Magnetic Engines*.—The prodigious force which electro-magnets manifest when excited even by a feeble current, and the power of annulling or reversing it in an instant, might seem to justify a hope of its affording a motive power as energetic and

more economical than the steam engine. An immense amount of inventive talent has been expended in attempts to realize this hope. These attempts have, however, shown (observes Dr. Robinson), that electro-magnetic engines can scarcely ever be a cheap or a very efficient source of power. Electricity is now known to have a definite mechanical equivalent. The zinc and acid required to produce it are more costly than the coal which will evolve *isodynamic* heat, and the hitherto contrived methods of converting Electro-magnetism into moving force, involve much more loss than the mechanism of the steam engine does in respect of heat. It may be added that the great magnetic force exists only in contact; on the least separation of the keeper it decreases rapidly, not merely because magnetic force follows the law of the inverse squares of the distance, but because that separation destroys in a very great degree the actual Magnetism of the magnet. It must, however, be kept in mind, that there are many cases, where economy and intensity are of less consequence than facility of application and convenience, in which therefore the electro-magnetic engines deserves a preference either for industrial purposes, and much more for the work of the experimental physicist, although its action may be more costly. In particular, the absence of all danger, and perfect quiescence when not put in action, and the capability of being moved to any locality where a couple of wires can be led from its battery, deserve special consideration.

(972) A series of experiments on the application of Electro-magnetism as a motive force, is described by Dumont (*Comp. Rendus*, August, 1851), and the following consequences deduced:—

1°. The electro-magnetic force, though it cannot yet be compared to the force of steam in the production of great power, either as it regards the absolute amount of power produced, or the expense, may nevertheless, in certain circumstances, be usefully and practically applied.

2°. While in the development of great power the electro-magnetic force is very inferior to that of steam, it becomes equal and even superior to it in the production of *small* forces, which may thus be subdivided, varied, and introduced into trades and occupations using but small capitals, where the absolute amount of mechanical power is of less consequence than the facility of producing it instantaneously and at will. In this point of view the electro-magnetic force assists, as it were, the usefulness of steam in the place of uselessly competing with it.

3° Other things being proportional, electro-magnetic machines, with direct alternating movement, present a great superiority of the power developed, over rotating machines, since, in the first, there are

no components lost, and with the same expense a much more considerable power is obtained than with rotating machines.

4° In machines of direct movement the influence of the currents of induction appears less considerable than in rotating machines.

(978) To describe in detail all, or the most ingenious even, of the electro-magnetic engines that have been invented during the last eighteen years would involve far too great an expenditure of time and space. We select a few that have been thought by their inventors worthy of being patented.*

* For the convenience of those who feel inclined to see and examine the descriptions of the numerous electro-magnetic machines that have been proposed by different experimentalists, a list of references to the periodicals containing some of the principal ones, is subjoined.

Sturgeon's Electro-magnetic Engine for turning Machinery. "Annals of Electricity," vol. i. p. 75.

Jacobi's valuable paper on the application of Electro-magnetism to the moving of machines, with a description of an Electro-magnetic Engine. "Annals of Electricity," vol. i. p. 408—419.

Mr. Joule's Electro-magnetic Engine. "Annals of Electricity," vol. ii. p. 122.

Mr. Davenport's Electro-magnetic Engine. "Annals of Electricity," vol. ii. p. 257.

The Rev. F. Lockey's Electro-magnetic Engine. "Annals of Electricity," vol. iii. p. 14.

Dr. Page on Electro-magnetism as a moving power. "Annals of Electricity," vol. iii. p. 554.

Mr. Joule's second Engine. "Annals of Electricity," vol. iv. p. 203.

Mr. Uriah Clarke's Engine. "Annals of Electricity," vol. v. p. 33.

Mr. Thomas Wright's Engine. "Annals of Electricity," vol. v. p. 108.

Mr. U. Clarke's Electro-magnetic Locomotive Carriage. "Annals of Electricity," vol. v. p. 304.

Jacobi on the "Principles of Electro-magnetical Machines." *Report of the Meeting of the British Association*, Glasgow, September, 1840. "Annals of Electricity," vol. vi. p. 152. (This is a most valuable paper, and is well deserving of attentive study.)

Mr. Robert Davidson's Electro-magnetic Locomotive. *Engineers' Magazine, &c.* Part 14, p. 48.

Mr. Taylor's Engine. *Mechanics' Magazine*, vol. xxxii. p. 694.

Mr. Watkins's Electro-motive Machine. *Phil. Mag.*, vol. xii. p. 190.

An Inquiry into the possibility and advantage of the application of Electro-magnetism as a moving power, by the Rev. James William M'Gauley. *Report of the Proceedings of the British Association for the Advancement of Science*, Dublin, 1835.

"Experiments and Observations on the Mechanical Powers of Electro-magnetism: Steam and Horses. By the Rev. Dr. Scoresby. *Phil. Mag.*, vol. xxviii. p. 448.

Dr. Kemp's Patent for a new Method of obtaining Motive Power by means of Electro-magnetism. *Repertory of Patent Inventions*, Feb. 1852.

Hansen's Electro-magnetic Engraving Machine. *Athenæum*, June 17, 1854.

A new Electro-magnetic Engine, invented by M. Marie Davy. *Comptes Rendus*, May 15, 1854; and *Phil. Mag.*, vol. vii. 1854.

(974) In *Silliman's Journal*, for April, 1837, there is a notice of a rotative engine, invented and patented by Mr. Thomas Davenport of Brandon in the county of Rutland, and State of Vermont, United States. The following is a general outline of its construction: The moving part is composed of 2 iron bars, placed horizontally, and crossing each other at right angles; they are covered with insulated copper wire, and sustained by a vertical axis; proper connexion with the voltaic battery being made in the usual manner. Two semicircles of strongly magnetized steel form an entire circle, interrupted only at the two opposite poles; and within this circle, which lies horizontally, the galvanized iron cross moves in such a manner, that its iron segments revolve parallel, and very near to the magnetic circle, and in the same plane. Its axis, at its upper end, is fitted by a horizontal cog wheel to another and larger vertical wheel, to whose horizontal axis the weight is attached, and raised by the winding of a rope. By the galvanic connexion, these crosses, and their connected segments are magnetized, acquiring N. and S. polarity at their opposite ends; and being thus subjected to the attracting and repelling force of the circular fixed magnets a rapid horizontal movement is produced, at the rate of 600 revolutions in a minute, when a large calorimotor is employed. The movement is instantly stopped by breaking the contact with the battery, and then reversed by simply interchanging the connexion of the wires of the battery with those of the machine, when it becomes equally rapid in the opposite direction. Another machine, composed entirely of electro-magnets, both in its fixed and revolving members, is also described.

(975) In a subsequent number of the same *Journal*, it is stated that the proprietors had been engaged in experiments on magnets of different modifications, as well as on the proper distance between the magnetic poles of the circle; that they had entirely altered the form and arrangement of the magnets, greatly increasing thereby the energy of the machine. The use of magnets in the form of segments of a circle, was discontinued, and horse-shoe formed magnets substituted; the poles being changed once in every $3\frac{1}{2}$ inches of the circle. On this arrangement, a machine with a wheel 7 inches in diameter, elevated 90 lbs. 1 foot per minute, and performed about 1200 revolutions in the same time. It is also stated that the proprietors were engaged in constructing a machine with a motive wheel of about $2\frac{1}{4}$ feet in diameter, from which, it was expected, that sufficient power to propel a Napier's printing press (requiring a 2-horse power), would be obtained.

(976) In 1838 Captain Taylor obtained a patent for an electro-

magnetic engine in the United States; and on November 2nd, 1839, he patented the same engine in England. In the London *Mechanics' Magazine*, vol. xxxii. p. 694, there is a full description and drawing of this engine, a working model of which was for some time exhibiting in the Colisseum, in active operation, turning to the wonder and admiration of thousands, articles in wood, ivory, and iron. Referring to the above periodical for a detailed description of this engine, we shall confine ourselves to the peculiar principle of its action, as explained by Mr. Taylor. "The generality of the plans which have been hitherto devised for obtaining a working power from Electro-magnetism, have depended on taking advantage of the *change of polarity*, of which masses of iron fitted as electro-magnets are susceptible, so as to cause them alternately to attract and repel certain other electro-magnets, brought successively within the sphere of their influence, and thus to produce a continuous rotatory movement; and the failure of these attempts is owing to the difficulty, if not impossibility, of accumulating power by such means. Instead of this, Mr. Taylor employs as his prime movers a series of electro-magnets, which are alternately and almost instantaneously magnetized and demagnetized, without any change of polarity whatever taking place, and certain other masses of iron or electro-magnets, are brought successively under the influence of the said prime movers when in a magnetized state, which latter are demagnetized as soon (or nearly so), and as often as their attractive power ceases to operate with advantage; or in other, and perhaps plainer words, his invention consists in letting on, or cutting off, a stream of the electric fluid in such alternate, quick, and regular succession, to and from a series of electro-magnets, that they act always attractively or positively only, or with such a preponderance of positive attraction, as to exercise a uniform moving force upon any number of masses of iron or magnets, placed so as to be conveniently acted upon." The power of the machine constructed on this principle, which was exhibiting at the Colisseum, was small, certainly much below that of a single man. Mr. Henley, however, afterwards constructed a very large engine on the same principle, which did some work, though at an enormous expense, the battery employed containing 13 cwt. of metal.

(977) It appears from a letter in the *Phil. Mag.*, (vol. xv. p. 250,) from Professor P. Forbes, of Aberdeen, and also from a communication from Mr. Robert Davidson to the *Mechanics' Magazine*, (vol. xxxii. p. 63,) that the latter individual had anticipated Mr. Taylor in the principle of his machine, having in 1837 employed the electro-magnetic power in producing motion by *simply suspending the*

Magnetism without a change of the poles: "so close," says Mr. Davidson, "is the resemblance between Mr. Taylor's machine and one of mine, that, independently of the frame work, I believe the chief differences are, first, that the circumference of Mr. Taylor's revolving disc is composed of alternate parts of copper and ivory, while the circumference of mine is composed of alternate parts of copper and box-wood; and second, that in Mr. Taylor's machine the armatures appear to be sunk to about half their depth in the periphery of the wheel to which they are attached, while in mine they are sunk their whole depth, so as to be *flush* with the cylindrical surface."

(978) In the *Practical Mechanics' and Engineers' Magazine* for November, 1842, there is a full account and drawing of a large electro-magnetic locomotive constructed by Mr. Davidson, and tried on the Edinburgh and Glasgow Railway. The carriage is 16 feet long and 6 feet broad, and weighs above 5 tons, including batteries, magnets, &c. The electro-magnets are not one solid piece of iron, nor are they rounded behind. Each of the side parts or arms is constructed of 4 plates of soft iron put together, so as to form as it were a box for the sake of lightness. The arms are 25 inches long, and joined together behind by plates of iron. Their rectangular poles measure 8 by 5 inches, and at their nearest points are only about 4 inches asunder. The coils with which they are surrounded do not consist of a single copper wire, but of bundles of wire wrapped round with cloth to insure insulation. According to Mr. Davidson's first arrangement, these magnets were placed so that their poles were nearly in contact with the revolving masses of iron in their transit; but so prodigious was the mutual attraction that the means taken to retain the magnets and iron in their assigned position were insufficient. They required to be more firmly secured, and their distances had to be somewhat increased, which perhaps contributed very materially to the failure of the machine, which when put in motion on the rails travelled about 4 miles an hour only, thus exhibiting a power less than that of a single man, who on a level railway could certainly move a carriage of this weight at as great a velocity.

(979) In 1838, Professor Jacobi, of St. Petersburg, at the expense of an imperial commission, tried the grand experiment of propelling a boat by the agency of Electro-magnetism. The vessel was a ten-oared shallop, equipped with paddle wheels, to which rotatory motion was communicated by an electro-magnetic engine. The boat was 28 feet long and $7\frac{1}{2}$ feet in width, and drew $2\frac{1}{2}$ feet of water. In general there were 10 or 12 persons on board, and the voyage was continued (on the Neva), during entire days. The

difficulty of then managing the batteries, and the imperfect construction of the engine were sources of frequent interruption, and could not be well remedied on the spot. After these difficulties were in some degree removed, the professor gives as the result of his experiments, that a battery of 20 square feet of platinum will produce power equivalent to 1 horse: but he hoped to be able to obtain the same power with about half that amount of battery surface. The vessel went at the rate of *four miles* per hour, which is certainly more than was accomplished by the *first* little boat that was propelled by the power of steam. In 1839, Jacobi tried a second experiment in the same boat; the machine, which was the same as that used on the previous occasion, and which occupied little space, was worked by a battery of 64 pairs of platinum plates, each having 36 square inches of surface, and charged according to the plan of Grove with nitric and sulphuric acid. The boat, with a party of 12 or 14 persons on board, went against the stream at the rate of 3 miles an hour.

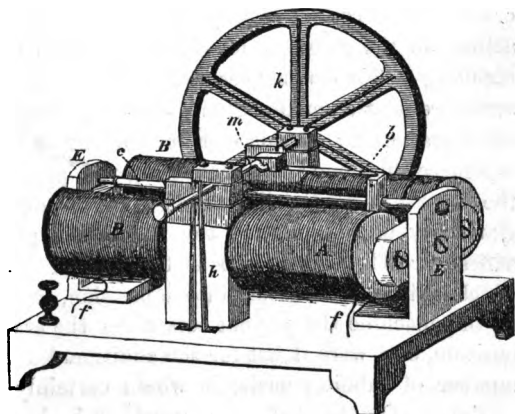
(980) Professor Page, of America, who has greatly distinguished himself by his researches in this department of science, has invented an electro-magnetic engine, the fundamental principle of which is thus described (*Silliman's American Journal*, Nov. 1850): "It is well known that when a helix of suitable power is connected with the poles of a battery in action, an iron bar within it will remain held up by the induced Magnetism, although the helix be placed in a vertical position; and if the bar be partly drawn out of the helix by the hand, it goes back with a spring when the hand lets go its hold. This power—the action of the helix upon the metallic bar within it—is the power used in Page's engine. The power, when a single coil is used, has its points of greatest and weakest force, and in this condition is objectionable. But by making the coil to consist of a series of short independent helices, which are to be brought into action successively, the metallic rod is made to pass through the coil and back again, with great rapidity and with an equable motion. In all the engines hitherto used there is a loss of power at the instant of the change of current, owing to the production of a secondary current, moving in the opposite direction, and to this loss is owing the fact that these engines cannot be rendered available. Professor Page had in view the obviating of this difficulty when he commenced his investigations. He exhibited one of his engines of between 4 and 5 horse-power at the Smithsonian Institute, the battery to operate which was contained within the space of 3 cubic feet. It was a reciprocating engine of 2-feet stroke, and the whole, including the battery, weighed about 1 ton. Page states that the consumption of 3 lbs. of

zinc a day would produce a 1 horse-power. Joule's estimate is widely different; he calculates that in an electro-magnetic engine, constructed most favourably to prevent loss of power, the consumption of zinc per 24 hours to produce 1 horse-power is in a Grove's battery 45 lbs., and in a Daniell's battery 75 lbs.

(981) By an extended application of the force which attracts a mass of iron within an electro-magnetic helix, Hankel also attempted to produce a motive power; his investigations established the important practical law "*that this force is as the square of the power of the current.*" Fessel has also described an engine constructed on the same principle (*Bibliothèque Universelle de Genève*). His model is formed of two helices placed end to end in a horizontal position. They serve to conduct the current always in the same direction, but in such a way that it traverses alternately each of the two helices, and consequently only one at a time. In the interior of the helices is a bar of iron which is alternately attracted from the one into the other by constantly maintaining the same polarity, and which thus executes a motion backwards and forwards. To the two extremities of the bar are fixed two slender horizontal shanks of brass, which rest upon two pulleys attached to the two extremities of the apparatus, and which thus support the whole weight of the iron. One of these shanks sets a wheel in motion; a commutator is moved by an eccentric, by means of a directing rod which is placed so as to be able to make the machine move backwards and forwards as in steam vessels. In his later machines, Fessel has replaced the pulleys by oscillating shanks of metal rod, similar to the oscillating cylinders of steam engines.

Fig. 363 represents a small working model of an electro-magneto-motive engine constructed by Mr. Bain, with some few improvements by the publishers of this work. On to a stout mahogany board are fixed the brass uprights *EE*; to these are attached the electro-magnets *A B*, covered with stout wire; through the upper part of these uprights, and above the

Fig. 363.



magnets, the two ends of the steel spindle *c* work; this spindle carries about its centre an iron bit, which is alternately attracted by the two magnets *A* and *B*, but prevented from absolute contact by pieces of paper; another spindle, *m*, at right angles with *c*, and supported by the uprights, *h h*, carrying at one end the fly-wheel, *k*, and on the other a small pulley, is cranked in the centre and connected with *c* by the spring and hook *b*. At *h* are seen two brass springs bearing lightly on the spindle, which is divided in the middle by a small piece of ivory, so that one only is in contact at the same time. The connexions are formed thus: one termination of the electro-magnet, *A*, is connected to one of the upright springs bearing on the spindle, and the other termination to the binding screws seen at the end of the board. The one termination of the electro-magnet *B* is connected with the other spring, and the other extremity to the same binding screw to which one end of *A* was attached, the remaining binding screw being in connexion by means of a wire with the brass box in which *m* works. The working of this machine is greatly assisted by two spiral springs fixed underneath the board attached to the moving bit. The whole arrangement performs extremely well, and no doubt if made on a large scale would be very powerful.

(182) Mr. Henley gives the following descriptions of two electro-magnetic engines, constructed by him for Mr. Talbot and Professor Wheatstone:—

“Mr. Talbot’s engine consisted of 6 powerful horse-shoe electro-magnets, placed in a line with their poles upwards; to each magnet was adapted an armature, to which was affixed a jointed arm; in the centre of the armature was a hole which was fitted to a 6-throw crank, the throws set at an angle of 60° with each other, the currents acting on the magnets in succession from 1 to 6; at the time of breaking at 6 it commences again at 1: contact is made when the armature is at a small distance from the magnet, and is continued till it reaches it; at this moment contact is broken and made with the succeeding one; the connecting rod playing through the hole in the armature allows the crank to pass down; when it remains stationary on the poles of the magnets a piece of paper prevents adhesion. There is a knob at the end of the connecting rod, by which it lifts the armature in one position, and is pulled in the other. In this machine the magnet acts when the crank is in the very best position, and were it not for the additional friction from the great number of rubbing parts, it would certainly be the best form of machine. On the shaft is mounted an A shaped frame, and at one end carries a heavy fly wheel, and at the other a contact-breaking

apparatus, which consists of a wheel and 6 levers, the points of which dip in mercury."*

The original of Professor Wheatstone's machine consists of a brass ring, within which are placed 8 magnets; an eccentric wheel revolves within, the longest radius of which passes close to each magnet successively, following the current as it were, which acts on each magnet a little in advance of the wheel; the break piece, which is stationary, is made of a piece of ivory, into which are let 8 pieces of brass; the shaft which passes through this without touching, carries a spring which presses on the break piece. The shaft and frame work is in connexion with one pole of the battery, one end of the coil on each magnet, and the other end of each with its corresponding piece of brass; the shaft also carries a fly-wheel and pulley to transfer the power. If there were a hundred magnets, of course the same battery would be sufficient, as they only act one at a time.

Mr. Henley has also constructed a machine which works a lathe, it is made with 3 horse-shoe magnets, with their poles upwards, the bent parts crossing each other; a bolt passes through them and holds them firmly to a base: within the poles revolves a soft iron cross; one magnet acts at a time, but the cross is attracted continually. The cross is suspended by 4 stout brass columns. At first there were but 2, it was found necessary, however, to add 2 more to resist the strain of the magnets, as the poles are curved, and the cross passes very close: there is a piece of apparatus to stop it immediately—it is a lever, which makes contact with one of the magnets independent of the break piece.

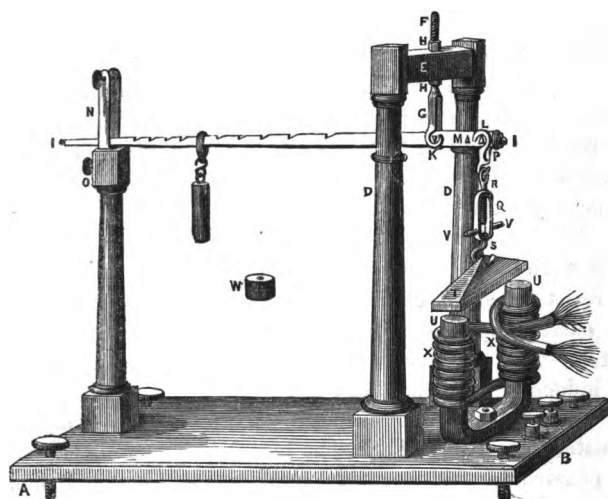
(983) Electro-motive power has been applied very successfully by M. Gustave Froment of Paris, who has obtained so high a celebrity for the construction of accurate mathematical and astronomical instruments. We had prepared a description of one of the large one-horse-power machines of this ingenious mechanician from the "Elements de Physique" of M. Pouillet; but having since been informed by the inventor that the description is inaccurate, and moreover that he had been obliged to abandon the use of the machine for giving motion to his lathes and planing machines, on account of

* This engine was 3 feet 6 inches long, and 2 feet 6 inches wide, but its power was not equal to the expectations that were formed of it; when excited by a Grove's battery, consisting of 4 cells with double plates of zinc 9 inches by 6½, platinum plates 9 inches by 5½, excited by diluted sulphuric acid 1 to 4, and concentrated nitric acid, Mr. Henley drove with it a lathe in which he turned a gun-metal pulley 5 inches in diameter, but in three quarters of an hour the battery was quite exhausted. This machine, it will be observed, was something more than a model.

the great expense of the battery, which amounted to 20 francs per day, we have not thought it worth while to have fresh drawings made of the machine. M. Froment states, however, that for delicate work, such as for giving motion to dividing instruments, polishing apparatus, &c., he finds electro-magnetic power very valuable as a mechanical agent, and constantly employs it in his workshop.

(984) *Hearder's Magnetometer*.—This simple but useful apparatus designed by its author for ascertaining the conditions which modify the development of Magnetism in iron by the action of electrical currents, is shown in Fig. 364.

Fig. 364.



A B is a strong base of wood, about 4 feet long and 1 foot wide, to which are attached 4 levelling screws. D D are two strong iron uprights, firmly screwed into the base, and connected at the top by a stout iron cross piece E, having a hole in the centre through which passes the screwed tail F, of a strong double suspension hook G. Two iron nuts, H H, serve to fix the suspension hook at any height. I I is a light and delicate, but strong steel yard, being graduated on one side to correspond with the distance between the knife edges K and M; these are respectively 1 and 2 inches apart. Different weights, from 1 oz. to 16 lbs., are applied on the long arm, according to the power to be measured. N is a rest to support the long arm of the lever, and is capable of being adjusted to any height by a tightening screw in

the hollow socket O. P is another suspension hook, upon which is hung the connecting piece Q; which, by means of the long screw R, and swivel hook S, will admit of elongation or contraction without altering the parallelism of the keeper T, of the magnet U U. The magnet is secured to the stand by a lever, which passes through a hole in the fork, and through two iron plates, one above and the other below the stand, the whole being tightened by a screw nut from below. V V are two projecting studs, which serve to support the cylindrical counterpoise weights W (seen in another part of the figure) which are made of lead cast with a hole in the centre, to allow of their being placed on, over the connecting piece Q, these weights are adjusted so as to exactly balance the long arm of the lever. A variety of magnets, differing in their shape and relative proportions, may be used in the place of N N: an extremely useful arrangement is represented in the figure. U U is a wire rope composed of 24 strands of No. 16 copper wire, each 12 feet long.

These are all previously covered with cotton and thickly varnished with sealing wax, so as to render them perfectly independent of each other. They are then twisted together into a rope, by which means every strand bears the same relative position on the magnet. The whole rope is again covered with tape and varnished. It is then coiled upon the magnet, as represented in the figure, the ends being left loose, and numbered by attaching tickets to them. The value of this arrangement will be seen by taking the two extremes of which it is susceptible. First, all the similar ends may be united in one by a binding screw at each end, thus forming one stout conductor, 12 feet long and 24 strands thick; or they may be united at dissimilar ends, so as to form one continuous length of 288 feet. A great variety of intermediate lengths and thicknesses can of course be formed, or the whole may be divided into independent conductors, carrying separate currents, either coincident or reverse. This arrangement will be found well adapted to determine the laws which govern a great variety of phenomena. For example, let it be required to ascertain the rate at which the magnetic development in iron proceeds, with known additions of exciting power. A small battery is attached to each wire, and the effect of each separately noted. The batteries are then added one after the other, and the difference between the actual and calculated effects can be thus ascertained. Again, the best mode of arranging wire upon a magnet, so as to obtain the greatest amount of power with a given quantity of wire and a battery of given dimensions, may be ascertained by taking any number of strands and uniting them in different lengths and thicknesses. The law of the resistance of wires and its relation to

electro-motive force may be investigated under a great variety of conditions, and the relative value of different voltaic arrangements for electro-magnetic purposes may be correctly examined. The practical magnetist will perceive a great variety of applications, of which the instrument is susceptible, in addition to those already mentioned.

(985) The following experiments with this instrument, having for their object to ascertain the rate of magnetic development in iron, by successive additions of exciting elements of known power, applied through separate and independent coils, have been communicated by Mr. Hearder. The 24 strands of wire upon the electro-magnet were separately tested by the same battery, and each was found to produce the same lifting power; 24 Smee's batteries were employed in separate cells, each having a platinized silver plate of 4 inches square, and 2 amalgamated zinc plates to correspond. The magnetizing power of each battery was first ascertained, and its value noted in lbs. Each battery had a single wire of the electro-magnet appropriated to it, independently of the rest, and in each case the electro-motive force of the battery was less than the resistance of the wire, or, in other words, each battery excited more Electricity than the wire would carry. The batteries were numbered, and superadded in succession each to its own wire. The 1st column in the following table gives the distinctive number of the battery wire. The 2nd, the distinctive number of the battery. The 3rd, shows the value or exciting power in lbs. of each battery. The 4th, the calculated sum of the elements employed; and the 5th shows the actual effect upon the electro magnet :

TABLE I.

Showing the rate of magnetic development in iron, by successive known increments of exciting voltaic power, applied through separate and independent coils.

No. of wire.	No. of battery.	Value of battery.	Calculated sum of the elements employed.	Total weight sustained.
1	1	14½	14½	14½
2	2	18½	32½	42½
3	3	17½	50	70½
4	4	13½	63½	94
5	5	15½	79½	111½
6	6	15	94½	125
7	7	14½	108½	142

No. of wire.	No. of battery.	Value of battery.	Calculated sum of the elements employed.	Total weight sustained.
8	8	18½	127½	155
9	9	17½	144½	169
10	10	13½	158½	174
11	11	15½	174½	186
12	12	15	189½	195
13	13	14½	203½	207
14	14	18½	222	218
15	15	17½	239½	229
16	16	18½	252½	236
17	17	15½	268½	238½
18	18	15	283½	244½
19	19	14½	298	252
20	20	18½	316½	256½
21	21	17½	333½	260
22	22	13½	346½	264
23	23	15½	262½	267
24	24	15	377½	271

(986) By this table it appears that, up to a certain point, the increase of magnetic power goes on more rapidly than is equivalent to the value of the additional exciting element. Up to 7 elements there appears an average excess of about 31 lbs., but the proportion which this excess bears to the sum of the elements, appears to diminish rapidly after this point; and when about 12 or 13 are used, the excess almost disappears, and the total weight sustained is nearly equivalent to the united power of the batteries employed. After this point the production of power bears a decreasing ratio to the power employed, and this diminution of effect becomes more and more considerable towards the end, so that the last 5 elements scarcely produce an increase of effect equivalent to the value of one. Hence, it would appear, that a limit would somewhere be found to the susceptibility of iron to undergo magnetic induction. As the addition of each battery was in effect a mere extension of surface, the intensity of battery being the same, and as each wire presented the same resistance, an experiment was afterwards made with 12 voltaic elements, separately applied to 12 wires, and after ascertaining the amount of weight sustained, the 12 silver plates were united by one common conductor on one side, and the 12 zinc plates on the other, so as to make a single pair of twelve times the area, the wires of the electro-magnet still remaining attached, *but no alteration of effect was observed.* Some results analogous to the preceding were obtained from

the following experiments, in which the increase of surface was effected by immersing a single pair of larger size in acid, by successive equal portions, and connecting an extra wire with it for each successive portion immersed: the results are given in the following table:—

TABLE II.

Showing the rate of magnetic development in wire, by successive and equal additions to the surface of the voltaic element, and corresponding additions to the capacity of the transmitting coil.

No. of wire.	Inches immersed.	Value.	Calculated sum of the elements employed.	Total weight sustained.
1	1	11	11	11
2	2	11	22	25½
3	3	11	33	40
4	4	11	44	53
5	5	11	55	66
6	6	11	66	80

This table shews the same kind of difference between the increasing ratio of the resulting magnetic power, and that of the sum of the elements employed, estimated according to their individual value.

(987) *Application of the Magnetometer to estimate the Electro-motive Character of different Voltaic Arrangements.*—Three voltaic elements were constructed as nearly as possible alike in size and surface. 1st. A Grove's nitric acid battery, consisting of a platinum plate, 4 inches square, immersed in a suitable flat diaphragm, externally to which were a pair of corresponding zinc plates. 2nd. A Daniell's sulphate of copper battery, having a copper plate of 4 inches square, and a diaphragm and zinc plates similar to the 1st. 3rd. A Smee's battery of similar dimensions, but having its zinc plates equidistant with those of the other batteries, in order to place each arrangement under the same conditions, with the exception of the omission of the unnecessary diaphragm. 4th. A Smee's battery, with the zinc plates at the ordinary distance from the silver. These batteries were first tested as to the relative quantities of Electricity excited by each, by employing a short helix of large dimensions, consequently opposing little or no resistance, the wires being united so as to form a helix 12 feet long, and 24 wires in thickness. Secondly, they were tested for intensity, by uniting the wires end to end, so as to form a single wire of 288 feet in length, thus opposing great resistance. The results are given in the following table:—

TABLE, showing the comparative power of Grove's, Daniell's, and Smee's batteries, in relation to quantity and intensity.

INTENSITY.		QUANTITY.	
Grove	87	Grove	44
Daniell	43½	Daniell	12
Smee, No. 1, open . .	27½	Smee, No. 1, open . .	42
Smee, approximated plates	32	Smee, approximated plates .	49

Thus, it appears, that nearly equal quantities of Electricity are excited by equal surfaces of Grove's and Smee's batteries, but that the electro-motive force or intensity of the nitric acid battery is rather more than three times that of Smee's. Daniell's arrangement holds an intermediate position with regard to intensity, but is deficient in quantity.

CHAPTER XIX.

MAGNETO-ELECTRICITY.

Electro-dynamic and Magneto-electric induction — Terrestrial Magneto-electric induction—Faraday's Researches—The Magneto-electric machine—Secondary currents—Electro-magnetic coil machines—The induction coils of Ruhmkorff and Hearder.

(988) *Electro-dynamic and Magneto-electric Induction.*—When a current of Electricity from a single voltaic pair is sent through a metallic wire, it induces a current of Electricity in a second wire forming a complete circuit and placed parallel to it, both at the moment when contact with the battery is made and when it is broken; but while the Electricity *continues* to flow through the first wire, no inductive effect on the second wire can be perceived. The direction of the induced current on breaking battery-contact is the reverse of that on making contact. In the former case it is in the *same* direction, and in the latter in the *reverse* of that of the inducing current. By arranging a length of about 200 feet of copper wire in a coil round a block of wood, and a second similar coil, as a spiral, between the coils of the first—metallic contact being everywhere prevented by twine—by connecting the ends of the second coil with a small helix formed round a glass tube in which was placed a common sewing needle, and then causing a current of Electricity from a voltaic battery to pass through the first coil, Faraday proved that the needle became a *magnet*, provided it was removed from the helix *before* battery contact was broken; if, however, it was allowed to remain, its Magnetism was entirely or very nearly destroyed. If the needle was introduced into the helix *after* battery contact had been made in the first coil, it acquired no magnetic properties unless it was allowed to remain till battery contact was broken, it then became a magnet, though with its poles in a contrary direction from the first, thus proving that it is only at the moment of making and breaking battery contact that a current of Electricity is induced in the second coil, and that the direction of the induced current is opposite in the two cases.

(989) If, instead of coiling the wires round a block of wood, they are arranged round a ring of iron as shown in Fig. 365, where *A* and

B represent the compound helices, being separated by about $\frac{1}{4}$ an inch of uncovered iron, a current of Electricity from the battery sent through one helix *A*, induces a current in the second helix *B*, much more powerful than when the arrangement is made round wood, but only on making and breaking contact as before; if the battery be large, a minute *spark* may be perceived between charcoal points fastened to the ends of *B*, at the moment of making, and sometimes, though not often, on breaking contact with the battery, but never while a continuous current is passing through *A*.

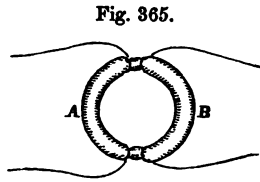


Fig. 365.

(990) To prove that the increased inductive power is occasioned by the iron and is not a common effect of metals, an arrangement of helices of copper wire may be wound round a hollow cylinder of thin wood or pasteboard, and the power of the induced current tested first with the helices alone; then, after inserting a bar of copper, lead, tin, or any other metal except iron, and perhaps nickel, in the axis of the cylinder, no effect beyond that of the helices alone will be found to be produced; but when a bar of soft iron is inserted, the power of the induced current will be found to be surprisingly increased.

(991) By the following beautiful experiment (*Ex. Resear.*, 36, 37), the property of *ordinary magnets* to induce electrical currents without the intervention of any galvanic arrangement, is clearly demonstrated. A long compound helix wound round a cylinder of pasteboard was connected with a galvanometer by two copper wires, each 5 feet in length; a soft iron bar was introduced into its axis; a couple of bar-magnets, each 24 inches long, were arranged with their opposite poles at one end in contact, so as to resemble a horse-shoe magnet, and then contact made between the other poles and the ends of the iron cylinder so as to convert it into a magnet, as shown in Fig. 366. By breaking the magnetic contacts, or reversing them, the Magnetism of the iron cylinder could be destroyed or reversed at pleasure. Upon making magnetic contact, the needle was deflected; continuing the contact, the needle became indifferent and resumed its first position; on breaking contact it was again deflected, but in the opposite direction; and then it again became indifferent; when

Fig. 366.



the magnetic contacts were reversed, the deflections were reversed.

In order to prove that the induced electrical current was not occasioned by any peculiar effect taking place during the formation of the magnet, Faraday made another experiment in which soft iron was rejected, and nothing but a permanent steel magnet employed. The ends of the compound helices being connected with the galvanometer, either pole of a cylindrical magnet was thrust into the axis, as shown in Fig. 367, the needle of the galvanometer was immediately deflected, but soon resumed its first position; on withdrawing the magnet a second disturbance of the needle took place, but in an opposite direction.

Fig. 367.



(992) When a powerful magnet is employed, induced electrical currents are evinced by the galvanometer, when the helix with its iron cylinder is brought near, but *without touching* the magnetic poles; and by experimenting with the large compound magnet belonging to the Royal Society,* Faraday was able to throw the needle of the galvanometer 80° or 90° from its natural position by placing the copper helix *without the iron cylinder* between the poles; and by using an armed loadstone capable of lifting about 30 pounds, he succeeded in *powerfully convulsing* the limbs of a frog by the induced electrical current.

(993) *Terrestrial Magneto-electric Induction.*—When a soft iron bar is held in the direction of the magnetic meridian, and inclined in the position of the *dip* of the needle, it becomes a temporary magnet, the lower end acquiring the properties of the N. pole; if the bar be inverted, its polarity is at the same time changed. Faraday took a soft iron cylinder, and having carefully deprived it of all traces of Magnetism by heat, he placed it in the axis of a coil of wire, the ends of which were connected with a galvanometer by wires eight feet long. The coil was held in the line of the dip, and then suddenly inverted; the needle of the galvanometer was immediately deflected, proving that a current of Electricity was evolved by means of the Magnetism of the globe; he afterwards succeeded in obtaining indications of Electricity *without the iron cylinder*; and by causing a circular plate of copper to rotate in a horizontal plane, electric phenomena were produced without any other magnet than the earth: when the plate was revolved in the same direction as the hands of a watch

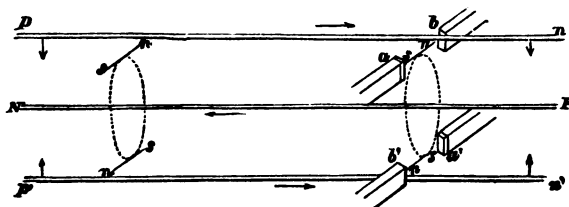
* This magnet is composed of about 450 bar magnets, each 15 inches long, 1 inch wide, and $\frac{1}{2}$ an inch thick, arranged in a box so as to present at one of its extremities two external poles. It requires a force of nearly 100 pounds to break the contact of an iron cylinder $\frac{1}{2}$ of an inch in diameter and 12 inches long, put across the poles. It formerly belonged to Dr. Gowin Knight.

move, the current of Electricity was from the centre to the circumference; when in the contrary direction, the current was from the circumference to the centre.

(994) *A new electrical machine* was thus formed, differing remarkably from the common machine in the circumstance of the plate being a most perfect conductor, and in the absolute necessity of a good conducting communication with the earth. When the plate was revolved in the magnetic meridian no electrical effects were developed, and they became most powerful when the angle formed by the plane of the plate with the dip was 90° . It was likewise shown by Faraday that a current of Electricity is produced in a wire by merely moving it from right to left, or from left to right, over a galvanometer, and he states it to be a remarkable consequence of the universality of the magnetic influence of the earth, that scarcely any piece of metal can be moved in contact with others, either at rest or in motion with different velocities or in varying directions, without an electric current existing within them; further researches likewise proved that the current produced by the magneto-electric induction in bodies, is exactly proportional to, and altogether dependent upon their conducting power.

(995) By the aid of the diagram, Fig. 368, the relation between volta-electric and magneto-electric induction may easily be understood. Suppose an electrical current to be passing through the middle wire from *P* to *N*, this wire is surrounded at every part by *magnetic curves*, diminishing in intensity according to their distance from the wire, and which in idea may be likened to rings situated in planes perpendicular to the wire, or rather to the electric current within it. The dotted rings may represent the magnetic curves round the wire *NP*, and if small magnetic needles be placed as tangents to it, they will become arranged as in the figure. But if instead of causing the needles to be influenced by an electric current,

Fig. 368.

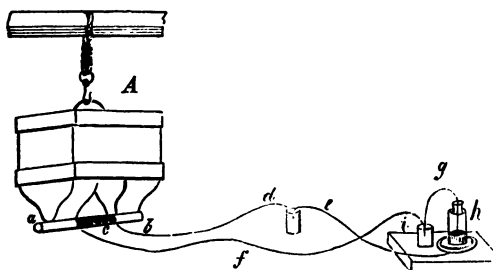


they are acted on by magnets, then in order that they shall take up the same position as before, the magnets must be placed as shown in the figure, the marked and unmarked poles *a b* above the wire being

in opposite directions to those $a' b'$ below it; in such a position, therefore, the magnetic curves between the poles $a b$ and $a' b'$ have the same general direction with the corresponding parts of the ring magnetic curve surrounding the wire $N P$ carrying the electric current. Now if a second wire $p n$ be brought near the wire carrying the electric current, it will cut an infinity of magnetic curves in the same manner as it would the magnet curves if passed from above downwards between the poles, and the electric current induced in the wire will obviously be the same in both cases; if the wire $p' n'$ be carried up from below, it will pass in the opposite direction between the magnetic poles, but then the magnetic poles themselves are reversed, consequently the induced current is in the same direction as before; it is also for equally evident reasons in the same direction, if produced by the influence of the curves dependent on the wire.

(996) *Electric Spark from a Magnet*.—Faraday first obtained a spark from a temporary or electro-magnet in November, 1831; but the first person who obtained the spark from a natural or permanent magnet in this country, was Professor Forbes of Edinburgh; the experiment was made on the 13th of April, 1832, with a powerful natural magnet capable of supporting 170 lbs., presented to the University of Edinburgh, by Dr. Hope.* The arrangement of the apparatus is shown in Fig. 369. A is the magnet; $a b$ a cylindrical

Fig. 369.



collector of soft iron passing through the axis of the helix c , and connecting the poles of the magnet; accuracy of contact was found to be of considerable importance in the success of the experiment, and one side of the cylinder was carefully formed to a curve of about 2 inches radius for this purpose. Great advantage was found from a mechanical guide—not represented in the figure—to enable an assistant to bring up the connector rapidly and accurately to the magnet in the dark. The helix c , consisted of about 150 feet of

* The first spark was obtained by Professor Forbes on the 30th of March. It appears that the first document giving an account of the excitation of a spark from a permanent magnet, is by Signor Nobili and another dated from the Museum at Florence, 21st January, 1832.

copper wire, nearly $\frac{1}{4}$ th of an inch in diameter, $7\frac{1}{2}$ inches long, and containing 4 layers in thickness, which were carefully separated by insulating partitions of cloth and sealing-wax. The one termination *d e* of the wire passed into the bottom of a glass tube *h*, half filled with mercury, in which the wire terminated, and the purity of the mercurial surface was found to be of great consequence. The other extremity *f*, of the helical wire communicated by means of the cup of mercury *i*, with the iron wire *g*, the fine point of which may be brought by the hand into contact with the surface of the mercury in *h*, and separated from it at the instant when the contact of the connector *a b*, with the poles of the magnet is effected. The spark is produced in the tube *h*.

The success of the experiment obviously depended on the synchronism of the production of the momentary current by connecting the magnetic poles, and the interruption of the galvanic circuit at the surface of the mercury; with a little practice, Mr. Forbes was able to produce for many times in succession at least two sparks of a fine green colour from every three successive contacts.

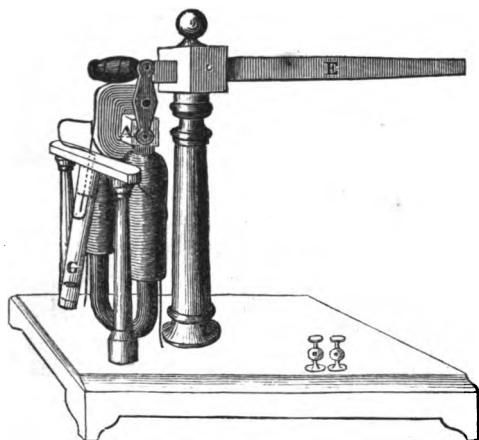
(997) The magnetic spark may be produced with great ease and certainty, and with a magnet of moderate strength by employing the little arrangement shown in Fig. 370. It consists merely of a cylinder of soft iron, round the centre of which is wound a few feet of small insulated copper wire; to one end of this wire is soldered a small disc of copper which is well amalgamated, the other end is bent up, the point cleaned and amalgamated, and brought into contact with the disc. On laying this cylinder across the poles of the magnet, and then suddenly breaking contact, the point and the disc become separated at the same time, and the spark appears. Another excellent method of showing the spark from a single pole, and which is well adapted for the lecture table, is to mount a strong bar magnet (about 2 feet long) horizontally on a stand, to wind 18 or 20 feet of wire, the ends of which are prepared, as in the last arrangement, round a piece of wood, through which a hole is cut large enough to allow the end of the magnetic bar to work freely; rapid horizontal motion is then given to the coil by means of a multiplying wheel, and contact between the point and disc is broken by the end of the bar striking a small piece of wood loosely placed at one end of the aperture in the wood, through which one end of the copper coil passes. A series of sparks which, if the magnet is powerful, are very brilliant, appear with such rapidity as to keep up a constant light.

Fig. 370.



(998) In the fourth volume of the *London and Edinburgh Philosophical Magazine*, page 104, a very simple method of detonating a mixture of oxygen and hydrogen gases by the magneto-electric spark was described by the late Dr. Ritchie. It forms an excellent class experiment. Round the soft iron lifter of a horse-shoe magnet capable of carrying fifteen or twenty pounds, 10 or 12 feet of insulated copper wire are wound. To the ends of the coil 2 thick copper wires are to be soldered in order to form a complete metallic circuit when the lifter is in contact with the poles of the magnet. The magnet is mounted, poles upwards, on a wooden stand, having a pillar with an arm or lever passing through a mortice in the top of it, for the purpose of removing, by a sudden jerk, the lifter from the poles of the magnet. In front of the magnet a glass tube is fixed, having its top closed by a cap of box-wood, through which the copper wires soldered to the extremities of the coil pass, as near air-tight as

Fig. 371.



possible, into the glass tube; the end of one wire being flattened, is bent at right angles and well amalgamated. The other, which is straight, can be brought down or removed from it by means of the lever. The whole arrangement will be readily understood by a simple inspection of Fig. 371. The mixed gases are introduced into the tube *G* by

means of a bent or flexible tube. On giving the lever *E* a smart blow with the palm of the hand, the iron lifter *A B* is suddenly removed from the poles of the magnet, a current of Electricity is induced in the coil, contact between the wires in the tube *G* is broken, a spark appears, and the gases are immediately exploded.

(999) *The Magneto-electrical Machine*.—The first magneto-electric machine—that is, an instrument by which a continuous and rapid succession of sparks could be obtained from a permanent magnet—was invented by M. Hippolyte Pixii, of Paris, and was first made public at the meeting of the *Académie des Sciences*, on Sept. 3rd, 1832. A description of this invention will be found in the *Annales des Chimie*, for July, 1832, and a representation of it in Becquerel's

"*Traité de l'Electricité*," vol. iii. With this machine, furnished with a coil about 3,000 feet in length, sparks and strong shocks were obtained; a gold leaf electrometer was made to diverge, a Leyden jar was weakly charged, and water was decomposed.

(1000) At the meeting of the British Association at Cambridge, in June, 1833, Mr. Saxton exhibited his improvement on Pixii's machine, and in the August of the same year, a large instrument on the new construction was placed in the Gallery of Practical Science, in Adelaide Street. With this machine were exhibited the ignition and fusion of platinum wire, and the excitation of an electro-magnet of soft iron; and in December, 1835, there was added to the instrument the double armature, producing at pleasure either the most brilliant sparks and strongest heating power, or the most violent shocks, and effecting chemical decompositions. Saxton's machine differs principally from Pixii's in two respects: first, in M. Pixii's instrument the magnet itself revolves, and not the armature; and secondly, the interruptions, instead of being produced by the revolution of points, were made by bringing one of the ends of the wire over a cup of mercury, and depending on the jerks given to the instrument by its rotation, for making and breaking the contact with the mercury.*

(1001) In the *Philosophical Magazine* for October, 1836, Mr. E. M. Clarke describes his ingenious arrangement of the magneto-electrical machine, in which the battery of magnets is placed in a vertical, instead of a horizontal position, whereby vibration (known to be so injurious to magnets) is materially lessened. Two soft iron armatures are employed; one is covered with 40 yards of thick copper bell wire, and is used for *quantity* effects, such as igniting platinum wire, magnetizing iron, producing the spark, deflagrating metals, &c.; and the other, the iron of which is only half the weight of the former, has 1,500 yards of fine insulated copper wire on it, and is used for the exhibition of those effects usually ascribed to intensity, viz., giving the shock, and effecting chemical decompositions.

(1002) Saxton's machine as at present constructed is exhibited in Fig. 372. Figs. 373, 374, 375, 376, 377, 378, show the different arrangements and their application to illustrate various phenomena. The letters in Fig. 372, answer to the same in the other figures. *A* is a compound horse-shoe magnet, composed of 6 or more bars, and supported on the rests *b c*, which are screwed firmly on the board

* A description and engraving of the machine deposited by Mr. Saxton in the Adelaide Gallery, in August, 1833, will be found in *Lond. and Edinb. Phil. Mag.*, vol. ix. p. 360.

B D; into the rest *e*, is screwed the brass pillar *c*, carrying the large wheel *f*, having a groove in its circumference, and a handle by which it can readily be revolved on its axis; a spindle passes from one end of the magnet to the other between the poles, and projects beyond them about 3 inches, where it terminates in a screw at *h*, to which the armatures, to be described immediately, are attached; at the further extremity is a small pulley, over which a gut band passes, by means of which, and the multiplying wheel *f*, the armatures can be revolved with great velocity.

(1003) The armatures or *inductors*, as seen at *F*, are nothing more

Fig. 372.

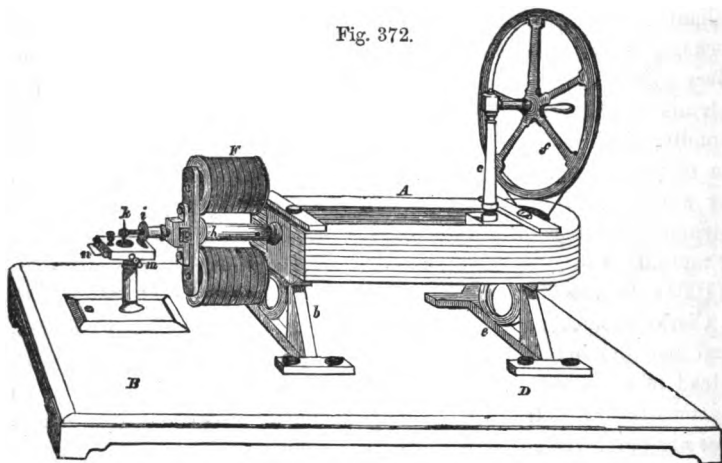


Fig. 373.

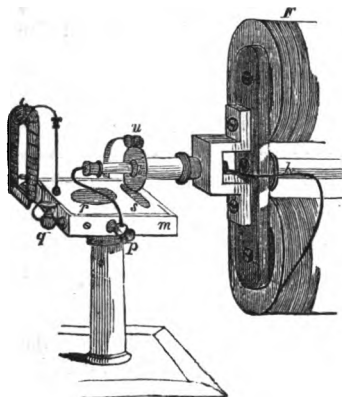


Fig. 374.

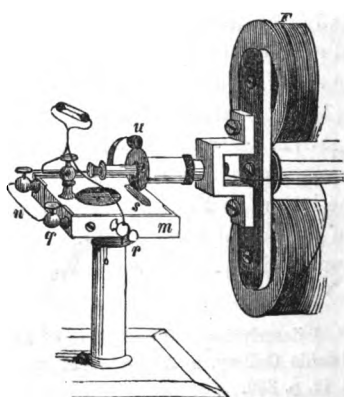


Fig. 375.

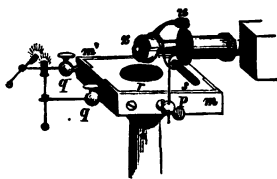


Fig. 376.

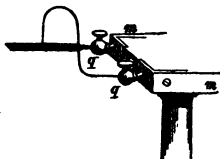


Fig. 377.

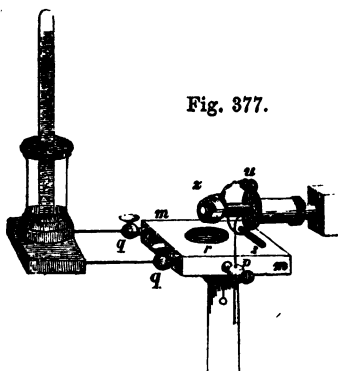
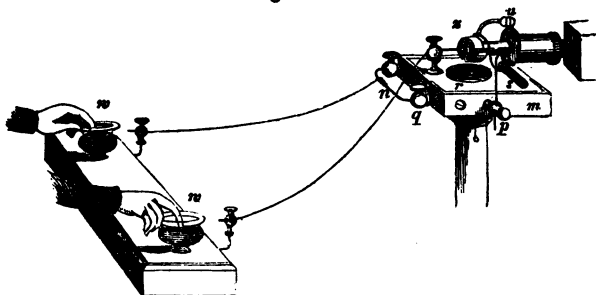


Fig. 378.



than electro-magnets; two pieces of round iron are attached to a cross piece, into the centre of which the spindle *h*, screws; round each of these bars is wound in a continuous circuit a quantity of insulated copper wire, one end being soldered to the round disc *i*, the other connected with the copper wire passing through, but insulated from it by an ivory ring. By means of the wheel and spindle, each pole of the armature is brought in rapid succession opposite each pole of the magnet, and that as near as possible without absolutely touching. The two armatures differ from one another. The one termed the *quantity* armature is constructed of stout iron, and covered with thick insulated wire. The other, the *intensity* armature, is constructed of slighter iron, and covered with from 1,000 to 2,000 yards, according to the size of the instrument, of fine insulated wire.

The *quantity* armature is adapted for exhibiting the magnetic spark, inducing Magnetism in soft iron, heating platinum wire, &c. The *intensity* is best adapted for administering the magnetic shock

Z Z

(which from only a moderate-sized machine is so powerful, that few will venture to take it a second time), and for effecting chemical decompositions.

(1004) *The Flood Cup* is that part of the instrument to which the different arrangements and apparatus used to illustrate various phenomena, are attached. The one here represented can be used either with or without mercury; it consists of a square block of wood supported on a stand capable of being raised or lowered to the height required. Two hollows, *r* and *s*, are made on the top, into which mercury is put when that medium is required; the round metal disc *i* (Fig. 372), revolves in *s*, and the point *h*, just dips into *r*; the wire fork *n*, connects the two floods of mercury together. On revolving the armature, contact is continually broken and renewed at the point *h*, and a brilliant succession of sparks, forming almost a continuous light, is produced. Two pieces of stout brass *m*, bent at two right angles, are fixed to the sides of the wood block, but insulated from each other; to these are attached binding screws, which answer in every respect the same purpose as the mercury.

(1005) Fig. 373 exhibits a small electro-magnet connected with the apparatus. A small roller *u*, attached to a spring, presses on the circumference of the metal disc *i*, at the same time a bent piece of wire is fixed by the binding screw *p*, into the centre of the copper pin, the terminating wires of the electro-magnet being connected with the binding screws *q q*. Fig. 374 exhibits the arrangement for heating platinum wire, which is enclosed in a small glass tube. Fig. 375, the arrangement for igniting charcoal points, the break piece *z*, being screwed to the copper pin, and a wire spring inserted into the binding screw *p*; by this means contact is broken and renewed, as with the mercury and points shown in Fig. 372. Fig. 377 illustrates the method of decomposing water. Fig. 376, the combustion of steel by inserting a piece of wire in one of the binding screws *q q*, and a small file into the other; on turning the wheel of the machine, and drawing the wire over the surface of the file, brilliant scintillations are produced. Fig. 378, exhibits the arrangement for administering the magneto-electric shock. *w w* represent 2 glass cups containing a little acidulated water; into these the fingers or hands are to be dipped; a small metal bottom connects them with the binding screws, one of which is connected by a wire with the fork *n*; the other is inserted into the centre of the copper pin: on turning the wheel the magneto-electric shock is communicated.

(1006) The magneto-electric machine is certainly one of the most beautiful and instructive instruments of modern science; by it we see exemplified the close connexion between, if not the identity of,

the electric and magnetic forces ; by it, the same heating, magnetizing, and decomposing powers, the same velocity of motion, the same physiological and the same chemical effects are shown to be common to both ; and let us not forget that it is to the genius and labours of an *English* philosopher that we are indebted for the development of the leading principles on which this beautiful instrument is constructed. Let us remember that the unfolding of the laws of electro-dynamic and magneto-electric induction was effected by a countryman of our own, and that these brilliant discoveries were not (as many of the first importance are known to have been) the offspring of accidental or fortuitous circumstances, but purely the result of, and affording fine illustrations of that method of physical research introduced by the great reformer of philosophy (Lord Bacon), viz., *well-founded and well-verified inductions and deductions.*

(1007) The application of the magneto-electrical machine to the art of *electro-plating* was made and patented by Mr. J. P. Woolrich, of Birmingham.* In the 38th volume of the *Mechanics' Magazine*, page 146, will be found a full and illustrated account of the machine which he employed, and of the method of conducting the process. Mr. Woolrich made use of sulphite of potash as the solvent for the gold, silver, and copper, with which the articles were plated ; and he gives in his specification a detailed account of the method of preparing the different "liquors." The thickness of the metallic coating to be deposited, depends on the time during which the article is submitted to the operation of the magnetic apparatus and solutions ; a thin coating will be deposited in a few seconds, whilst to obtain a thick coating the article must be submitted to the constant operation of the magnet and solution for several hours. The distance at which the poles of the magnet should be placed from the ends of the armature will depend on the superficies of the article to be coated ; the larger the superficies, the nearer must the magnet be placed to the armature ; and the smaller the article, the greater must the distance be increased, the distance being inversely as the superficies of the article to be coated. If the surface of the article under the operation of coating becomes, while in connexion with the magnetic apparatus, of a brownish or darkish appearance, or if gas be evolved from its surface, the distance between the poles of the magnet and the ends of the armature must be increased until the metal contained in the solution is properly deposited. Mr. Woolrich subsequently introduced such improvements into the magneto-electric machine, that at the cost of about £15 he was able to construct an

* Patent dated August 1st, 1842 ; Specification enrolled, February 1st, 1843.

apparatus which was capable of depositing 60 ounces of silver per week.

The magneto-electric machine is now very extensively used in Birmingham as a substitute for the voltaic battery in the operation of electro-plating. A single Saxton's machine will, if kept in continuous revolution, precipitate from 90 to 100 ounces of silver per week from its solutions; and machines have been constructed by which $2\frac{1}{2}$ ounces of silver per hour have been deposited upon articles properly prepared for this mode of plating (Miller's "Chemical Physics," p. 407).

(1008) A very few words will suffice to explain the theory of the magneto-electrical machine, as at present understood. As often as the bent ends of the armatures or inductors *F, F, F*, Figs. 372, 373, 374, are brought by the rotation of the wheel opposite the poles of the magnet, they become by induction magnetic; but they cease to be so when they are in the position shown in Fig. 372, viz., at right angles to it. Now, we have seen (991) that at the moment of the *induction* as well as of the *destruction* of the Magnetism in an iron bar surrounded by copper wire, currents of Electricity moving, however, in opposite directions, are induced in the wire, if the circuit be complete; the points *k*, Fig. 372, are therefore so arranged that they shall leave the mercury, and thus break the circuit in the wire surrounding the armature *F*, at the moment that its ends become opposed to the poles of the magnet; for which purpose they must be placed nearly at right angles to it: the circuit is thus broken at the precise moment that a rush or wave of Electricity is determined in the wire, and hence the electrical effects that are obtained. As, however, the currents alternate in opposite directions, we cannot obtain the oxygen and hydrogen gases from decomposed water *separately*, when the full power of the machine is employed; but by causing the wire *p*, Fig. 377, to rub on the break-piece *z*, instead of on the cylindrical part, one-half of the power of the machine is destroyed, but as the induced electrical current will be in one uniform direction, the usual results of polar decomposition may be obtained.

Various methods have been contrived for obtaining a continuous electric current in one uniform direction from the magneto-electric machines: several magnetic batteries are connected together, and the respective armatures are so arranged that each shall in turn become magnetic just before the preceding armature has lost its Magnetism, a current is thus caused to commence in one coil before it has ceased in that one which immediately precedes it.

(1009) The laws which regulate the magneto-electric force excited by Magnetism in the induction spirals, have been investigated by

Lenz, and his results agree with those which, in conjunction with Jacobi, he had previously found to regulate the intensity of the electro-dynamic force excited by voltaic currents.

These laws are ("Peschel's Elements of Physics," Vol. ii., p. 236):

1° That the magneto-electric energy excited in an induction spiral by means of Magnetism is equal to the sum of the electro-motive forces of all the individual coils of the wire; this is in accordance with the fundamental law of Ohm (394).

2° With equally powerful currents the magneto-electric force will be nearly proportional to the number of coils, the thickness of the wire exerting no influence on it; its intensity will, however, be slightly diminished by increasing the width of the coils.

The excitation of the current does not keep pace with the velocity of the rotation; the production and disappearance of the Magnetism in the iron cores requiring a certain time.

(1010) *Secondary Currents*.—If a small pair of voltaic plates be moderately excited, and a small short wire used to connect its mercury cups, no spark, or only a very minute one, will be perceived, either on making or breaking contact. As, however, the length of the connecting wire increases, the spark becomes proportionally brighter, "*until, from extreme length, the resistance offered by the metal as a conductor, begins to interfere with the principal result.*"*—(Faraday's "Ex. Researches," 1067.) If two equal lengths of wire be taken, and one made up into a helix, and the other laid out on the floor, and each used to connect the mercury cups of a small battery, very great difference will be observed in the size of the spark afforded by each on breaking contact. Supposing the length of each to be 60 feet, the wire laid on the floor will give a small bright spark, while the wire wound into a helix, will produce a large brilliant spark accompanied by a snap. Again, to render the fact still more decisive, take 100 feet of covered wire and bend it in the middle, so as to form a double termination, which can be communicated with the electrometer; wind one-half into a helix, and let the other remain in its extended condition; use these alternately as the connecting wire, and the helix will be found to give by far the strongest spark.

(1011) The spark and snap are much increased when a bar of soft iron, or what is better, a bundle of iron wires, are introduced into the axis of the helix; but it is only on breaking contact with the battery that the effect is produced; the reason is, that the iron, magnetized by the power of the continuing current, loses its Magnetism at the moment the current ceases to pass, and in so doing tends to produce an electric current in the wire round it.

(1012) These effects are evidently dependent on some affections of

the current in the conducting wire, and the spark produced when the cups of the electrometer are connected by a *short* wire, is the only one that can be considered as produced by the direct power of the battery; that the increase of the spark when the wire is lengthened does not depend on any thing analogous to *momentum* in the Electricity circulating through it, and consequently producing effects at the instant the current is stopped, is proved by the fact that the same length of wire produces the effects in very different degrees, according as it is simply extended or made into a helix, or forms the circuit of an electro-magnet. How then is it to be accounted for? The ingenuity of Faraday has provided an answer.

In his ninth series of "Experimental Researches," he has shown, that if a current be established in a wire, and another wire forming a complete circuit be placed parallel to the first, at the moment the current in the first is stopped, it induces a current in the same direction in the second, the first exhibiting then but a feeble spark; but if the second wire be away, disjunction of the first wire induces a current in itself in the same direction, producing a strong spark.

The strong spark in the single long wire, or helix, at the moment of disjunction, is therefore the equivalent of the current which would be produced in a neighbouring wire, if such second current were permitted. Viewing the phenomena, therefore, as the results of the induction of electrical currents, the different effects of short wires, long wires, helices, and electro-magnets, may be comprehended. If the inductive action of a wire a foot long, upon a collateral wire also a foot in length, be observed, it will be found very small; but if the same current be sent through a wire 50 feet long, it will induce in a neighbouring wire of 50 feet a far more powerful current at the moment of making or breaking contact, each successive foot of wire adding to the sum of action; and by a parity of reasoning a similar effect should take place when the conducting wire is also that in which the induced current is formed; hence the reason why a long wire gives a brighter spark on breaking contact than a short one, although it carries much less Electricity.

(1013) If the long wire be made into a helix, it will then be still more effective in producing sparks and shocks on breaking contact; for by the mutual inductive action of the convolutions, each aids its neighbour, and will be aided in turn, and the sum of effect will be greatly increased.

(1014) The following experiments were made by the author shortly after the publication of Faraday's researches. Two sheets of thin copper, each 4½ feet long, and 26 inches wide, were cut into ribbons

1 inch wide; all the lengths were soldered together, and formed into a single coil, with list intervening. A continuous coil of copper ribbon, 234 feet long, was thus provided. At the commencement of the coil, and at intervals of 25 feet through its whole length, wires were soldered, which projected about 2 inches, and supported small cups to contain mercury. By this arrangement, the current could be sent through any length of ribbon, from 234 to 25 feet, and by the aid of the mercury cups, the effect produced on one part of the wire by the action of an electrical current sent through any other part could be examined. In describing some of the experiments made with this coil, which seem to bear on the present subject, we shall distinguish the cups by figures, indicating their position on the coil, thus:—

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
corresponding to	25.	50.	75.	100.	125.	150.	175.	200.	234. feet.

Exp. 1. When communication was made with the positive end of a pair of plates, contained in a pint cup, and excited by dilute sulphuric acid, and cup 1, and the wire from the negative end, dipped in succession into 2, 3, &c., to the end of the arrangement, the spark and snap increased in intensity to 4; at 5, it appeared the same, and afterwards went on decreasing to 10, where the spark was not nearly so large, nor was the snap nearly so loud; the maximum effect, therefore, seems to be produced with the battery when the current has traversed between 75 and 100 feet.

Exp. 2. When a half-pint battery was employed, no difference in the size of the spark could be perceived in 4, 5, 6, 7, 8; but, it was larger and brighter in these cups than in 2, 3, and 9 and 10, in which it seemed about the same: with a pair of plates, containing about one-fourth the surface of metal, no difference in the size or appearance of the spark, could be perceived throughout the whole arrangement, after cup 2, being as bright at 10, as at 3.

Exp. 3. When a pair of plates, each 2 inches square, was employed, the spark seemed brighter at 9 and 10 than either 4, 5, or 6; with a pair 1 inch square, the difference was more marked; with a pair $\frac{1}{2}$ an inch square, it was feeble in 2, 3, 4, after which it went on increasing, and at 10 it was much larger; with a pair a $\frac{1}{4}$ of an inch, a slight snap was several times heard accompanying the spark in the last 3 cups; but the sparks produced in the first 6 cups were decidedly smaller, and less bright.

Exp. 4. A pair $\frac{1}{4}$ of an inch square was then tried: sparks were produced in all the cups; feeble in 2, and 3, but in 7, 8, 9, 10, bright; largest and brightest in 10.

Exp. 5. Strips of copper and zinc, $\frac{1}{2}$ an-inch long, and $\frac{1}{16}$ th of an

inch wide, were immersed in the acidulated liquor, and connected with the coil; sparks were obtained in all the cups, bright in 8, 9, 10; the strips were then cut in half, and by rapidly breaking contact, sparks were obtained in 5, 6, 7, 8, 9, 10; they could only occasionally be got from 4, and not at all from 2 and 3. The strips were then reduced to about $\frac{1}{4}$ th of an inch long, and $\frac{1}{16}$ th wide; in 9, and 10, several sparks were obtained, but none could be got from any of the other cups.

Exp. 6. A large calorimotor, highly excited with nitrous acid, was then tried; the brightest and loudest spark was at 2; the snap was very loud, and could be distinctly heard in a room, at the bottom of a flight of stairs, the door being shut, and also the door of the room in which the experiments were made; it was as loud, every time contact was broken, as the explosion from a pint Leyden phial; the sparks were very vivid, and evolved copious fumes of mercury; these effects rapidly diminished as the connecting wire approached the termination of the coil, and at 8, 9, 10, the sparks were not more brilliant nor louder than those produced by the half-pint battery.

Exp. 7. The shock with this apparatus did not increase with the spark: when a brass conductor was grasped by the hand, and kept permanently in 1, and another held in the left hand, and dipped successively into each of the other cups, in which contact with the battery was rapidly broken by an assistant, the large calorimotor being employed, the following were the results:—

Exp. 8. The left hand conductor being in cup 2, and contact with the battery broken in it, the shock was very slight; in 3 it was stronger, and went on increasing to 10, where it was strong enough to be felt at the elbows; now the spark and snap were most intense in 2, and least in 10; hence the shock appears to be inversely as the spark.

Exp. 9. The left hand conductor was then dipped into the cup next to that in which contact was broken, being out of the circuit of the current, as for instance in 3, while contact was broken in 2; the shock went on increasing, as before, to the end of the arrangement; it was then kept permanently in 6, while contact was broken in all the other cups; in 2, 3, 4, the shocks were distinctly felt, and went on increasing to 9.

Exp. 10. The current was then passed from 2 to 9, while the conductors were held in 1 and 10, then from 3 to 8, then from 4 to 7, then from 5 to 6, shocks were felt in all cases; strongest when the current was from 2 to 9, and weakest when from 5 to 6.

Exp. 11. The wires from the battery were then connected with 1

and 2, and the conductors held in 3 and 4, then in 1 and 3, while the conductors were in 4 and 5, 1 and 4, 5 and 6, &c.; but no shocks were felt, even when the wires from the battery were in 1 and 8, and the conductors held in 9 and 10.

Exp. 12. Although, however, no shock could be obtained *directly* from this arrangement, yet the existence of a secondary current was easily proved by the galvanometer, when the positive wire from the battery was in 1 and contact broken by the negative wire in 2, one wire of the galvanometer being in 3, and the other in 10, the needle was strongly deflected in a direction indicating the passage of a current in the same direction as the inducing current, that is, from 3 to 10. When the needle had taken up its position, it was retained in it by a pin; contact was then broken in 2, and the needle was immediately deflected in a contrary direction, showing now the passage of a current from 10 to 3.

Exp. 13. By employing a coil apparatus powerful shocks were obtained from the secondary current; the wires from the large calorimotor being in 1 and 2, and the terminal wires of the primary coil in 3 and 10, shocks felt at the elbows occurred every time contact was broken, and when this was done rapidly by a revolving wheel, or by Ritchie's rotating magnet, the succession of shocks was almost intolerable; when one of the wires of the primary coil was dipped in the same cup in which contact with the battery was broken, the shocks were very violent, even with a half-pint battery. When a wheel was employed to break contact, the scintillations were very brilliant, when it was connected with the first four cups of the coil. The well known optical illusion, of a body in rapid motion appearing stationary, was beautifully shown when the room was darkened, and the large battery used. Without the intervention of the coil, the shocks obtained on breaking contact, by means of a wheel, were not so strong as was expected. The most efficient method in this case was to draw the end of the connecting wire rapidly over the edges of the ribbon, from the centre to the circumference.

Exp. 14. Secondary shocks were obtained from the coil *immediately*; i. e., without the intervention of the coil, by dipping the conductors grasped by the hand, in 10, and the negative cup of the battery, while contact was broken, in 2, 3, 4, 5, 6, 7, 8, and 9; in the last three, the shocks were as strong as could be given with any other arrangement of the apparatus, and when the coil was interposed, very severe, even when contact was broken by 2, and a half-pint battery employed.

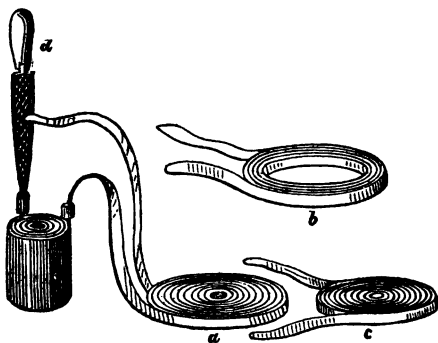
Exp. 15. The wire from the zinc end of the battery was then kept permanently in 10, and contact with the copper end broken in 9, 8, 7,

6, 5, 4, 3, and 2, the left-hand conductor being in 1, and the right in the positive cup. Shocks were felt in all; slight in 9 and 8, and strong in 4, 3, 2.*

These results agree very closely with those obtained by Professor Henry, of New Jersey, Princeton, to whom we are indebted for a very elaborate investigation of the phenomena of the induction of galvanic currents, and for the discovery of analogous results in the discharge of ordinary Electricity.

(1015) It was found by this experimentalist that when the length of the coil is increased, the battery continuing the same, the deflagrating power decreases, while the intensity of the shock continually increases, but that there is a limit to the increase of the intensity of the shock; and this takes place when the increased resistance or diminished conduction of the lengthened coil begins to counteract the influence of the increasing length of the current. When the intensity of the battery is increased, the action of the short ribbon coil decreases, but it is surprisingly increased when the length of the coil is increased in proportion. Thus Dr. Henry found that the current from a battery of 10 pairs of Cruickshank's trough, which, when sent through the ribbon, *a*, *b*, or *c*, (Fig. 379) produced scarcely any effect; when passed through a spool of copper wire $\frac{1}{4}$ of an inch in diameter, and *five miles* long, gave shocks too strong to be taken through the body; and that a battery composed of 6 pieces of copper bell-wire $1\frac{1}{2}$ inch long, and an equal number of pieces of zinc of the same size, was capable, through the medium of this long spool, to give shocks at once to *twenty-six persons* joining hands; though when a simple battery, exposing a zinc surface of $1\frac{1}{2}$ square foot was employed, no shock, or at most a very feeble one only, could be obtained.

Fig. 379.



(1016) Fig. 379 represents the method by which battery contact was broken and renewed in Professor Henry's experiments: *a* is the ribbon coil about 100 feet long; *d*, a rasp, the end of which communicates with the zinc cylinder of the battery through the medium of a cup of mercury; one end of the ribbon is placed perma-

* After these experiments were made, the ribbon was cut down the middle, and

nently in the cup connected with the copper element, and by drawing the other end smartly over the surface of the rasp, a series of brilliant sparks are produced, and the electrical current through the coil is rapidly broken and renewed.

Now on placing coil *c*, containing about 60 feet of insulated copper ribbon on coil *a*, a plate of glass being interposed, and sending the electrical current from the battery through *a*, it was found that as often as the circuit was interrupted, a powerful secondary current was induced in *c*, and that when the ends of this coil were rubbed together, sparks were produced; when a small coil of wire enclosing a needle was interposed, the needle became magnetic; when a small horse-shoe of soft iron, surrounded by a coil of wire, was interposed, Magnetism was developed; when the ends of the coil were attached to a small decomposing apparatus, gas was given off at each pole; and when the body was interposed, a shock, though a feeble one, was experienced.

When, instead of a ribbon coil, a helix containing 2,650 yards of fine insulated wire was placed on coil *a*, the magnetizing effects disappeared, the sparks were smaller, and the decomposition less; but the shock even from a single rupture of the battery current was sufficiently powerful to be sent through 56 persons, and was too strong to be received with impunity by a single individual. When a helix containing 1,500 yards of wire $1\frac{1}{2}$ of an inch in diameter was placed on coil *a*, scarcely any effects could be obtained; nevertheless when the ribbon coil was made into a ring, as shown in *b*, (Fig. 379) and the long spool of wire placed in the centre, shocks sufficiently intense to be felt at the shoulder, when passed only through the forefinger and thumb, were obtained, sparks and decomposition were produced, and needles were rendered magnetic.

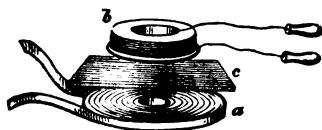
(1017) By these experiments it is proved that the induced current is diminished by increasing the *length* of the wire, and that the more so in proportion as the *size* of the wire is diminished; it is also shown that when a ribbon coil is employed, the induced or secondary current has the properties of one of considerable *quantity*, but of moderate *intensity*: and that when a helix of small copper wire is used, the

soldered together so as to form a length of about 460 feet, $\frac{1}{4}$ an inch wide, which was insulated and wound as before, into a spiral: the maximum spark, with this arrangement, a pint battery being used, was at about 150 feet; and with a very small voltaic pair, the largest and brightest spark was still at the extremity of the spiral; on the whole, the effect of dividing the copper ribbon was to diminish the *size* of the spark, but greatly to increase the intensity of the shock, which, when obtained from the last cup, and the negative end of the battery, was very severe. Water was readily decomposed by the secondary current, developed by this arrangement.

secondary current is one of small *quantity*, but of great *intensity*; the difference between the currents induced in the two cases is precisely similar to the difference which we notice between the Electricity from a voltaic battery consisting of a single pair of plates, and that from a voltaic arrangement consisting of a number of pairs in series weakly charged, as from the water battery (339). The fact that the induced current is diminished by a further increase of the wire after a certain length has been attained, is, as Dr. Henry observes, important in the construction of the magneto-electrical machine, since the same effect is produced in the induction of Magnetism. The wire on the inductor of the machine may therefore be of such a length, relative to its diameter, as to produce shocks but no decomposition; and if the length of the coil be still further increased, the power of giving shocks may also become neutralized, from the increased resistance offered to the induced current by the great length of wire: a good idea of the difference between *quantity* and *intensity* may be formed by supposing that in the first there is a large current moving slowly without any or but small resistance, and in the second a small current moving with great velocity, but still having a resistance to overcome.

The experiments of Professor Henry, relative to the induction of secondary currents at a distance, are exceedingly striking. By

Fig. 380.



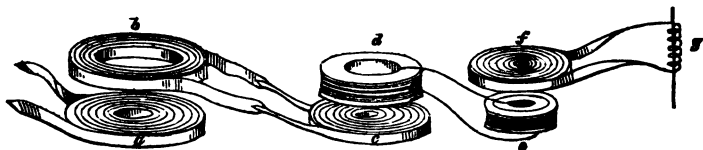
sending an intermitting current of Electricity through the spiral *a*, (Fig. 380), and placing the helix of thin wire *b*, over it, a plate of glass being interposed, shocks may be obtained on grasping the handles

attached to the coil. When *a*, consisted of about 300 feet of copper ribbon, $1\frac{1}{2}$ inch in width, and *b*, a helix of copper wire 5 miles long: Dr. Henry found that shocks might be obtained when the coils were *four feet apart*; and at a distance of 12 inches they were too strong to be taken through the body: the Professor also mentions a very instructive method of exhibiting these astonishing experiments, which we have frequently adopted in the lecture-room, viz., to cause the induction to take place through the partition walls of two rooms, for which purpose a coil, about 100 feet of ribbon, is suspended against the wall in one room, while a person in the adjoining room receives the shock by grasping the handles of a helix of about 300 yards of thin wire, and approaching it to the spot opposite to which the coil is suspended. The effect is as if by magic, without a visible cause. It is best produced through a door or thin wooden partition.

(1018) When an intermitting electrical current is sent through the

ribbon coil *a*, (Fig. 381), a secondary current is, as we have seen, induced

Fig. 381.



in *b*, placed at a distance above it. Dr. Henry further ascertained that this induced secondary current, by passing through the coil *c*, was capable of inducing a current of the *third* order in the helix *d*; and that this coil again, by passing through the helix *e*, induced a current of the *fourth* order in the coil *f*, as was proved by the power possessed by this coil of magnetizing the needle *g*; he further determined that there existed an *alternation* in the direction of the currents of the several orders, commencing with the secondary,—it was as follows:

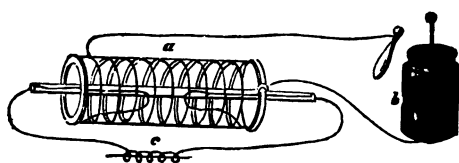
Primary current	+
Secondary current	+
Current of the third order	—
Current of the fourth order	+
Current of the fifth order	—

From our previous knowledge of this subject, the induction of currents of different orders, of sufficient intensity to give shocks, &c., could scarcely have been anticipated. The secondary current consists, as it were, of a single wave of the natural Electricity of the wire, disturbed but for an instant by the induction of the primary: yet this has the power of inducing another current, but little inferior in energy to itself; and thus produces effects apparently much greater, in proportion to the quantity of Electricity in motion, than the primary current.

(1019) In Fig. 381, the current induced in *f* by the helix *e*, is one of *quantity*; the effects, however, of the induced tertiary current in *d* would be those of *intensity*; and by grasping metallic handles, attached to the ends of that helix, shocks may be received; thus a quantity current can be induced from one of intensity, and the converse. Dr. Henry found that on interposing a screen of any conducting substance, between *a* and *b*, no secondary currents could be obtained; a circular plate of lead, for instance, caused the induction in *b* almost entirely to disappear; but when a slip of the metal was cut out in the direction of a radius of the circle, the induction was not in the least interfered with: again, the coil *b* being placed upon *a* with the two ends separated, and on the coil the helix *d*, shocks could be obtained from the latter as if the coil were not present; but when

the ends of *b* were joined, so as to form a perfect metallic circuit, no shocks could be obtained. The explanation of this apparent mystery was at first obscure; it was, however, subsequently referred by Dr. Henry to the changes in the direction of the induced currents: the secondary current, which is induced in the screening plate, or closed ribbon coil, is in the same direction as the current from the battery; it nevertheless tends to induce a current in the adjacent conducting matter of a contrary direction. A similar reaction, as it were, may be observed by placing on a flat ribbon coil, containing about 100 feet of metal, another similar coil, and then taking the shock from the first when the ends of the second are joined, the intensity will be found to be very materially diminished; although, if the ends of the second coil be not joined, no difference in the intensity of the shocks will be perceived.

Fig. 382.



(1020) By employing the arrangement shown in Fig. 382, Professor Henry succeeded in demonstrating that the discharge from the Leyden jar possesses the

property of inducing a secondary current precisely the same as the galvanic apparatus. A hollow glass cylinder *a*, of about 6 inches in diameter, was prepared with a narrow ribbon of tinfoil, about 30 feet long, pasted spirally around the outside, and a similar ribbon of the same length pasted on the inside; so that the corresponding spires of each were directly opposite each other. The ends of the inner spiral passed out of the cylinder through a glass tube, to prevent all direct communication between the two. When the ends of the inner ribbon were joined by the magnetizing spiral *c*, containing a needle, and a discharge from a half-gallon jar sent through the outer ribbon, the needle was strongly magnetized in such a manner as to indicate an induced current through the inner ribbon, in the same direction as that of the current of the jar. When a second cylinder, similarly prepared, was added, a *tertiary* current was induced in the inner ribbon of the second; and by the addition of a third cylinder, a current of the *fourth* order was developed.

(1021) In all the experiments that were tried, the results with ordinary and galvanic Electricity proved to be similar. A most interesting fact, however, came out in the course of the investigation: when the Leyden experiments were made with the glass cylinders, the currents, instead of *alternating*, as was the case in the galvanic experiments, were all in the same direction as the discharge from the

jar; but when the arrangement of coils and helices, Fig. 358, was used, the coils being furnished with a double coating of silk, and the contiguous conductors separated by a large plate of glass, the discrepancy vanished, and the alternations were found the same as in the case of Galvanism: thus the cylinders gave currents all in one direction, the coils in alternate directions. Dr. Henry made a great number of experiments, in order to get some explanation of these apparently anomalous results; and he at last succeeded satisfactorily in tracing them to the distances *of the conductors*. Thus two narrow strips of tinfoil, about 12 feet long, were stretched parallel to each other, and separated by thin plates of mica to the distance of about $\frac{1}{16}$ th of an inch. When a discharge from the half-gallon jar was passed through one of these, an induced current in the same direction was obtained from the other. The ribbons were then separated by plates of glass to the distance of $\frac{1}{8}$ th of an inch—the current was still in the same direction, or *plus*. When the distance was increased to about $\frac{1}{4}$ th of an inch, no induced current could be obtained; and when they were still further separated, the current again appeared, *but was now found to have a different direction, or to be minus*; no other change was observed in the direction of the current, and the intensity of the induction decreased as the ribbons were separated. Thus, when the conductors are gradually separated, there is, it appears, a distance at which the current begins to change its direction, and this distance depends on the amount of the discharge, and on the length and thickness of the conductors. With a battery of 8 half-gallon jars, and parallel wires of about 10 feet long, Dr. Henry found that the change in the direction did not take place at a less distance than from 12 to 15 inches; and with a still larger battery and longer conductors, no change was found, although the induction was produced at a distance of several feet.

(1022) This subject has been more recently examined by Reiss. (*Pogg. Ann.* lxxxi., p. 428, and lxxxiii., p. 309; translated, *Phil. Mag.* 4th series, vol. iii., p. 173.) To infer the strength of the current, this excellent Electrician resorted to the ignition of a fine platinum wire, introduced into the circuit and passing through an air thermometer (168) of peculiar construction.

The following were the results of his investigation:—

1st. Two portions of the connecting wire of a battery which run closely parallel, act upon each other; the current will be weakened by this action when its two parallel portions move in the same direction, and strengthened when they move in opposite directions.

2nd. Two portions of a secondary current which run closely parallel, act upon each other; when the direction of the current through both

portions are identical, a weakening is the consequence ; and when the directions in both portions are opposed to each other, a strengthening of the current is the result.

3rd. Currents of the *third*, *fifth*, and other *odd* orders, have the same direction as the original current ; and those of the *second*, *fourth*, and other *even* orders, have among themselves one and the same direction.

When primary and secondary flat spirals, each containing about 50 feet of copper wire, are placed opposite to each other a peculiar reaction of the secondary upon the primary is observed. If the ends of the secondary be connected by a thick wire, the effect upon the primary current is the same as when the ends of the secondary remain wholly unconnected. If the ends of the secondary be joined by a long thin platinum wire, the reaction of the secondary is such as to enfeeble the primary. This enfeeblement increases up to a certain limit as the resistance is increased, from which forwards it diminishes until it becomes insensible.

Fig. 383.

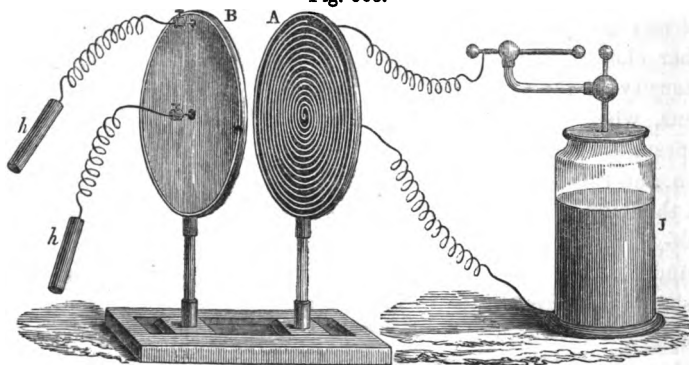


Fig. 383 shows Matteucci's arrangement of the apparatus for the development of secondary, or induction currents produced by the discharge of a Leyden jar or battery. A and B are discs of glass or gutta percha fixed vertically in metallic frames, and supported on insulating stands. They are about a foot in diameter. On one face of each is wound spirally, commencing from the centre, a long and well insulated copper wire, about $\frac{1}{16}$ th of an inch in diameter, the ends of the wire pass through the discs at the centre, and near to the circumference, and are there terminated by binding screws. A is brought into the circuit of the jar or battery through a Lane's discharger (159), and the wired face of B brought close to it ; every time the jar discharges, a shock of greater or less intensity, according to the interval between the discs, is experienced by a person

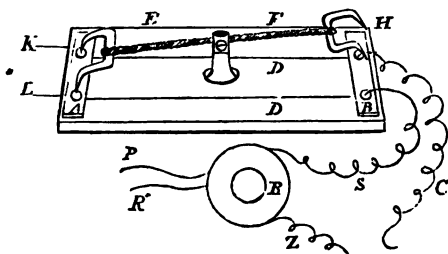
grasping the handles, *h h*. The spirals should be laid symmetrically on the discs, and the wire, after being well covered with silk, should be thickly coated with gum lac.

(1024) The reader, after the perusal of these beautiful experiments, will have no difficulty in understanding the rationale of the electro-magnetic coil machine. It was Mr. Callan, of Maynooth College, who first contrived a convenient apparatus for the illustration of secondary currents. A coil of thick insulated copper bell-wire is wound on a small bobbin; and on a larger rod with a hollow axis, in which the bobbin may be introduced at pleasure, a length of about 1,500 feet of thin wire is wound; the two coils are thus perfectly distinct from each other, and by sending the current from the battery through the interior coil, the Electricity present in the exterior coil is set in motion by its inductive influence; and from it both physiological and electrolytical effects may be obtained. The spark obtained on breaking battery-contact with the primary wire is generally fine and bright, in consequence of the *reflex wave* of Electricity which is generated in it; but if the ends of the exterior coil be brought into metallic contact, then little or no spark is seen when the primary circuit is broken, in consequence of the reaction of the induced current. If 100 yards of fine insulated copper wire be wound on a reel, and contact with an electrometer rapidly broken, shocks may be obtained by grasping metallic cylinders in connexion with the ends of the coil, from the reflex wave of Electricity which is generated; and if a bundle of iron wires be placed in the axis of the helix, the brilliancy of the sparks and the intensity of the shocks will be much increased in consequence of the *second wave* of Electricity, which we have seen is produced at the moment of the demagnetization of the iron.

Fig. 384 represents a very convenient little apparatus devised by Dr. Golding Bird (*L. and E. Phil. Mag.*, vol. xii., p. 18), for rapidly breaking and renewing battery-contact with the primary coil. It is thus constructed:—a

Fig. 384.

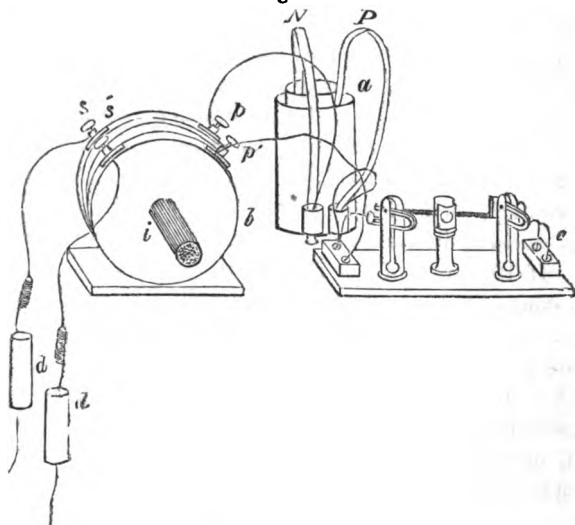
base board, about 8 inches in length, and 3 in breadth, is furnished at both ends with a piece of hard wood, *A* and *B*, each having 2 holes excavated for the purpose of holding mercury; each of these holes



communicates by means of thick copper wires, *D D*, with that

opposed to it in the other piece of wood at the opposite end of the board. Midway, between the receptacles for mercury, is a wooden support, so contrived, that a piece of soft iron wire, $\frac{1}{4}$ th of an inch in diameter, and 5 inches in length, may oscillate between the cheeks cut in its upper part, with as little friction as possible. Around this iron wire, EF , are wound two helices of thin insulated copper wire, in the same direction (from right to left), in such a manner that the two ends of one helix may terminate in the copper points $G H$, and the ends of the other helix in the points $K L$. Two small horse-shoe magnets (not shown in Fig. 384, but shown in their proper places, in Fig. 385) are then fixed on proper supports, so that

Fig. 385.



they may each be placed near an end of the iron bar, EF , in a vertical plane just posterior to it, so that on depressing the end F , of the bar, it may be opposite one pole (say the $S.$) of one magnet, and consequently the end E , will be opposite the other pole of the second magnet. On elevating the end E , the contrary will of course take place, and for this purpose, it is hardly necessary to say that the similar poles of the magnet should be in the same direction.

(1025) From this description it is evident that on connecting the cup of mercury in A or B , with the 2 plates of a single voltaic battery, the bar EF will become a temporary magnet, if the ends of either helix are allowed to dip in the mercury; and if connexion with the battery be properly made, the ends or poles of the temporary magnet will be repelled by the poles of the permanent magnet, to which they are opposed; the bar will consequently move, and so

cause the immersion of the ends of the second helix in the other cups of mercury; repulsion will again occur, and so on; about 800 oscillations of the iron bar can thus be obtained in a minute.

The coil is thus arranged: on a reel, with a hollow axis, 3 inches in length, are wound about 60 feet of copper wire, $\frac{1}{16}$ th of an inch in diameter, covered with cotton thread for the purpose of insulation, the two ends being connected with *pp* (Fig. 385), so that by means of the binding screws communication may be made by wires with the contact-breaker and battery; this is the primary coil; over it a second insulated copper wire, $\frac{1}{16}$ th of an inch in diameter, and about 1,500 feet in length, is wound, and the two ends are connected with *ss*, furnished with binding screws, for forming connexion with wires, for communicating the shock, &c.

(1026) The connexion with the battery is best made in the way shown in Fig. 384, in which *R* represents a section of the reel, *S* an end of the short helix connected with the mercury cup in *B*, *Z* the other end of the short helix connected with one plate of the battery, whilst the wire *C* connects the other cup of mercury in *H* with the other plate of the voltaic couple. When this is properly arranged, a series of induced currents may be obtained from *ss*, the extremities of the long helix, capable not only of communicating a series of intense shocks, but of exerting powerful electrolytic action; and when a bundle of soft iron wires is inserted in the hollow axis of the reel *i*, (Fig. 385), the dynamic power of the coil is considerably increased. In this case, indeed, the sparks produced when the ends of the helices round the iron bar *EF* leave the mercury, are very brilliant, accompanied by a loud snapping noise and a vivid combustion of mercury, clouds of the oxide of that metal being copiously evolved.

(1027) If the ends *PE*, of the long and thin coil are furnished with platinum points, and immersed in water acidulated with sulphuric acid, rapid electrolytic action ensues, torrents of minute bubbles of oxygen and hydrogen gases being evolved. If, instead of water, the points are pressed on paper moistened with iodide of potassium, electrolytic action ensues, iodine and oxide of potassium being separated. Solutions of neutral salts, such as sulphate of potash and soda, chloride of potassium, sodium, antimony, and copper, are also rapidly decomposed. In these experiments, as Dr. Bird remarks, it will be found that the great majority of the electro-positive elements (for example) appear constantly at one termination of the coil, *cæteris paribus*, but not all, for it must not be forgotten that on making, as well as breaking contact with the electromotor, an induced current takes place in the long coil, though of far weaker

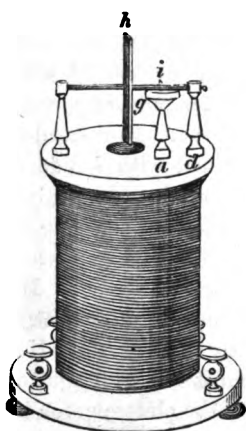
intensity than the latter, to which it is opposed in direction, and consequently in electrolytic effects.

(1028) If the brass conducting tubes *d d'* (Fig. 385), are grasped, even with the unmoistened hands, the intensity of the rapid succession of shocks will be found intolerable, even when the battery used consists but of two plates, presenting 4 or 5 square inches of surface; and with pairs of half an inch, the shocks obtained, when contact is rapidly broken (which in this case, is best done by a rotating magnet, motion being communicated by the fingers), are very disagreeable.

When the wires at the end of the conducting tubes, *d d'* are made to touch, small bright sparks are produced; and if, while the oscillating bar of the contact-breaker is vibrating rapidly, a large pair of plates being employed, a piece of well-burnt charcoal is fixed on one of the terminations, and the other drawn lightly over it, a rapid succession of brilliant sparks is obtained. These sparks depend entirely upon the induced currents, as the fine coil has no connexion with the battery. For the exhibition of this, as well as of the electric light of an energetic arrangement, pencils of that kind of artificial graphite found lining the interior of the iron cylinders used for the distillation of coal in gas manufactories are very far superior to box-wood, or indeed to any other form of charcoal.

By connecting the ends of the primary coil of this arrangement with the quantity inductor of the magneto-electrical machine, powerful shocks and strong electrolytic effects are obtained; the spring must rub on the double break, which in this experiment performs the same office as the contact-breaker; the coil, which, as

Fig. 386.



we have seen, is, when revolving before the magnets a powerful source of Electricity, supplying the place of the voltaic couple.

(1029) There are several other forms of the electro-magnetic coil machine, and many other modes of breaking battery-contact with the primary coil. Fig. 386 is a very elegant arrangement; the primary coil consists of about 35 feet of insulated copper wire (No. 12), and the secondary of 1,400 feet of silk-covered copper wire (No. 20), battery-contact is broken and renewed by the rotation of the soft iron bar *h*, which, mounted between two brass pillars, is situated immediately over the axis of the coil, in which is placed a bundle of iron wires; the electrical

current from the battery passes through the pillar *d*, and the axis carrying the iron bar; and contact is broken and renewed by the point *i* dipping, as *h* revolves, into, and out of, the mercury contained in the brass cup *g*, mounted on the brass pillar *a*, through which the circuit is completed; communication with the voltaic battery is made through one pair of the binding screws on the base of the instrument; and the shocks, electrolytical effects, &c., are obtained from wires attached to the other pair.

(1030) Fig. 387 represents another form of the instrument which possesses this advantage over the last, viz., that it does not require mercury. The current from the battery passes from the binding screw *p*, up the wire *a*, which terminates in a small disc of iron, arranged immediately over the bundle of iron wires in the axis of the coil, from which however it is prevented from coming immediately into contact, when the machine is not in action, by the horizontal spring by which it is connected with the wire *a*. The binding screw *c*, is connected with a wire, the top of which is seen in the figure rising above the coil. On the top of this wire is a horizontal strip of metal tipped with platinum, and with this, by the action of the spring, the disc of iron is kept in contact; now, when connexion is made with the battery through the wires *p* and *c*, the central core of iron wires becomes magnetized, and consequently attracts the disc of iron, thus breaking battery-contact; the current being shut off, the disc of iron is again raised by the spring, and thus contact is broken and renewed with amazing rapidity. The secondary effects are obtained from the handles attached to *p* *c*. For medical purposes, this is decidedly the best arrangement of the coil machine, as it is more compact than any other, and dispenses with the use of mercury.

Fig. 387.

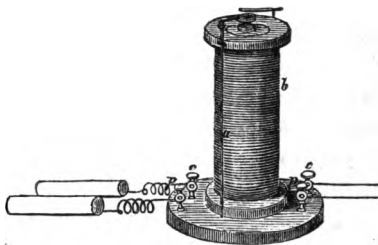
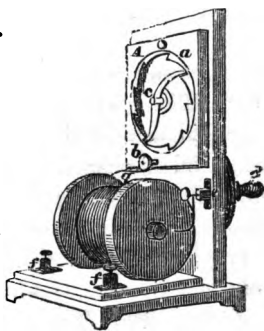


Fig. 388.

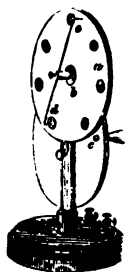
(1031) In Fig. 388 is a representation of the Rev. F. Lockey's electro-magnetic coil machine, to which is attached an apparatus for producing luminous galvanic rings. The contact-breaker is the curved spring *C*, which is carried rapidly round by the multiplying wheel and handle *d*, striking in its course against the notches



in the interior of the metallic circle *b*. This circle must have an odd number of teeth or notches, in order that the ends of the S shaped spring may produce the spark at opposite parts of the ring; when there are 25 or 35 breaks, the resulting ring of sparks is exceedingly beautiful.

The diameter of the ring *a b* may be about 5 inches; rings a foot in diameter produce very brilliant effects; they may be made of different metals, and if corresponding springs be used, there will be a different light for each. The rings are secured in the circular rabbet of the square piece of wood, *A*, by small turn buttons; one end of the primary coil is in communication with the ring, the other is in connexion with the binding screw *e*, where one of the battery wires is to be fixed. The spring *c* has metallic communication with the other pole of the battery by means of its metallic socket, to which a wire is soldered and brought down to another connecting piece symmetrical with *e*, but not visible in the figure; a small portion of this wire is seen at *g*; *f f* are the usual connecting pieces for administering the shock.

Fig. 389.



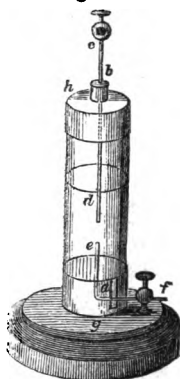
(1032) The *Scintillating circle*, Fig. 389, is another of Mr. Lockey's instruments. Seven or any other uneven number of fine files are procured, such as are used in certain engravers' work; they are of a flat and circular form, about $\frac{1}{4}$ ths of an inch in diameter; they are arranged and fixed upon an immovable disc *a*; each is in metallic contact with the other, and the whole with the terminal wire of the battery, a powerful coil being interposed. In the centre of the disc is the brass axis *b*, carrying a small pulley, to which rapid rotation can be communicated by the multiplying wheel *c*. This pulley carries the steel wire *d, e*, pointed at its extremities, and bent at such angles as lightly to drag over the faces of the files in rotation. The wire is removable at pleasure to admit of its adjustment or replacement. The central axis has a wire leading to the other terminal of the battery. On putting the apparatus in action, contact is made and broken alternately at nearly opposite diameters of the disc. The effect to the eye is a continuous circle of radiant and splendid scintillations. This is perhaps one of the most delicately beautiful of electrical experiments. The effect is much improved if instead of separate pieces of steel inserted in the brass ring, the *whole circle* is formed of steel, either cleaned off with a fine file and left purposely unpolished, or, better still, formed into a continuous and fine file over its whole surface.

(1033) The *Water Regulator*, Fig. 390, also contrived by Mr.

Lockey, is a useful piece of apparatus for the purpose of modifying the physiological effects of the galvanic shock obtained by the medium of the self-acting *coil* or other source of power. The most powerful shock can by this regulator be readily reduced to one in the mildest form. In the medical administration of galvanic Electricity, this is a point of some importance, as obviating the necessity of any adjustment of the size of the battery, the depth to which its plates are immersed, &c.; *h* is a glass tube about 5 inches in length, capped at each extremity; this tube rests upon, but is not fastened to, the base *g*, as it may sometimes be desirable to attach the regulator *directly* to the connector of the coil, by the wire *f*. The fixed copper wire *e a f* bent to a right angle at *a*, passes out close to the bottom of the cap, and is fastened by the screw connector *f*. This part is not quite correctly represented in the figure. The base *g* should be so shaped that the whole of the connector be on a level with the bottom of the cap *a g*. The copper connecting wire *c b d* passes through a stuffing-box in the centre of the upper cap *h* (which unscrews in order to introduce any convenient quantity of water). The apparatus is interposed in the circuit between one of the extremities of the coil and the person about to receive the shock; and, according as the points of the wire *d* and *e* are approximated to, or separated from one another, will be the strength or the gentleness of the shock.

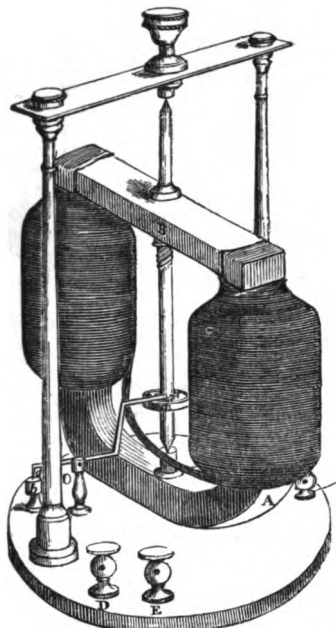
(1034) In Fig. 391, we have an engraving of a very powerful arrangement of the electro-magnetic coil machine, made, and presented to the author, by Mr. W. T. Henley. A, a series of U-shaped bars of soft iron, bolted down to a base board, and wound with 4 coils of No. 14 covered copper wire to within an inch from either extremity; over this are wound 1,000 yards of No. 34 covered wire in one continuous length. B, the revolving armature which rotates between the poles of the magnet fixed on an axis, the lower end resting on a hard steel cap, the upper kept in its position by a screw passing through a flat piece of metal mounted on 2 brass columns. O, the apparatus for breaking contact, consisting of a small lever *a*, suspended on a pillar, one end dipping into a mercury cup *b*, and the other end provided with a friction roller, running on an undulating wheel *c*, the prominent part of which, raising the end of the lever, dips the other end into the mercury, a spring *d*, raising it out when the roller falls on the lower parts of the wheel. A break-piece formed of ivory and brass may be

Fig. 390.



substituted for this, but the oxide of the metal formed by the spark is such an imperfect conductor, that 3 cells have no more effect than 1 with the mercury. D E are the binding screws for forming connexion with the battery; the opposite screws are the ends of the secondary coil. On the same side of the base with the last (not seen in the wood-cut), is an ivory knob, which being turned, connects the ends of the secondary coil, either to diminish the primary spark, as the armature will then rotate for hours without burning the mercury, or to prevent the operator from receiving an unpleasant shock while adjusting the instrument. The ends of the thick wire are passed through the base, those from one pole soldered to E, those from the other to the mercury cup; the pillar C, and binding screw D, are connected together. This machine works very well with 1 or 2 cells of Smee's battery; and with an intensity series of 8, the secondary current is exceedingly powerful, the spark passing $\frac{1}{4}$ th of an inch through air; with a battery of 10 of Sturgeon's cast iron pots, the spark from the secondary coil passes $\frac{1}{4}$ th of an inch through air, and brilliantly deflagrates gold and silver leaf; the shock would be far too powerful to be taken through the body, for when only two fingers are included in the circuit, it is sufficiently intense to be felt at the shoulders. With such a battery power the sparks from the primary coil are brilliant in the extreme; and from the ease with which the ends of the secondary coil are united and disunited, viz., by merely turning the ivory knob, the instrument is admirably adapted for demonstrating at the lecture table the induction and reaction of electrical currents; when the ends of the secondary, are disunited, the sparks from the primary are large and brilliant; when united, they are small and faint.*

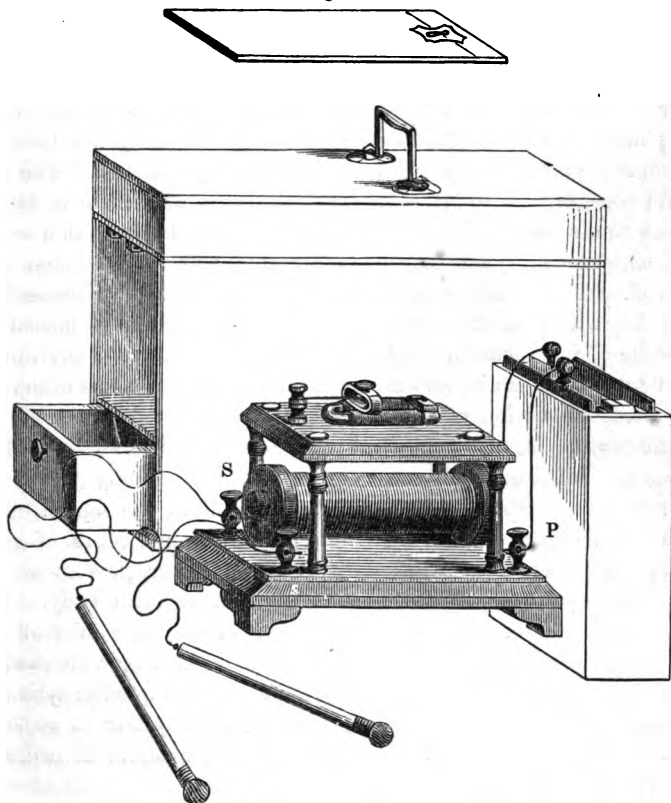
Fig. 391.



* Bachhoffner and Sturgeon appear to have first noticed that a bundle of iron wires insulated by a coating of varnish, and introduced into the axis of the primary coil, give a more powerful induced current than a massive bar of iron. Magnus and Dove (Peschel's Elements of Physics, vol. iii., p. 237) tried to ascertain the cause of this increased effect. They found that when the wires were enclosed

(1035) The electro-magnetic coil machine is from its convenience and portability admirably adapted for the medical administration of Electricity, and numerous are the forms which it has received for this purpose. Fig. 392 shows Messrs. Knight's arrangement, which they

Fig. 392.



thus describe: Round a hollow cylinder of wood a considerable length of stout copper wire, covered with cotton thread for the purpose in a metal case, the force of the current was the same as if it had been sent through solid iron. But when the tube was slit, or when the wires were not enclosed at all, the efficiency of the current was greatly heightened. Dove found on prosecuting his inquiries still further, that two perfectly equal induction spirals provided with different bars or sets of wires, even if they deflected the needle of a galvanometer equally, gave shocks of unequal intensities; he therefore inferred that the increased physiological effects depend partly on the internal structure of the iron, partly on the discontinuity of the mass, and that the greater effect is owing to the more rapid suspension of the current caused by this discontinuity. The greater intensity of the shock caused by rapidly establishing and breaking the contact of the battery admits of a similar explanation.

pose of insulation, is wound. The two ends of this coil are metallically connected with the binding screws P P on the base board of the apparatus (one of these is not seen in the cut); over this coil a very considerable length of much finer copper wire, also insulated, is wound. The two ends of this second coil are metallically connected with the binding screws S S. The coil of thick wire is the *primary*: through it the current from the battery circulates, to which it is connected by means of two stout copper wires, one proceeding from the silver and the other from the zinc element, 2 ends of the wires being inserted respectively into the binding screws of the battery, and those representing the ends of the primary coil P P. The coil of thin wire, termed the *secondary*, is destined to communicate to the patient the Electricity which is developed in it by induction every time contact between the primary coil and battery is broken and renewed. The breaking and renewing of the battery contact is effected by a little electro-magnet with a vibrating armature, placed on the stage of the apparatus, through which, by a suitable contrivance, the current from the battery is caused to pass at very short intervals. The vibrating motion of the armature throws on and cuts off the electric current from the coil, and a rapid series of shocks may thus be communicated to a patient, being directed through any part of his body, by means of the sponge directors shown in the figure. The wires to which the sponges are attached pass through tubes of glass which, while they serve as handles for the operator, prevent at the same time the shocks from passing through his own body. The inductive effects of the coil, or, in other words, the power of the shock, is increased or diminished, by introducing into, or withdrawing the bundle of soft iron wires from, the axis of the wooden cylinder. The apparatus is packed in a convenient mahogany box, in which it is worked, but from which it is removed in the figure in order to show its construction.

(1036) Fig. 394 represents the author's arrangement of the *Medico-Electro-Dynamic Coil Machine*, which is constructed with the object of regulating to the greatest nicety, not only the strength, but also the frequency in the direction of the shocks. It consists of a coil of about 100 yards of covered copper wire wound on a hollow core of wood, in the axis of which a bundle of iron wires may be inserted, so as to combine the effects of *magneto*- with those of *volta*-electric induction. The coil is covered with black leather or velvet, and is fixed by screws to the base board of a platform, on the upper table of which stands a piece of clock-work apparatus, destined to give revolving motion to a brass disc, provided with platinum teeth or cogs, as seen in the figure. This clock-work is in metallic connexion

with one of the poles of the battery, which consists of two cells on Mr. Smee's plan; the other pole of the battery is metallically united through the coil with a small brass stage, to which is adapted a piece of steel spring tipped with platinum, and which is so arranged as to come into contact with each tooth or cog of the disc during its rotation; by means of a screw, the degree of force with which it presses on the cogs is readily adjusted.

The manner in which this machine acts will be clearly understood by reference to the general principles of *volta-inductive action*. When the battery circuit is completed through the coil, and contact established between one of the cogs of the disc and the steel spring, the current traverses the coil, and no sensible spark, or only a very feeble one, is perceived; but the moment the spring leaves the cog, and on the consequent return of the wire to its natural state, a *reflex wave* of Electricity, moving in a *contrary direction* to that of the battery current, is generated, and a bright spark is produced. Now this bright spark is not occasioned by any direct action of the battery, as Faraday has shown,* but by a force exerted in the wire of communication, that is, in the coil; and if 2 wires, connected respectively with either extremity of the coil, be brought almost into contact, at the very moment that contact with the battery is broken, the spark will appear at the interval between them, while that at the disc will be very feeble; so also, if a fine platinum wire be interposed between the two cross wires, it will remain unaffected as long as the spring and the disc are in contact, but the moment the former leaves one of the teeth of the latter, the platinum wire either fuses or becomes red-hot.

The spark which passes between the cross wires is one of great intensity, and if the body be interposed, a shock, more or less violent according to the size of the coil, is experienced; if a bundle of iron wires be thrust into the axis of the coil, it becomes insupportable. That this *induced* current does really move in a direction *contrary* to that of the battery current, may be proved both by the galvanometer and by chemical decomposition. If a galvanometer of no great delicacy be interposed between the cross wires, it will show a current in the direction of the battery current, as long as the spring remains in contact with the disc, a portion of the Electricity excited by the battery passing through the wire of the galvanometer; but if the needle of the instrument be forced back by pins applied upon opposite sides of its two extremities, so as to retain it in its natural position, when uninfluenced by a current, and if then the spring be caused to leave the tooth of the wheel with which it is in contact,

* See his Experimental Researches, par. 1,078, *et seq.*

the needle will immediately be strongly deflected in an opposite direction, showing evidently that the induced current follows a course *contrary* to that of the battery. Again, if two platinum discs be covered with bibulous paper, moistened with iodide of potassium, and attached respectively to the ends of the two cross wires, a feeble evolution of iodine is *sometimes*, though rarely, obtained during the maintenance of contact, but the moment the spring leaves the cog the salt is decomposed in such a manner as to show the passage of a current in the reverse direction to that of the battery.

From these facts it will be seen at once that we have in this arrangement of the coil a ready method of administering to a patient, either *direct* or *inverse* shocks at pleasure. In the front of the lower platform in the figure, and between the two supports of the upper stage, will be seen a small water regulator. This is interposed in the circuit of the coil, and by raising or depressing the upper wire, which is done in the most gradual manner by making it a screw, the intensity of the shocks may be modified to any required degree, and such perfect command does this simple arrangement give us over the power of the induced shock, that we are enabled by means of it to apply this form of Electricity to so delicate an organ as the eye, or to administer shocks sufficiently severe to bring a stout man to his knees. The method of connecting the water regulator with the coil will be understood by the slightest reference to the figure. The clock work is so contrived as to give the disc one revolution per minute. Several of these discs are provided each with a different number of cogs, and we have thus a convenient method of regulating the frequency of the shocks. The binding screws are marked respectively A and B, A representing the positive and B the negative pole of the battery; at the moment of making contact, and during the time the current is circulating, not the slightest shock is experienced; but the instant the spring slips over one of the teeth of the disc, the shock passes from B to A. If, then, we wish to administer *direct* shocks to a paralytic limb, say

Fig. 393.

the leg, we apply a sponge director or saddle, moistened with salt water, and connected with B to the hip, a metallic plate in connexion with A being placed in a basin of salt water, and the foot of the patient laid upon it; if, on the other hand, we wish to apply *inverse* shocks, we merely reverse the disposition of the conductors.

(1038) *Ruhmkorff's Induction Apparatus*.—In the year 1842, MM. Masson and Breguet constructed a coil with which they

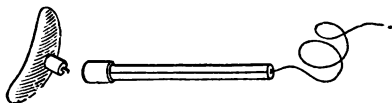
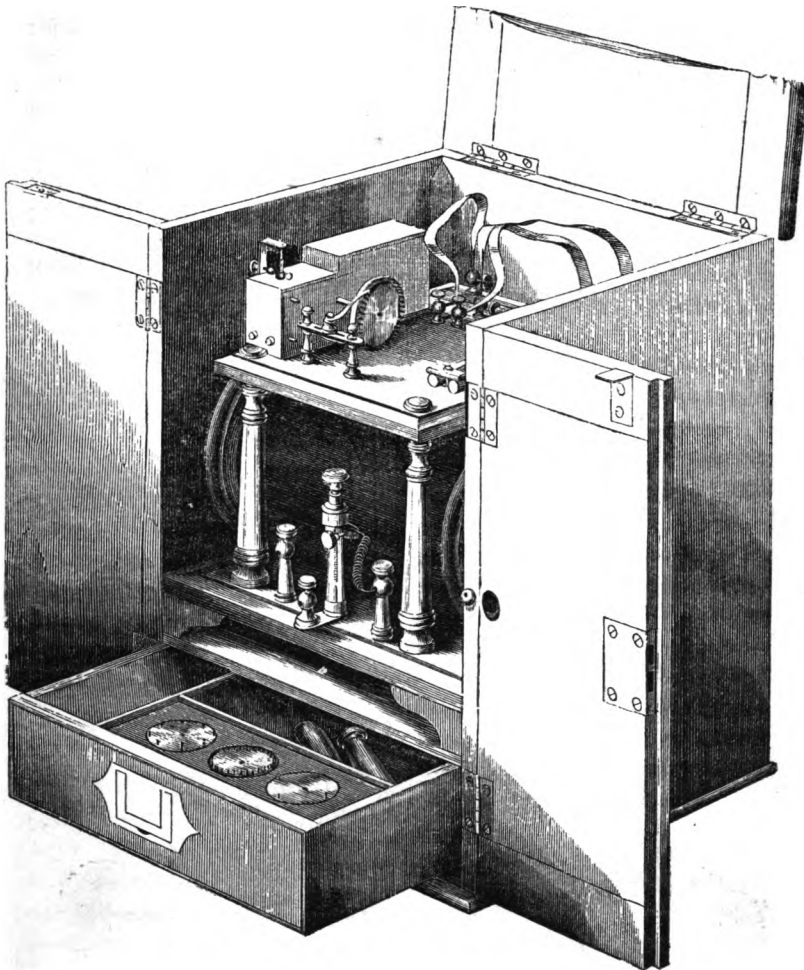


Fig. 394.

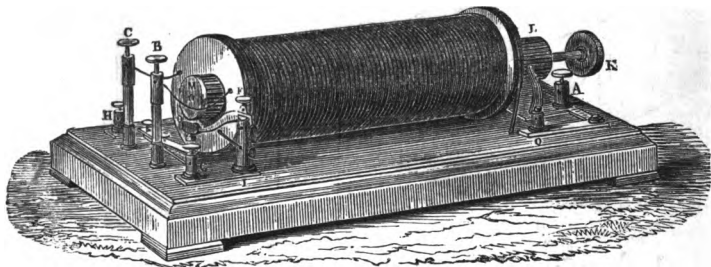


obtained a spark between the terminals of the secondary coil *in vacuo*, and also ignited platinum wire; but from the imperfect way in which the wire was insulated, they could not obtain a sensible spark in free air, though they succeeded in charging a condenser. About the same time, Mr. Hearder, of Plymouth, constructed a powerful arrangement of primary and secondary wires under the form of a medical instrument for which, in September, 1846, he received the silver medal of the Royal Polytechnic Society of Cornwall. With this apparatus surprising electrical effects were produced; strong sparks were obtained *in air*, Leyden jars were charged, and

a striking distance obtained of several inches through rarified air. In 1851, M. Ruhmkorff, of Paris, brought the induction coil to a far greater degree of perfection than it had hitherto attained, by paying the greatest possible attention to the insulation of the secondary wire, which after being covered with silk, was surrounded with a layer of gum lac, and the ends attached to glass columns fixed on the base board of the instrument; he likewise increased considerably the length of the coil, diminishing at the same time its thickness, having found experimentally that the inductive effects of the apparatus are increased in proportion as the number of the spirals is augmented. As thus constructed, the instrument exhibited extraordinary effects: brilliant sparks were not only obtained at the points of disjunction, but also between the wire and a conducting body in communication with the earth, whilst in vacuo a brilliant and continuous stream of *stratified* light was produced. By interposing in the circuit of the primary or inducing wire a single condenser, as recommended by Fizeau, a further augmentation of power was obtained; the sparks in free air were increased to nearly $\frac{3}{4}$ ths of an inch in length, and were accompanied by a snapping noise, while the power of the shocks was exalted to such a degree as to be excruciating and even dangerous.*

(1038) The *induction* apparatus as at present constructed by M. Ruhmkorff is shown in Fig. 395. The bobbin is arranged horizon-

Fig. 395.



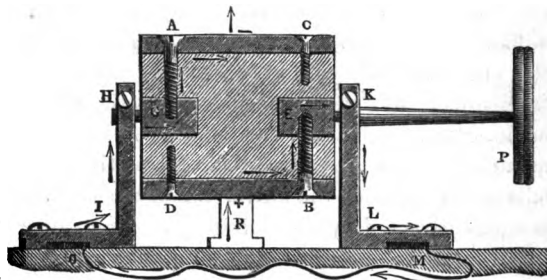
tally; the core is of thin cardboard, and the ends are either of glass or of well varnished wood. The primary coil is a well insulated wire of about $\cdot 078$ inch in diameter; the secondary is a fine thin wire, the No. 36 of commerce. The extremities of the latter pass through tubes of glass at the end of the bobbin, if the ends are made of wood, but simply through holes drilled in them, if they are of glass. In

* It is stated by Du Moncel (*Notice sur l'Appareil d'Induction Electrique de Ruhmkorff*), that M. Quet was so violently affected by incautiously exposing himself to a shock from the coil, that he was obliged to keep his bed for some time.

the figure the extremities of the thick coil are attached to the columns I O, while the ends of the fine wire are inserted in the brass caps B C, insulated on glass columns. The wires leading from the voltaic battery are attached to the screws A A on either side of the commutator K, L. Fig.

Fig. 396.

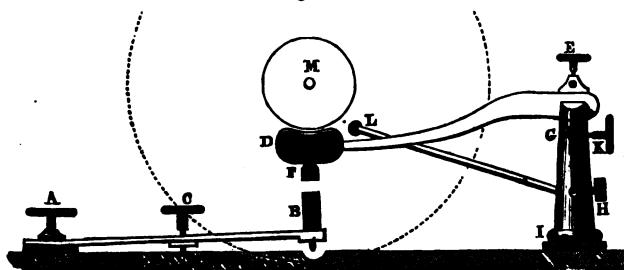
396. It is composed of a cylinder of ivory supported between 2 copper uprights. On this cylinder are fixed by screws of unequal size, 2 metallic plates



A C B D made slightly convex. The largest screws A and B, passing through the ivory, are inserted into the brass cylinders G and E; the smaller screws C D, are merely sunk in the ivory; the copper uprights are in communication with the plates M and O, of the inducing circuits. On turning the button P, suppose the plate B D to be brought into contact with the spring R, in communication with the positive pole of the pile, the current will proceed in the direction of the arrows, entering the cylinder E along B, descending R I, and traversing the coil through M, will re-enter the commutator through O, and rising up H, into the cylinder G, will proceed through the screw A, completing the circuit by A C, in communication with the negative pole. If, on the other hand, the plate B D, touch the spring in communication with the negative pole, it is easy to see that the direction of the current through the coil must be reversed.

The *interrupting* apparatus is shown in Fig. 397. M is the fasci-

Fig. 397.



culus of iron wires in the axis of the coil, the ends being surrounded by a hoop of polished iron; E D is a lever terminated by a plate of iron D, called the *hammer*; A B is a spring terminated by a massive

piece of copper B, called the *anvil*. The screw A is connected with one of the metallic strips which convey the current to the primary coil. The ends B and F, of the hammer and anvil are tipped with finely polished platinum. The end of the lever E D, drops into a slit in the upper end of the column G I; one end of the primary coil enters the column at H. The operation of this interrupter is sufficiently obvious: as long as the anvil and hammer remain in contact the current is closed, but under the influence of this current the fasciculus of iron wires becomes magnetic, and the iron head of the hammer is attracted, the current is thus interrupted, but at the same moment the iron wires lose their Magnetism, and the hammer again falls on the head of the anvil; this act restores contact, the hammer is again attracted by the remagnetized iron, and thus the current is interrupted and renewed with a rapidity the greater as the distance between the hammer and anvil is less.

The Condenser.—This invention of M. Fizeau has been adapted to his coil with great effect by M. Ruhmkorff. It consists of 2 sheets of tin foil pasted on either side of a band of varnished silk, about 12 feet long, and folded between 2 other bands of the same silk, the whole being introduced into the interior of the wooden frame of the instrument. The coatings of this condenser are in contact with G H (Fig. 395), where they receive the *extra current*. The function of the condenser is not very clearly understood; according to Fizeau, it condenses and destroys by a *static* effect the Electricity of tension or induction which gives rise to the *extra current* in the induction wire, and which reacts on the induced current in the secondary wire, in a direction, contrary to that of the voltaic current. When the condenser is interposed the interruption spark, is seen to diminish in intensity, that of the induced current on the other hand is greatly increased. According to Faraday the action of the condenser is to diminish the intensity of the inducing current at the moment when it would otherwise produce inconvenient results. At the first moment of the birth of a current in the wire, *lateral* induction is brought about at the expense of the direct induction in the body of the wire, but as soon as the former has attained its maximum, then the latter (that of the wire) becomes proportional to the intensity of the pile. Thus on connecting the two coatings of a Leyden phial by a long insulated wire, and presenting near the points of its attachment to the armatures, the two ends of another wire, so near, that the resistance of the air shall be less than that of the wire, a great part of the discharge will take place across the air; but if the wire be in contact with one of the coatings of a condenser, then no spark will be perceived between the points; and

it is for a similar reason that the spark in the interrupter, in Ruhmkorff's apparatus is sensibly enfeebled. Faraday does not explain the function attributable to this condensation; he only says, that it diminishes the intensity of the inducing current at the moment when it would otherwise produce wasteful results. It does not however, appear in what way this is rendered profitable, in the creation of an induced current, possibly by slackening the rapidity of the passage of Electricity, thereby giving the iron core a more energetic degree of Magnetism.

(1039) According to Poggendorff's view (*Pogg. Ann.*, vol. xciv. p. 2), the function of the condenser is to draw away the Electricity of tension, which when the battery current is interrupted, accumulates at the two ends of the inducing coil, where it would otherwise be retained by the resistance of the air reacting on the fluid set in motion in the thin wire, and so diminishing its intensity. The same result is obtained by uniting the *hammer* and *anvil* by a long thin wire. The condenser does not increase the quantity of Electricity set in motion in the secondary wire, as may be proved by the galvanometer, but it *does* increase vastly the physiological effects. In general, it increases the energy of the apparatus, whenever there is a great resistance set up between the poles; hence the great power it gives to the sparks in free air; while *in vacuo*, where the resistance is small its influence is not seen. For the condenser to continue to act, it must be discharged before every interruption of the current, and this takes place in the form of a visible spark. The hammer then gives a double series of sparks, which though they cannot be separated by the eye, owing to their quick succession, are nevertheless distinguishable in character. The spark, on breaking contact, is always weakened by the condenser, and the degree in which it is so weakened, may be considered as a measure of the condenser's action. These interruption sparks, as well as the discharge sparks, attack the hammer strongly; there is a transfer of platinum from the more highly heated *negative* to the *positive* pole, and if the negative or zinc end of the battery be connected with the hammer, and the positive or platinum end with the anvil, the first only will wear away, and on the plate of the latter there will be a deposit of pure platinum. Instead of a long strip of coated silk, Halske employs as a condenser a single covered sheet of mica, about the octavo size, which he finds to act nearly as well. Poggendorff uses thin waxed paper, covered with a solution of shell-lac, and he found, that a condenser of this substance, or of gutta percha, was as effective, or nearly so with respect to the length of the induction spark, when it contained on each side 4, or 9, or 16 square inches, and that it was nearly as effec-

tive as the long oiled silk of Fizeau. The sole advantage, according to this eminent physicist which the great condensers possessed over the small ones, was that the former gave less noisy sparks than the latter, and that the sparks followed one another more quickly. His experiments were, however, made with the current from *one* or from *two* pairs of Grove's battery; with larger batteries the relations between the actions of the different condensers would be different. The small condensers do not act well when the primary wire is lengthened; in fact, they then become almost useless. With a primary wire $\frac{1}{4}$ of a millimetre thick and 1,000 feet long, the condenser of 1 square inch surface was found to be without effect. Again, the action of the condensers depends essentially on the induction coils: when instead of using a very thin induction wire 10,000 feet long, Poggendorff used one of thicker wire, and 2,400 feet long, the small condensers actually *weakened* the sparks between the ends of the wire; on the contrary, the oiled silk large condensers still retained their energy of action, and it was clearly perceptible that the condenser 8 feet long was superior to that 2 feet long. It appears, therefore, that the more intense and energetic the *inner* induction or *extra* current is made, the greater the condenser must be, to obtain the most energetic development of sparks. A most extraordinary fact was discovered by Poggendorff during these researches, viz., that by making the contact breaker act in a partial vacuum, the condenser may be dispensed with, the sparks from the induction coil being quite as strong, indeed in some cases stronger, and the luminous phenomena in the electric egg, quite as well developed without the condenser as with it. Poggendorff thinks that the cause of the action of the hammer in vacuo, is of the same nature with that of the condenser.

(1040) M. Poggendorff (*Annalen*, vol. xciv., p. 2, and *Phil. Mag.*, 1855) divides the coil into several parts, the ends of the wire being made to run out at opposite extremities. If the layers extend without interruption from one end of the coil to the other, the *tension* of the Electricity must increase from the middle towards each extremity, and the lateral passage of sparks is thereby much facilitated. Instead of covering the silked wire with a solution of shell-lac in alcohol, Poggendorff recommends a mixture of wax and oil, or paraffine. He coils the wire round a glass cylinder, at the extremities of which are rings of gutta percha; he then covers it well with wax and binds it to its wooden stand with strong rings of gutta percha. This primary wire is 1 millimetre ($\cdot 039$ inch) thick, each of its halves being 100 feet (French) long.* The secondary or induction coil in

* 1 Paris foot = 12 789 English inches.

one of his instruments is 10,000 feet (Parisian) long, and makes 16,000 windings in 8 parts, each of which contains 33 layers. The diameter of the wire is 0.15 millimetre; the coils are $5\frac{1}{4}$ Parisian inches long, their internal diameter $1\frac{1}{4}$ inch, and external diameter $2\frac{1}{4}$ inches. The induction wire of another coil is 2,400 feet long, each of its parts containing 19 layers; diameter of the wire 0.25 millimetre. Notwithstanding the insulation, internal sparks passed; the phenomena of sparks and tension are described as having been at first wonderful, but after a quarter of an hour, the action decreased considerably. At first with two pairs of Grove's, a spark could be obtained at a distance of 12 millimetres, but afterwards it sunk down to 9.5. It is wrong, therefore, to strain the coil too much, when the current is broken so as to obtain sparks in air, because the Electricity then possesses great tension. When used to take sparks in a partial vacuum, great insulation is not necessary, the tension of the Electricity being much less; and as soon as the resistance of the partial vacuum is small in comparison to that of the induction wire, an increase in the length of the wire does not add anything to the brilliancy of the phenomena. For obtaining sparks in air, and for other phenomena of tension, the most perfect insulation is required, and the thicker the insulating medium the better.

Poggendorff recommends. 1°. That the wire be not less than $\frac{1}{4}$ of a millimetre in diameter. 2°. That it be covered with very thick silk. 3°. That the insulating medium be liquid, such as rectified oil of turpentine. 4°. That the coil, instead of being cylindrical, should have a *solenoid* or spindle shape, because the inducing coil and the soft iron core are most effective in the middle. The soft iron cores he uses are composed of a bundle of wires 0.45 millimetres in diameter; they are heated to redness, cut into pieces of convenient length, bound in a bundle with silk thread, and put into a paper covering. A core 6 inches long and 13 ounces in weight, contains 4,200 wires; but it was found that a hollow core of wire, containing an empty cylindrical space $\frac{1}{4}$ of an inch in diameter, was quite as effective as a solid one, nor was the action of the coil increased when a massive bar of soft iron was introduced into the hollow axis. Under otherwise equal circumstances, the inducing action of a current, just as its magnetic action, is a product of the intensity and length. Hence a short thick wire and great intensity of current may sometimes be advantageously replaced by a long thin wire and small intensity of current.

(1041) *Phenomena of the Induced Current.* 1°. *The Spark in Air*—Taken between two wires of sufficient thickness, it appears under the form of a bundle of 3 or 4 darts of fire, more or less curved, and

passing between different parts of the *Rheophores*; between larger surfaces the sparks pass at longer intervals, but with greater noise and energy. When the interruptions of the primary are slow, the sparks are longer than when they are rapid, *time* being required for the development of induction. If two zinc wires be used as rheophores and brought within striking distance of each other, the *negative* pole only will become red hot and burn, so that this property may be taken advantage of to determine the direction of the induced current in the place of a galvanometer. It must here be observed that although when the poles of the induction coil are connected by a metallic wire, or by a good conducting liquid, there are *two alternate* currents moving in opposite directions, according to the well known principles developed by Faraday (*Ex. Research.*, x., &c.). Yet, when the poles are separated by a thin stratum of air, *one* only of the two induction currents acts, that namely due to the breaking of the galvanic current; the other, that produced by closing the current is stopped off from the secondary wire, being expended in the primary wire itself. The secondary wire gives then a series of intermitting currents, all of which have a common direction; it has, in fact, *fixed* poles, and chemical decompositions are obtained in accordance with the voltaic law.

As a proof of the difference of electrical tension in the two poles, sparks may be drawn from the *exterior* end of the helix, but not from the *interior*; but by connecting two coils properly together, a current having poles of equal tension may be obtained.

(1042) By attentively watching the spark in the dark, it is seen to be surrounded with a sort of yellow-green atmosphere of greater or less thickness, according to the force of the pile. It is generally of an ovoid form, and seems to be collected principally round the negative pole. It is probably due to the high temperature imparting a luminosity to the circumambient air. A curious appearance is presented when a steady current of air is propelled from the lungs or from a bellows upon the spark taken between two metallic wires, the luminous atmosphere becomes expanded into a large mass of irregular violet-coloured flame, surrounded by bundles of rays, the spark itself not appearing to undergo any variation. The influence of heated air in deviating the spark is well seen by bringing the rheophores in the vicinity of a candle; the spark takes a curved form to get into the flame, though its passage is thereby lengthened; in the centre of the flame, it expands into a sphere of white light. When the rheophores are of unequal size, the darts of fire spread out on the larger surface, especially if this be the negative, the luminous atmosphere then becoming conical. If the negative rheophore be terminated by a large

metal plate, the surface of which is either dirty or covered with very fine powder, the positive being simply a wire, the spark spreads over the metal plate like a splash of water, or like the leaves of a tree, the extension varying with the size of the plate. If the negative plate be polished, this appearance is not presented, the spark leaves on the plate the imprint of its passage (*Grove's experiment*, (554), and round the striking point a coloured ring is seen analogous to that produced by heat on a copper plate.

Fig. 398.



In this ring, that surrounding the central point is *blue*, round it is a diffused *brown* ring. If the negative rheophore be in contact with a surface of water, the spark ramifies like the root of a tree, and if a few drops of oil be poured on the water, the root-like rays become terminated with white luminous globules, having the appearance of a tree loaded with fruit. Between charcoal points the light is very brilliant, and when the poles are brought near, quite white, like those between the charcoal terminals of the voltaic battery. *Cork* rendered conducting by immersion in sulphuric acid, or *leather* moistened with acidulated water, gives a still more brilliant light—both the cork and the leather being carbonized and burnt. It is singular that these substances thus once rendered conducting by acid, retain their conducting power for a long time after the acid has evaporated. When one of the terminals is immersed in mercury, the spark is brilliantly white and diffused.

Fig. 399.



(1043) If the coil be vigorously excited with 4, 6, or 8 pairs of Grove's battery, and the spark passed through a glass tube by means of wires hermetically sealed into its sides, and the ends about $\frac{1}{8}$ of an inch apart, *red vapours* are formed in from 10 minutes to $\frac{1}{2}$ an hour, proving that the oxygen and nitrogen have entered into chemical combination. Becquerel and Fremy have proposed this experiment as a test for nitrogen. In condensed air the spark is shorter and more collected, as is the case with ordinary Electricity. In rarefied air, on the contrary, the spark receives a wonderful development, but is less intense in light. In *hydrogen* the spark is feeble and very red; in *carbonic acid* it is vivid and white; in *oxygen and nitrogen*, as in air, perhaps more brilliant in oxygen; in *hydrochloric acid gas*, it has a very characteristic blue tint. *Ozone* may be produced by the induction spark, either directly or indirectly. In the former case the spark is taken between two wires sealed into a tube filled with *pure*

dry oxygen; the sparks must not be continuous, but must succeed one another slowly and gently; before sealing up the tube a strip of paper, covered with starch and iodide of potassium, is introduced—it soon becomes blue (545). In the latter case the sparks must be made to stream over the *outside* of the tube. To succeed in these experiments, no foreign bodies must be present.

(1044) 2°. *The Induction Spark in Liquids.*—In all good conducting liquids, there is, of course, no spark; but in those liquids which conduct either imperfectly or not at all, short crackling sparks are obtained. In *oil* the sparks are greenish white, in *alcohol* they are red and crepitating; brilliant sparks are obtained in *spirits of turpentine* and in *sulphuret of carbon*. If some oil be poured on the surface of water in a glass vessel, and one of the rheophores, covered with gutta percha, introduced beneath the water, and the other immersed in the oil within striking distance, strong crepitating sparks are obtained and hydrogen gas is liberated, which burns on the surface of the liquid. Between a pair of Wollaston's "guarded" poles (211), a continuous light may be kept up in acidulated water, or in solution of sulphate of copper.

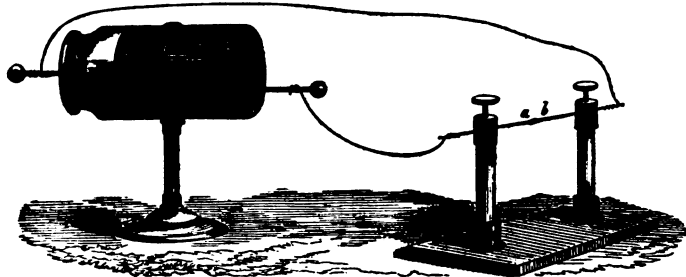
(1045) In the year 1853, M. Masson (*Prize Essay*, Haarlem) made a series of experiments by which he proves that a condenser may be charged by the induction coil machine. He placed the two poles of the coil in connexion with the coatings of the condenser, which coatings he at the same time connected with an insulated Lane's discharger, the balls being $\frac{1}{8}$ of an inch apart; he thus obtained a permanent discharge surpassing in intensity that of the direct discharge of the apparatus in a degree proportional to the size of the condenser and the number of the elements of the pile. Grove and Gassiot have since repeated these experiments on a much larger scale (*Phil. Mag.*, Jan., 1855), and with results of a singularly interesting character. When a pint Leyden phial was interposed between the terminals of the secondary coil, the *exterior* pole being connected with the interior of the jar, the noise and brilliancy of the discharges were greatly increased, but no advantage was gained by increasing the number of the cells of the battery; on the contrary, the platinum contact-breaker was thereby rapidly burnt; when, however a Leyden phial of double the capacity was employed, the brilliancy of the discharge spark was again increased, and on adding more coated surface, a further addition could be made to the battery, with a further increase in the effects, and without any injurious action taking place at the contact breaker. With a powerful apparatus in the possession of Mr. Gassiot, as many as 30 battery cells and 5 square feet of coated surface were used; the effects were very

striking—a roar of voluminous discharge 0·6 of an inch long, increased to 1·5 inch when the flame of a spirit lamp was placed between the terminals. “I have never,” writes Mr. Grove, “witnessed such a torrent of electrical discharges—the noise could not be borne long without great discomfort. . . . It is very curious to see the *absorption*, so to speak, of the voltaic power by the Leyden battery : when the maximum effect for a given Leyden jar has been passed, the contact breaker shows by its sparks the unabsorbed induced Electricity, which now appears in the primary wire ; an additional jar acts as a safety-valve to the contact breaker, and utilizes the voltaic power, and so on.”

(1046) The difference between the ordinary induction spark and that produced when the secondary terminals are connected respectively with the inner and outer coating of a Leyden jar is very striking ; in the former case it is flame-like, soft, and quiet ; in the latter, it is bright, sonorous, and apparently large ; but while the rattling spark cannot fire wood, paper, or even gunpowder, the soft spark at once inflames either of them. The effect of the static induction thus introduced is not so much to vary the *quantity* of Electricity which passes, as the *time* of the passage. That Electricity which, moving with comparative slowness through the great length of the secondary coil, produces a spark having a sensible duration (and therefore in character like that of a Leyden jar passed through a wet thread) is when the jar is used, first employed in raising up a *static induction* charge, which, when discharged, produces a concentrated spark of no sensible duration, and therefore much more luminous and audible than the former. The following experiment of Faraday (*Notices of the Meetings of the Royal Institution*, June 8, 1855) well illustrates this difference in the character of the two sparks : A piece of platinum wire is fixed horizontally across the ball of a Leyden jar, and the platinum wire secondary terminals brought respectively near its ends ; two interruptions are thus produced in the secondary circuit, the sparks at which are like each other and equal in quantity of Electricity, the jar as yet forming only an insulating support. But if, in addition, either secondary terminal be connected by a wire with the outside of the jar, the spark on that side assumes the bright loud character before described, but ceases to fire gunpowder or wood ; and no one would at first suppose—what is really the case—that there is the same Electricity passing in one as in the other. If one of the secondary terminals be connected with the outside of the Leyden jar, and the other be continued until near the knob, a soft spark appears at that interval for every successive current in the primary circuit. This spark is,

however, *double*; for the Electricity thrown into the jar at the moment of induction is discharged back again at the same place the instant the induction is over. The first discharge heats and prepares the air there for the second discharge, and the two are so nearly simultaneous as to produce the appearance of a single spark to the unaided eye. In all these experiments the exterior pole of the induction wire must be in contact with the knob of the jar; if, however, the jar be insulated as in Fig. 400 it is immaterial which way the

Fig. 400.



connexions are made. The discharge takes place between *a* and *b*, and a strip of writing paper moved slowly across the line of discharge will become punctured with a row of holes, which will be the more closely approximated in proportion as the succession of discharges is more rapid. When *two coils* are properly connected together through their primaries and secondaries, and a battery of from 10 to 15 cells of Grove employed, the extent of coated surface may be increased to 7 square feet, and the discharges are then most magnificent, fully .75 of an inch in length, piercing stout card, and accompanied by an almost insupportable noise.

(1047) *Transmission of the Induced Current through Rarefied Air—Gassiot's Cascade.*—Perhaps the most beautiful experiment that can be made with the induction coil is the following, described by Mr. Gassiot (*Phil. Mag.*, vol. vii., p. 854). Two-thirds of a beaker, 4 inches deep by 2 inches wide, are coated with tin foil, leaving 1.5 inch of the upper part uncoated. On the plate of an air-pump is placed a glass plate, and on it the beaker, covering the whole with an open-mouth glass receiver, on which is placed a brass plate having a thick wire passing through a collar of leathers; the portion of the wire within the receiver is covered with a glass tube; one end of the secondary coil is attached to this wire, and the other to the plate of the pump. As the vacuum improves, the effect is truly surprising: at first a faint, clear blue light appears to proceed from the lower part of the beaker to the plate, this gradually becomes brighter,

until by slow degrees it rises, increasing in brilliancy until it arrives at that part, which is opposite, or on a line with the inner coating, the whole being intensely illuminated; a discharge then commences from the inside of the beaker to the plate of the pump in minute but diffused streams of blue light; continuing the exhaustion, at last a discharge takes place in the form of an undivided continuous stream, overlapping the vessel, as if the electric fluid were itself a material body running over. If the position of the beaker be reversed by placing the open part on the plate of the air-pump, and the upper wire is either in contact or within an inch of the outside of the vessel, streams of blue lambent flame appear to pour down the sides to the plate, while a continuous discharge takes place from the inside coating. The following experiment is also a very beautiful one: cut out a design, such as a letter, a star, or a head, on a piece of tin foil, and paste it on a thin piece of glass or talc; paste an entire piece of foil on the other side also, connect the latter with the negative pole of the coil, and by means of a glass rod bring the positive pole into contact with the figure, which, in the dark, will become brilliantly illuminated, throwing out on all sides long rays of blue light, which may be increased by blowing gently upon it.

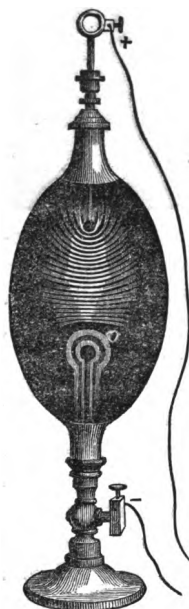
Fig. 401.



(1048) Mr. Grove, in his investigations to determine the electro-calorific effects due to the polar reactions of induced currents on metallic plates (556), made among other experiments the following. He put a piece of carefully dried phosphorus in a little metallic cup, and covered it with a receiver having a cap and wire; on making a good vacuum, instead of a simple diffused light, he obtained a light completely stratified, that is to say, divided transversely to the direction of the jet by a multitude of very straight and mobile dark bands. About the same time (*Th. Du Moncel*) Ruhmkorff noticed the same phenomenon in an *alcohol* vacuum, viz., magnificent vibrating stratifications in the middle of the red light issuing from the positive pole. These phenomena were studied in 1852 by M. Quet (*Compt. Rend.*, Dec. 1852). When the poles are about 3 or 4 inches apart in an excellent vacuum produced in the electric egg (Fig. 402), two distinct lights are produced differing in colour, form, and position; that round the negative ball and wire is blue—it envelopes it regularly; that round the positive is fire-red—it adheres to one side and stretches across towards the negative, and has for its lateral

limits a surface of revolution about the axis of the receiver. On close examination this double light is seen to have a singular constitution: it is stratified, being composed of a series of brilliant bands separated from each other by dark bands. These are best observed in vacua of wood spirit, spirit of turpentine, alcohol, naphtha, and bichloride of tin, and the vacuum must be as perfect as the best air-pump can make it. The appearance is then that of a *pile* of electric light. In the red light, the brilliant bands approaching nearest to the negative ball have the form of capsules—the concave part being turned towards the ball; their position and figures are sensibly fixed, so that it is easy to see that there is a rotation of continuity in passing from one to the other. The extreme capsule does not touch the violet light of the negative pole, being separated from it by a dark band, greater or less according to the nature and perfection of the vacuum, that with spirit of turpentine giving the greatest. Fig. 402 presents an accurate representation of this singularly beautiful phenomenon.

Fig. 402.



(1049) There are a multitude of bright beds in the red light, varying in colour and form according to the media, the degree of exhaustion, and the distance between the balls, the greatest variety being with bichloride of tin, but they are not fixed in position. If the balls are some distance apart they have an undulating motion, if nearer they seem to have a gyratory movement round the axis of the receiver. Since the two stratified lights of red and blue are in most vacua separated by a dark red band, M. Quet thought that by approaching the two balls nearer to each other, one of the lights might be extinguished while the other was preserved, and this actually was the case in an *air vacuum* when the positive ball was well polished, but in those vacua in which the red light is excessively developed round the positive ball the extinction is not complete. In all cases the blue light so far from disappearing or becoming weaker when the red light has dis-

appeared, is considerably extended. M. Quet found that when a galvanometer was interposed at the circuit, no current was indicated as passing through the electric egg till the exhaustion was tolerably good, and the light continuous; the needle then became permanently deflected. The first light that appeared was the red round the

positive ball, but it is not until the exhaustion becomes very perfect, that the blue light becomes well developed and extended round the negative wire; if then the two balls be brought nearer together, the deviation of the needle of the galvanometer sometimes reaches 80° . Thus the facility of the transmission of the induced currents depends on the perfection of the vacua and the distance between the balls.

(1050) Grove's beautiful experiment with phosphorus is made in the following manner: A small piece of perfectly dry phosphorus is placed in a small platinum capsule, on the lower ball of the electric egg; to keep the receiver dry, a stick of caustic potash is suspended in a tube from the upper wire, the exhaustion is then made as perfect as possible, when the crimson light becomes gradually furrowed with beautiful stratifications, through a length which may be extended to 12 inches; and when once obtained, the experiment may be stopped, and after 20 minutes or more, resumed with more brilliancy than before. The cause of these stratifications is not at present known, but they depend, not only on the nature

Fig. 403.

of the vapour, but on the form of the receiver, and the tension of the current. With a battery of 30 pairs of Grove, they cannot be obtained at all, the receiver being then filled with a brilliant white light.

A light (though less red and brilliant) may be obtained from one pole only, that of the exterior wire, which, as we have seen, possesses Electricity of the greatest tension; and if the vacuum be very good, this light may be made to bifurcate by placing the finger against the outside of the glass, as shown in Fig. 403.

If a considerable resistance be introduced into the induced circuit, or if the two currents are made to circulate in opposite directions through the receiver, the red light disappears from the positive pole, giving place to a blue light; the positive and negative lights are now the same, the appearance in the egg being as represented in Fig. 404. According to Masson, a proof is here afforded of the circulation of two currents moving in *opposite directions* along the same wire. Gaugain refers the phenomenon to an action of resistance, charge and discharge taking



Fig. 404.



place across the induced wire without any passage of the current. The resistance alluded to may be best accomplished by interposing a condenser between one of the rheophores and one of the balls of the egg. A uniform blue light is thus obtained round both balls, which with a good exhaustion may be stratified.

In the Torricellian vacuum the induction spark is white, filling the whole tube.

(1051) *Transmission of the Induced Current across Secondary Conductors.*—Certain substances, such as very thin metallic leaves and powdered charcoal are sufficiently good conductors to allow the passage of electricity, but not without the phenomena of light. A good way of exhibiting the action of secondary conductors with the Ruhmkorff coil is to employ a gilt-edged book; sparks from $1\frac{1}{2}$ to 2 inches long may thus be obtained. It is also shown in a very brilliant manner by sprinkling finely powdered metallic dust on a varnished board; induction sparks, or rather *furrows of fire*, 2 or 3 inches long, may thus be obtained; with fine copper filings the colour of the fire is yellow green; with zinc it is blue, with iron red; and with steel scintillating. Another method is to smear a drop of water with the finger over a varnished board, and to pass the spark across it; it is thus obtained very brilliant, the colour depending on the thickness of the stratum. The part played by the vapour of water, rain, and currents of air unequally dilated, acting as secondary conductors, is evidently very important during storms; they facilitate the passage of the lightning, the great length and zigzag character of which may thus be explained.

(1052) The luminous spectrum produced by taking the spark from the induction coil between different metals has been studied by Masson (*Memoires de l'Academie de Haarlem*, 1853). Between *cadmium* terminals the blue and green rays were beautifully developed, more beautifully perhaps than with any other metal; *antimony* and *bismuth* gave brilliant rays of a pure white colour; *lead* was remarkable for the great extension of the violet part of the spectrum, and for the great beauty of the rays given by this colour; *zinc* was characterized by the extent of the apple-green colour of its spectrum; *silver*, by the surpassing brilliancy of green; *gold* was more yellow than silver, and *carbon* emitted a multitude of remarkably brilliant rays.

(1053) *Chemical Effects of the Induced Current*:—The induced currents of the secondary coil may produce two distinct chemical effects, according as they pass along the electrolyte in the state of

luminous discharge, or in the state of *dark* discharge. In the latter case the decomposition is *electrolytic*; but in the former, the medium across which the discharge takes place, is highly heated in the vicinity of the poles; *here* alone, therefore, the decomposition takes place, and the gases are mixed. M. Masson calls this kind of decomposition *photo-electric*, the former being *polar*. According to Grove, in the photo-electric decomposition of water there is excess of hydrogen when the water is only feebly acidulated or alkalinized; when the water is rendered a better conductor, the excess of hydrogen vanishes; and after it has reached its maximum of conducting power there is excess of oxygen.

In order to produce a decomposition of water, such that the two gases shall be mixed at both poles, a pair of Wollaston's guarded points (211) must be used, the wires not projecting beyond the glass; sparks then pass. If one of the wires be soldered to a small plate of platinum (Fig. 405) all the action is concentrated on the other wire, and now we have an evolution of the mixed gases at one pole only.

To produce true polar decomposition, the platinum wires must project beyond the glass tubes, as shown in Fig. 406.

Therapeutical Applications of the Induction Coil Apparatus.—The induction shock being exceedingly violent, great care is required in administering it; it should never be attempted without a water regulator. The *inner* end of the wire is kept in permanent contact with the body of the patient, and the operator excites the spark with the exterior pole; or sparks may be excited by simply touching the part to be electrized with the exterior pole, the patient not touching the inner end of the wire, in which case no water regulator is required. When the current is employed, it must be graduated most carefully, which may be done by interposing greater or less resistances. If the rheophores are very fine wires, the points alone being applied to the part affected, the shocks are infinitely weaker than when metallic plates or wet sponges are used. To avoid, however, the calorific effects, it is better to employ for the rheophores

Fig. 405.

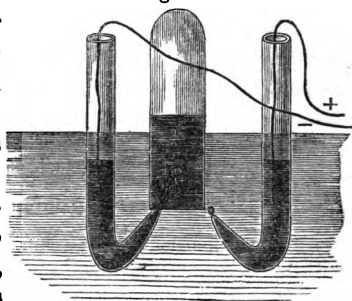
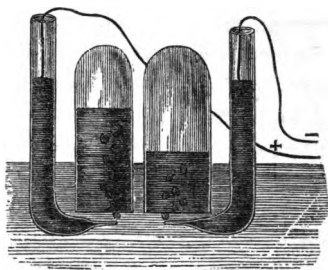


Fig. 406.



small glass tubes filled with water, the points being filed off. In extreme cases, such as in asphyxia, and in obstinate cases of paralysis, the condenser may be employed. Supplementary rheophores are then put in contact with the coating of a Leyden jar and the other wires used for transmitting the shock through the patient.

Very energetic, but not painful, muscular contractions may be obtained by circulating through the fine wire of the apparatus the current from a small battery of 8 pairs of Daniell's cells; the physiological action is then entirely due to the *extra* current, that is to the reaction of the voltaic current on itself. To one of the poles of the secondary, one of the rheophores of the pile is attached; to the other pole is fixed a wire terminated by a sponge, plate, &c.; the other rheophore of the pile is attached to another plate or sponge. These two plates or sponges are then applied to the part to be electrized, and contacts are broken and renewed by the hand holding an insulated wire.

(1054) Since the foregoing observations upon this interesting apparatus were written, we have had an opportunity of comparing Ruhmkorff's instrument with one constructed by Mr. Hearder of Plymouth. The bobbin upon which the wire of this coil is wound is 6 inches in length, the coil itself being about $4\frac{1}{2}$ inches thick. The quantity of secondary wire is about 3,000 yards (No. 35). The length of the primary is so adapted to the electro-motive force of the battery, as to enable it to develope in the iron core the highest amount of magnetic power; the energy of the instrument depending according to Hearder's view entirely on the degree of magnetization of the iron, and being quite irrespective of any peculiar arrangement of the primary wire. The iron core is, as in Ruhmkorff's instrument, a bundle of small wires capped with solid ends, through one of which passes transversely to the axis an iron adjusting screw serving to regulate the distance between the end of the core and the iron armature on the end of the vibrating spring, which acts as the contact breaker. This spring is a very strong one, having a platinum stud in the middle of its length, which makes contact with a platinum spill below; the spring being strong, and the armature heavy, the vibrations are rapid, and the contacts very firm. The sparks between two platinum terminals followed one another with great rapidity through *five-eighths* of an inch *in air*, the primary wire being excited by 4 cells of Grove's battery; the discharge *in vacuo* was very magnificent through several inches, though (contrary to the statement of Poggendorff), when the conductor was turned off, a very feeble discharge through not more than two inches could be obtained. When a Leyden jar containing 3 square feet of coated glass was

interposed in the circuit of the secondary, as in Fig. 400, a battery of 10 cells being employed, a remarkably sonorous and vivid discharge was maintained in an uninterrupted manner. The noise of the discharge was decidedly greater, and the light more voluminous and bright than with Ruhmkorff's instrument similarly excited.

(1055) In adapting the condenser to his induction coil, Header has been guided by considerations derived from a laborious course of experiments. He found that the action of the condenser depends much upon the arrangement of the primary wire, and that with certain modifications of this element the action of the condenser is much diminished; for example, supposing only *one* wire to be used, the amount and intensity of the current induced in this wire will be in proportion to the number of its convolutions, and the magnetic intensity of the core inducing upon it. Accordingly, when a long primary wire is used, and a voltaic current is passed through it capable of developing a high magnetic intensity in the core, the *secondary* current, on the interruption of the circuit, is possessed of so high an amount of electrical tension that a *static* spark immediately passes between the ends; but if these ends be respectively connected with the opposite coatings of a condenser, the static intensities are exerted in charging the latter, by which the tension is so far reduced that the spark is now unable to overleap the distance, and the electric current is thus made to react upon itself, the coatings acting, as it were, like two springs. Now, if the *length* of the primary wire be increased, maintaining at the same time its conducting quality by increasing its *size*, the secondary current soon acquires intensity enough to break through the non-conducting medium of the condenser, and strong discharges can be heard in the interior, and this took place when the condenser consisted of 80 square feet of coated oiled silk, arranged either as one large condenser or in the form of three smaller ones connected together. It was found, moreover, that the increased action of the secondary wire did not bear the same ratio to the increase of battery power *after* the sparks had begun to appear in the condenser as it did *before*. From these results it would appear that we should not endeavour to increase the effect of the machine by an *intensity* battery and a long primary coil: but rather by a *quantity* battery, consisting of a few large elements and a shorter but stouter wire, which will give the same available magnetic intensity in the core for the production of the current in the *secondary* wire without developing in the *primary* wire a current too great for the condenser to dispose of.

The shock which the condenser gives to the system, when the hands are applied to the coatings, increases with its size, and is at

times exceedingly violent; whilst the primary wire, without the condenser, scarcely gives a shock that is appreciable. Hearder constructs his secondary coil independent of the primary, by which arrangement he is enabled to use different lengths and thicknesses of the latter to suit different arrangements of the voltaic battery, as for instance, a short stout coil for a quantity battery, and a longer and thinner wire for batteries containing a greater number of smaller elements. In the insulation of his wire he does not cement the whole together with melted shell-lac, so that he can at any time wind off the secondary for the purpose of examining any defects in it, or for altering its arrangement. He finds common cartridge paper an excellent material for the condenser.

CHAPTER XX.

THE ELECTRIC TELEGRAPH.

History—Lesage—Lomond—Reiser—Salva—Ronalds—Soemmering—Ampere—Gauss and Weber—Steinheil—Morse—Alexander—Cooke and Wheatstone—The five-needle Telegraph—The single-needle Telegraph—The double-needle Telegraph—The earth circuit—The magneto-electric Telegraph—Henley—Bright—The French Telegraph—Froment—Electro-magnetic clocks—Bain—Shepherd.

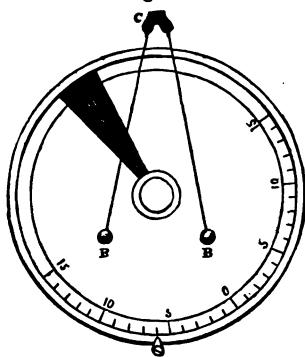
(1056) *The Electric Telegraph.*—The idea of employing Electricity as an agent to effect communication between distant places, is of no recent date; for almost as soon as it became known that conducting wires had the power of transmitting Electricity instantaneously through distances of several miles, it occurred to several Electricians, that correspondence between distant parties might be accomplished by electric action. In 1747, Dr. Watson, Bishop of Llandaff, with several other philosophers, made experiments at Shooter's Hill, which showed that electrical discharges from a Leyden jar could be propagated through a distance of upwards of 4 miles, without any appreciable loss of time, although a considerable portion of the circuit was formed of land and water. The success of these experiments appears to have given rise to the first ideas of forming electric telegraphs, by means of which distant parties might hold correspondence. From the time that Dr. Watson made his experiments at Shooter's Hill, there have been many contrivances for applying electric agency to telegraphic communication. Before 1750, Winkler, at Leipsic, discharged Leyden jars through very long circuits, in some of which a river formed a part; Le Monnier, at Paris, produced shocks through 12,789 feet of wire; and it is said that Betancourt, at Madrid, discharged electric jars through a distance of 26 miles.

(1057) The first distinct proposition to employ Electricity as a mode of telegraphic communication, appears to have originated with Lesage, who, in the year 1774, established in Geneva an electric telegraph consisting of 24 metallic wires, well insulated from each other, and each in communication with a small pith ball electrometer, which could be diverged by an electrical machine, and caused to point to a letter or any other conventional signal; and by this means a communication between two distant places was proposed to be established. A few years later, M. Lomond (Young's "Travels in France," vol. i., p. 212) suggested the employment of a single pith

ball electrometer; and in 1794, Reiser, a German, invented a telegraph in which signals were transmitted by electric discharges sent through strips of tin foil, in which were breaks, so arranged as to represent letters, which became illuminated by the discharge, as in Fig. 46, p. 82. Cavallo, in his *Treatise on Electricity*, published in 1795 (vol. iii., p. 285), proposed to transmit signals by the inflammation of various combustible or detonating substances, such as gunpowder, phosphorus, phosphuretted hydrogen, &c., by the discharge of a Leyden phial; and in 1787, Betancourt tried similar experiments in Spain.

(1058) The following report on a telegraph invented by Dr. Salva occurs in the *Gazette de Madrid*, Nov. 25, 1796:—"The Prince de la Paix having learnt that M. de F. Salva had read at the Academy of Sciences a memoir on the application of Electricity to telegraphic purposes, and presented at the same time an electric telegraph of his own invention, wished to examine it; and charmed with its promptitude and the facility of its operations, he showed it afterwards to the King and to the court, when it performed equally well. After this experiment, the Don Antonio wished to obtain a more perfect telegraph, and undertook a calculation of the force of the Electricity required to work a telegraph at different distances under land and water. The *Magazin de Voight*, in reference to these experiments, announced two years afterwards that Don Antonio constructed a telegraph upon a very grand scale, and to a very great extent. It adds, that the prince was informed *at night*, by means of his telegraph, of news that highly interested him."

Fig. 407.

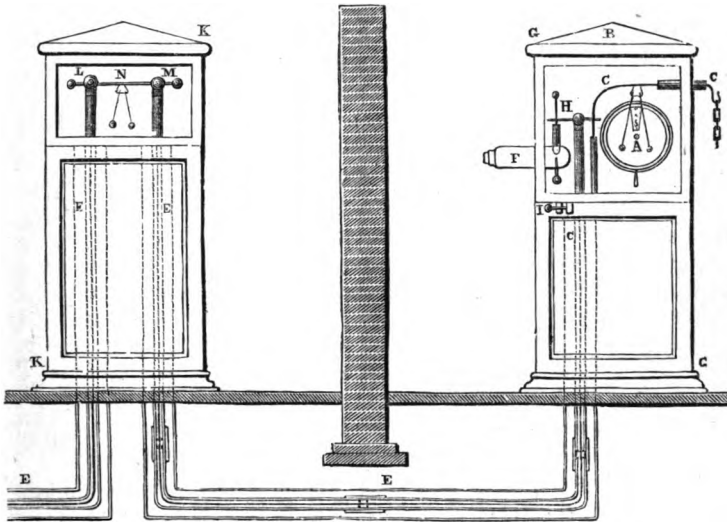


Q, U, W, X, Z. Before and over this disc was fixed another brass plate (Fig. 407), capable of being occasionally moved by the hand round its centre, and which had an aperture of such dimensions, that whilst the disc was carried round by the motion of the clock, only

(1059) In 1816, Mr. Ronalds, of Hammersmith, invented and constructed an electric telegraph, of which he published a full description in 1823. A light circular brass plate, divided into 20 equal parts, was fixed upon the seconds' arbor of a clock which beat dead seconds. Each division was marked by a figure, a letter, and a preparatory sign. The figures were divided into two series, from 1 to 10, and the letters were arranged alphabetically, leaving out J,

one of the letters, figures, and preparatory signs upon it could be seen through the aperture at the same time; for instance, the figure 9, the letter V, and the sign "Ready," are now visible through the aperture in Fig. 407. In front of this pair of plates, A (Fig. 408), was suspended an electrometer of Canton's pith balls, from a wire C, which was insulated, and communicated with a cylindric electrical machine of only 6 inches in diameter, and with the wire, E

Fig. 408.



525 feet long, which was insulated in glass tubes, surrounded by a wooden trough filled with pitch, and buried in a trench cut 4 feet deep in the ground.

Another similar electrometer was suspended in the same manner before another clock, similarly furnished with the same kind of plates and electrical machine. This second clock and machine were situated at the other end of the buried wire, and it was adjusted to go as nearly as possible synchronously with the first. Hence it is evident, that when the wire was charged by the machine at either end, the electrometers at both ends diverged; when it was discharged suddenly at either station, they both collapsed at the same instant; and when it was discharged at the moment when a given letter, figure, and sign on the lower plate of one clock appeared in view through the aperture, the same figure, letter, and sign appeared also in view at the other clock; and that by such discharges of the wire at one station, and by noting down the letters, figures, or signs in view at the other, any required words could be spelt, and figures

transmitted. But by the use of a telegraphic dictionary, a word, or even a whole sentence, could be conveyed by only 3 discharges, which could be effected, in the shortest time, in 9 seconds, and, in the longest, in 90 seconds, making a mean of 54 seconds. This dictionary consisted of 10 leaves, cut in the manner of a commonplace book, or ledger; each leaf was also divided into 10 columns, and each column numbered on the top of the page. The columns were intersected by 10 horizontal lines, each numbered on the left side; the space produced by the intersections was occupied by words or sentences.

It was necessary to distinguish the preparatory signs from those intended to spell or refer to the dictionary, by giving the wire a rather higher charge than usual, and thus causing the pith balls to diverge more; and it was always understood that the first sign, viz., "*Prepare*," was made when that word, the letter A, and figure 1, were in view at the communicator's clock; so that should the communicant's clock not exhibit the same sign (in consequence of its having gained or lost more than the communicator's), he noted how many seconds it had lost or gained, and moved his upper plate on its centre through just so many seconds to the right or left as occasion required, and the communicator continually repeated his sign "*Prepare*," until the communicant had adjusted his clock, and had discharged the wire at the moment when the word "*Ready*," appeared in view.

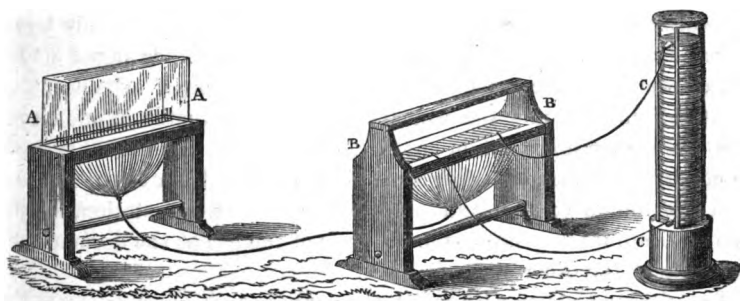
A second preparatory sign was now made by the communicator, provided that the word or sentence was not contained in the dictionary, or that the figures were to be noted, not as referring to the dictionary, but in composition; and this was done by discharging the wire at the moment when the term "*Note Letters*," or "*Note Figures*," came into view. The gas pistol, F, Fig. 408, which passed through the side of the clock-case, G, was furnished with an apparatus, H, by means of which a spark might pass through it when the communicator made the sign "*Prepare*," in order that the explosion might excite the attention of the communicant, and the handle, I, enabled him to break the connexion of it with the wire when necessary.

At half the distance between the two ends of the wire was placed the apparatus, K, by which its continuity could be broken at pleasure, for the purpose of ascertaining (in case any accident had happened to injure the insulation of the buried wire) which half had sustained the injury, or if both had. It is seen that the two portions of the wire and tube rose out of the earth, and terminated in two clasps, or forks, L and M, and the wire, N, carrying a pair of

pith balls resting on these forks, connected them. Now, by detaching this connecting wire from the fork L, whilst it still remained in contact with the fork M, or *vice versa*, it could be seen which portion of the wire did not allow the balls of the electrometer to diverge, and, consequently, which had lost its insulation, or if both had. One of the stations was situated in a room over a stable, and the other at the end of a garden, a distance of 525 feet, and the wire was buried under a gravel walk. It does not appear that Mr. Ronalds ever tried to work his telegraph at greater distances, for on communicating his discovery to the Admiralty, he was informed "that telegraphs of any kind were then wholly unnecessary, and that no other than the one then in use would be adopted." (See his pamphlet, p. 24.)

(1060) The first electro-chemical telegraph was that of Soemmering, thus described by him in 1812:—"My telegraph was constructed and used in the following manner: In the bottom of a glass reservoir containing acidulated water AA, (Fig. 409), are 35 golden points or pins passing up through the bottom of the glass; each pin corresponded to one of the letters of the alphabet and to the ten numerals. The 35 points are each connected with an insulated copper wire soldered to them, and extending to the distant station BB, where they are soldered to 35 brass plates fixed transversely on a wooden bar; through the front of each of the plates there is a small hole for the reception of 2 brass pins, one of which is connected

Fig. 409.



with the positive, and the other with the negative pole of a voltaic pile, CC. Each of the 35 plates is arranged to correspond with the arrangement of the 35 gold points in the glass reservoir, and are lettered accordingly. When thus arranged, the two pins from the column are held one in each hand; and the two plates being selected, the pins are then put into their holes and the communication is established; gas is evolved at the two distant corresponding

points in an instant; the peg on the hydrogen poles evolves hydrogen gas; and that on the oxygen pole, oxygen gas. In this way every letter and numeral may be indicated at the pleasure of the operator. The following rules should be observed:—

“*First.* As the hydrogen gas evolved is greater in quantity than the oxygen, therefore those letters which the former gas represents are more easily distinguished than those of the latter, and must be so noted. For example, in the words ending *ak, ad, em, ie*, we indicate the letters *A, a, e, i*, by the hydrogen: *k, d, and e*, on the other hand by the oxygen poles.

“*Second.* To telegraph two letters of the same name we must use a unit unless they are separated by a syllable. For example—the word *anna* may be telegraphed without the unit, as the syllable *an* is first indicated, and *na*. The word *nanni*, on the contrary, cannot be telegraphed without the use of the unit, because *na* is first telegraphed, then come *nn*, which cannot be indicated in the same vessel. It would, however, be possible to telegraph even three or more letters at the same time by increasing the number of wires from 35 to 50, which would very much augment the cost of construction and the care of attendance.

“*Third.* To indicate the conclusion of a word the unit 1 must be used; therefore, it is used with the last single letter of a word, being made to follow the ending letter. It must also be prefixed to the letter commencing a word, when that letter follows a word of two letters only. For example, *sie, lebt*, must be represented *si, el, le, dt*, that is the unit 1 must be placed after the first *e*. *Er, lebt*, on the contrary, must be represented *Er, 1l, eb, tl*; that is the unit 1 is placed before the *l*. Instead of using the unit, another signal may be introduced—the cross † to indicate the separation of syllables.”

(1061) Suppose now the decomposing table is situated in one city and the pin arrangement in another, connected with each other by 35 continuous wires extending from city to city. Then the operator with his voltaic column and pin arrangement at one station, may communicate intelligence to the observer of the gas at the decomposing table of the other station.

The metallic plates with which the extended wires are connected, have conical-shaped holes in their ends; and the pins attached to the 2 wires of the voltaic column are likewise of a conical shape, so that when they are put in their holes there may be a close fit, preventing oxidation and producing a certain connexion. It is well known that slight oxidation of the parts in contact will interrupt the communication. The pin arrangement might be so contrived as to use permanent keys, which for the 35 plates or rods would require

70 pins. The first key might be for hydrogen A, the third key for hydrogen B, the fourth key for oxygen B, and so on. Schweigger proposed to diminish the number of signals by employing 2 piles, one considerably stronger than the other, sometimes using one, sometimes the other and at other times both combined. By varying the amount of gas given off in a given time—by varying also the periods of time, the number of wires might be reduced from 35 to 2, and the construction of the telegraph thus much simplified. A method of permanently recording the signals was also indicated by Schweigger, which was in principle nearly identical with a plan subsequently employed by Wheatstone, viz., by stamping the letters on paper covered with red-lead or lamp-black. Coxe of Philadelphia (*Thompson's Annals of Philosophy*, 1810) also suggested the employment of the pile to indicate signals. He gives two methods—one by the decomposition of water, and the other by that of metallic salts.

(1062) Oersted's grand discovery of Electro-magnetism was made in 1819, and the first proposal to apply this discovery to telegraphic purposes was that of Ampère, who, in a memoir presented to the Royal Academy of Sciences in Paris, on the 2nd of October, 1820, announced the practicability of an electric telegraph constructed with magnetic needles surrounded by coils of wire. He says (*Annales de Physique et de Chimie*, xv. p. 72): "The success of this experiment demonstrates that by employing as many conducting wires and magnetic needles as there are letters, and by placing each letter under a different needle, signals may be communicated by a pile placed at a long distance off. The communication between the pile and the different coils was to be opened and shut by means of a set of keys. In 1832, Baron Schilling constructed at St. Petersburg, an electric telegraph consisting of a certain number of platinum wires, insulated and bound together with a silk cord, which set in motion by means of a key connected with a galvanic pile, five magnetic needles placed vertically in the centre of the coil. The motion of one of the needles at the commencement of the signalling, caused a leaden weight to fall, the concussion of which set in action a clock-work alarum. This telegraph was exhibited before the Emperor Alexander, but Schilling died before he had perfected or extended his invention.

(1063) The first report of the electric telegraph experiments of MM. Gauss and Weber is to be found in the *Scientific Publications of Göttingen* for 1855, and in *Schumacher's Annuaire* of 1836. Instead of the galvanic pile they employed the magneto-electric machine to give motion to the magnetic needle, which was enclosed in a coil composed of 3,000 feet of wire. By means of a com-

mutator the needle could be deflected in either direction, and its movements were observed with the aid of a lens. This telegraph was actually worked at a distance of one mile and a quarter, viz., between the "Cabinet de Physique" of the University of Göttingen and the Observatory.

(1064) Steinheil's telegraph was at work in July, 1837. A full description of it was communicated to the Academy of Sciences at the meeting of the 10th September, 1838. It was a printing and a sounding telegraph, and was worked like that of Gauss and Weber, by the magneto-electric machine; only one wire was employed, the earth being used to complete the circuit. To communicate signals by sound, Steinheil used two bells of different tones, either of which could be struck at pleasure by the needles; and to make a permanent record of a signal, dots were made on paper moved by machinery in front of the needles, each of which was furnished with a little tube containing ink. This telegraph was worked through 12 miles and with 3 stations in the circuit: its invention was a great step in the advancement of electro-telegraphing, since it established the fact of the sufficiency of the earth to complete the circuit.

(1065) Professor Morse conceived the idea of his electric telegraph in 1832; it does not appear, however, that he can claim an earlier date than 1837 for its actual construction.* His contrivance included a pen at one end of a wire, which as contact was made or broken, produced an arbitrary alphabet of dots and strokes, which might represent definite characters. An experiment, with a circuit of 10 miles, was tried before several scientific men, well known in the United States and members of Congress; and the result being favourable, a sum of money was voted by the government for a trial on a larger scale. This telegraph being in very general use in America at the present time, a more detailed description of it is necessary:—

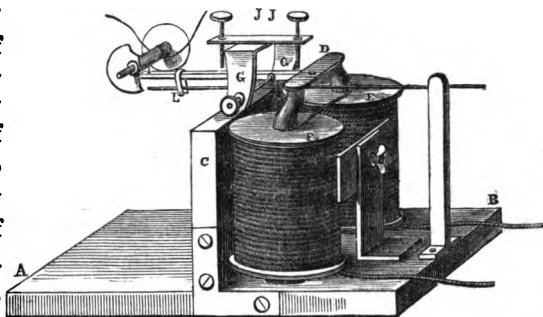
On a wooden platform, A B, is fixed a vertical support, C, to which is screwed an electro-magnet E F; on the upper part of the vertical support is a metallic band, G G, the sides of which are pierced horizontally to carry 2 screws tipped with sharp and tempered steel points, between which the lever, L, moves with as little friction as possible. To one of the extremities, D, of the lever is soldered the armature of the electro-magnet; the other end carries one or more steel points, which fit corresponding holes in a steel cylinder, under which the sheet of paper to receive the transmitted message passes, being unwound regularly by clock-work. The galvanic current being established, the armature of the electro-magnet is attracted,

* See *Traité de Télégraphie Electrique*, par M. l'Abbé Moigno, p. 75, *et seq.*

and at the same moment the points at the opposite end of the lever come into contact with the cylinder, S, and make marks on the paper of greater or less

Fig. 410.

length, according to the interval of time elapsing between the making and breaking of the circuit. To secure the rapidity and certainty of the contacts, a metallic plate, J J, is fixed across the



band, G G, carrying 2 screws, the extremities of which serve to regulate the motion of the lever, and to keep it within certain narrow limits just sufficient to secure exactness and regularity. The paper is in one continuous length, and is wound lightly round a wooden cylinder, from which it is afterwards cut into convenient lengths. The operation of the instrument is as

Fig. 412.

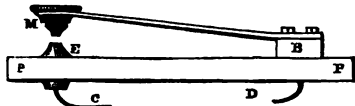


Fig. 411.

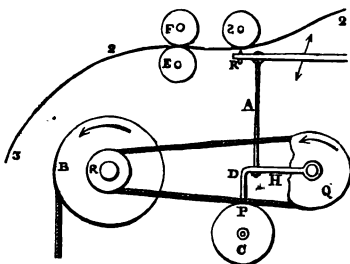
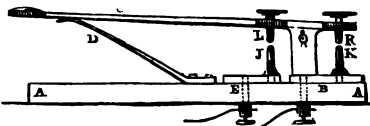


Fig. 413.



follows: Motion is given to the drum or barrel B (Fig. 411) in the direction of the arrow by a weight attached to a cord acting on wheel-work within; the motion is communicated through a series of intermediate wheels to the cylinder E, between which and the cylinder F the paper passes; F is kept in close contact with E by means of a spring; S is the steel cylinder underneath which the paper passes, and R is one of the steel points attached to the lever L (Fig. 410); the pulley Q receives motion in the direction of the arrow from the pulley R in the centre of the barrel B. It carries on its axis a horizontal arm, H, which is immediately under the lever; it is bent at D so as to come into contact with the wooden friction-wheel, C, at the point P. This friction-wheel is fixed under the last screw of the machine, and below the lever. From the lever, L, proceeds a

strip of metal, A, which traverses the arm, H; a screw and nut, I, placed at the extremity of the rod serving to lengthen or shorten it. It must act freely at its point of junction with the lever as well as at its point of junction with the screw H; it also works a hammer, which striking a bell below the platform of the apparatus, warns the operator when a signal is about to be transmitted. Now, as long as the bent arm, H D, is in contact with the friction-wheel, the whole machine is at rest; but when by the action of the electro-magnet on the lever, the rod A is raised, the weight being no longer restrained, gives motion to the barrel B, and the apparatus is put into action, but is again stopped the instant the bent arm touches the friction-wheel. In this way the operator, both near and at a distance, has perfect control over the instrument.

The apparatus or key for opening and shutting the circuit is shown in Fig. 412. A small metallic anvil, E, is secured on a platform, P P; it is in metallic communication underneath with a copper wire, C; M is a metal hammer attached to a spring and soldered to the block, B, also in contact with a copper wire, D. Another and better form of key-apparatus is that shown in Fig. 413, the operation of which will be understood by a single inspection. The hammer, L, is prevented from touching the anvil, J, when the telegraph is at rest, by the spring, D, acting on the lever C; the hammer, R, and the anvil, K, being then in contact: on pressing down the lever, L and J come into contact—the voltaic current passes through the telegraph.

(1066) The alphabet used with this telegraph is constructed by various combinations of the lines and dots in the following manner:—

A	B	C	D	E	F	G	H
I	J	K	L	M	N	O	P
Q	R	S	T	U	V	W	X
Y	Z						
1	2	3	4	5	6		
	7	8	9	0			

Suppose, now, a message has to be transmitted from one station to another, say from Baltimore to Washington, the key of the first operator is at Baltimore, and his register at Washington; the key of the second operator, on the other hand, is at Washington, and his register at Baltimore. Each has perfect control over his own apparatus, and sets the paper to receive his correspondent's message. The apparatus, wires, and batteries being found to be in good order, the Baltimore correspondent commences his communication, and however

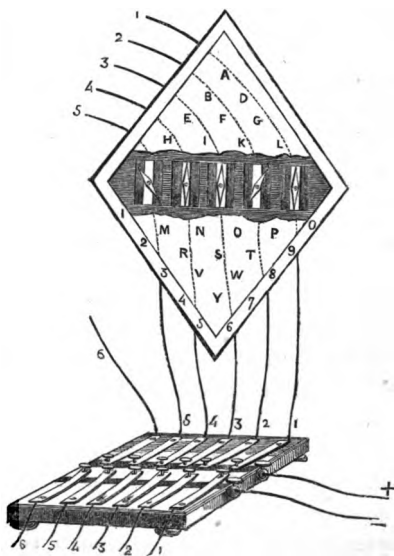
rapidly and suddenly he establishes in his key the contacts between L and J (Fig. 413) the electro-magnet at Washington becomes excited, its armature attracted, the whole machinery of the telegraph brought into full operation, and the communication stamped on the paper in accordance with the above alphabetical characters. It having, however, been found in practice somewhat difficult to regulate the contacts between the hammer and anvil, so as to give full effect to this notation, Morse has substituted for it another code of signals by which a far greater precision is secured.

(1067) Alexander's telegraph, a description of which appeared in the *Mechanics' Magazine* for November, 1837, consisted of 30 coils and 30 magnetic needles. Each needle carried a screen which concealed a letter behind it. On the transmission of the voltaic current through either of the coils (which was effected by pressing down its corresponding key), the needle was moved aside, and the letter on the dial exposed to view; by confining the motion of the needle to one direction only, oscillation was prevented. Mr. Alexander's original instrument was shown at the Great Exhibition of 1851. In Davy's telegraph (1837) the letters or signals were painted on glass, which was illuminated by a lamp placed behind the instrument; as in Alexander's, the letters were exhibited by the deflection of a magnetic needle carrying a screen, which, when the telegraph was at rest, concealed them from view.

(1068) The first patent of Messrs. Cooke and Wheatstone "for improvements in giving signals and sounding alarms at distant places by means of electric currents transmitted through metallic circuits," was sealed on the 12th of June, 1837. The telegraph here patented is shown in Fig. 414, and is thus described by Mr. Wheatstone in his examination before the Parliamentary Committee on Railways:—

"Upon a dial are arranged 5 magnetic needles in a vertical position; 20 letters of the alphabet are marked upon the face of the dial, and the various letters are indicated by the mutual convergence of 2 needles

Fig. 414.



when they are caused to move. These magnetic needles are acted upon by electrical currents passing through coils of wire placed immediately behind them. Each of the coils forms a portion of a communicating wire which may extend to any distance whatever; these wires at their termination are connected with an apparatus, K, which may be called a communicator, because by means of it the signals are communicated. It consists of 5 longitudinal, and 2 transverse metal bars, fixed in a wooden frame; the latter are united to the poles of a voltaic battery, and in the ordinary condition of the instrument, have no metallic communication with the longitudinal bars which are each immediately connected with a different wire of the line; on each of these longitudinal bars, 2 stops are placed, forming together 2 parallel rows. When a stop of the upper row is pressed down, the bar upon which it is placed forms metallic communication with the transverse bar below it, which is connected with one of the poles of the battery; and when one of the stops of the lower row is touched, another of the longitudinal bars forms a metallic communication with the other pole of the voltaic battery; and the current flows through the 2 wires connected with the longitudinal bars to whatever distance they may be extended, passing up one and down the other, provided they be connected together at their opposite extremities, and affecting magnetic needles placed before the coils, which are interposed in the circuit."

The 5 galvanometers or multipliers are numbered 1,1; 2,2; 3,3; 4,4; 5,5; and of the terminal wires 5 are represented as passing out of the side of the telegraph case on the left hand, and the other 5 on the right—they are numbered 1, 2, 3, 4, 5. The wires of the same number as the multiplier are those which belong to it, and are continuous. Thus the wire 1, on the left hand, proceeds from the first coil of multiplier 1, then to the second coil, and then coming off, passes out of the case, and is numbered 1 on the right hand; and so on with the other wires. The letters C, J, Q, U, X, Z, are not represented on the dial. Each needle has two motions, one to the right, and the other to the left. For the designation of any of the letters the deflection of two needles is required, but for the numerals one needle only. The letter intended to be noted by the observer is designated in the operation of the telegraph by the *joint deflection* of two needles pointing by their convergence to the letter. For example—in the figure the needles 1 and 4 cut each other by the lines of their joint deflection at the letter V on the dial, which is the letter intended to be observed at the receiving station. In the same manner any other letter may be selected. Suppose the needle 1 to be vertical as needles 2, 3, and 5, then needle 4 only being deflected points to the numeral 4 as the number intended to be signified.

A second patent for improvements on the needle telegraph was specified by Messrs. Cooke and Wheatstone in October, 1838. It relates principally to a method of enabling two intermediate stations to communicate with each other and with either terminus; and to sounding an alarm by liberating wound-up mechanism by the *angular motion of a magnetic needle*.

(1069) The patent for Messrs. Cooke and Wheatstone's electro-magnetic telegraph bears the date of January 21, 1840. In this apparatus Mr. Wheatstone availed himself of the property possessed by soft iron of immediately acquiring and losing magnetic properties, by the establishment or interruption of a current in a wire covered with silk with which it is surrounded. To transmit all the letters of the alphabet and the figures which may be required in a telegraphic communication, two conducting wires between one station and another, were found sufficient. By means of a commutator, which served to interrupt or establish the circuit at one of the stations, soft iron was magnetized and demagnetized an equal number of times at the other station. The commutator was a wheel turning on its axis, and the circumference of which presented 48 portions alternately conductors, so that for one complete revolution of the wheel the current was 24 times interrupted and re-established; a letter of the alphabet corresponded to each of these 24 alternations; the soft iron at the other station was in like manner magnetized and demagnetized 24 times. This alternate state of the magnetization and non-magnetization of the soft iron, gave an oscillating motion to a small appendix of soft iron, which communicated a similar motion to a wheel by which each of the twenty-four letters of the alphabet engraved on the wheel were brought successively before the observer. Care was required to insure an agreement between the letters corresponding to the alternations of the commutator, and those produced by the alternate movement effected by the magnetization and demagnetization of the electro-magnet. The following was the method of working this telegraph: Suppose the commutator placed at A, and the letter A brought to the observer by the electro-magnet (at each station they agree to arrange the apparatus that the starting point shall be the same), we wish to transmit the letter D; the commutator must be moved onwards 3 alternations; B, C, and D, have been successively introduced at the other station, and so on for each of the letters. A large bell which was struck by a piece of iron attracted by the electro-magnet at the moment when the circuit was re-established, served to give the signal. It is evident that in order that the transmission be reciprocal, there must be

a double set of apparatus, so that each station may possess those necessary to transmit, and those necessary to receive the communication.

(1070) An addition to this was afterwards made and patented by Mr. Wheatstone, by which the letters were *printed* instead of their being merely presented to the eye. The following are the means by which this is effected : For the paper disc of the telegraph, on the circumference of which the letters are printed, a thin disc of brass is substituted, cut from the circumference to the centre, so as to form 24 springs, on the extremities of which types or punches are fixed ; this type-wheel is brought into any desired position just as the paper disc is. The additional part consists of a mechanism, which, acted upon by an electro-magnet, occasions a hammer to strike the punch, brought opposite to it, against a cylinder, round which are rolled alternately several sheets of thin white paper, and of the blackened paper used in the manifold writing apparatus ; by this means, without presenting any resistance to the type-wheel, several distinct copies of the message transmitted are obtained.

The great practical difficulty with this telegraph was that of insuring the synchronism of the movements of discs at the different stations,

Fig. 415.

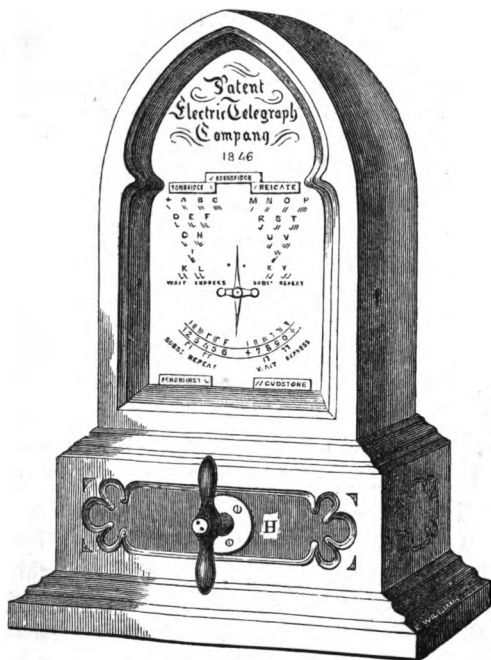
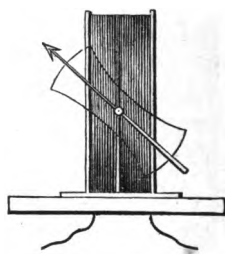


Fig. 416.



or if they did not move precisely together, then when B was visible at one station, A would be in view at another, and thus all would go wrong. It has, therefore, been entirely abandoned for other and better plans.

(1071) Messrs. Wheatstone and

Cooke's single-needle telegraph, patented May 6th, 1845, is shown in Fig. 415. The essential part of the instrument is composed of a single multiplier, with an indicator fixed vertically on a horizontal axis, and moving in front of a dial plate. This indicator may be either a light strip of wood, or a magnetic needle; if the latter, its poles must be in a reversed position to those of the needle within the bobbin. When the voltaic current is sent through the coil the needle is deflected to the right or to the left, according to the direction in which the current passes. The alphabet is situated both on the right and the left hand side of the needle; some letters require 4 movements of the needle, but the last motion which completes the indication of a letter situated on the right hand side is always a movement to the right; in like manner the last motion which completes the indication of a letter on the left side is always a movement to the left; for example—the letter W is indicated by 4 motions of the needle, 3 to the left and 1 to the right; the letter L also is indicated by 4 motions, first to the right, then to the left, then again to the right, and finally to the left.

(1072) The code of signals adopted is shown in the following diagram; and bearing in mind that the deflections of the symbols for each letter commence in the direction of the short marks and end with the long ones, it will be seen that the deflections of a single needle may be made to denote all the letters of the alphabet.

The numerals are inscribed on the dial underneath the needle, and are indicated by the movements of its lower half; for example—the figure 4 is designated by the motion of the lower extremity once to the right and once to the left; the figure 9 by a movement once to the left and once to the right, and so on. The internal mechanism of the telegraph is exhibited in Fig. 418. B A is the bobbin, in the interior of which is placed either a single magnetic needle, in the form of a rhomboid, $1\frac{1}{2}$ inch long by $\frac{1}{4}$ ths of an inch broad; or which Mr. Walker found to be still better, several highly magnetized short needles, firmly secured on either or both sides of a very thin ivory disc. The exterior or index needle is about 3 inches long. The frame of the coil, B, is made of copper,

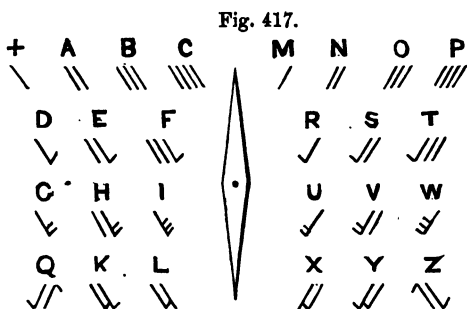
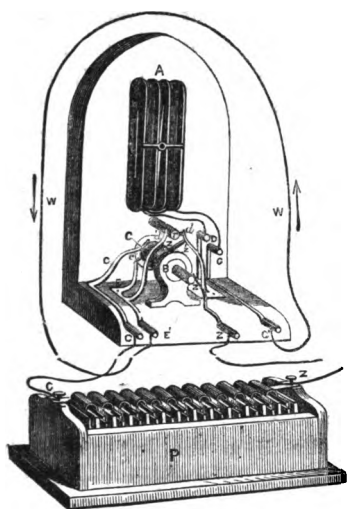


Fig. 418.

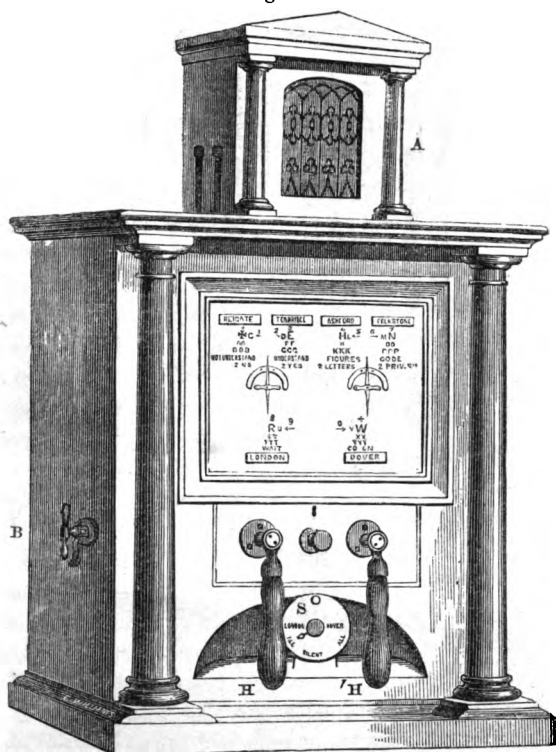


wood, or ivory; it is screwed to a plate of varnished copper against the side of the telegraph case. The copper wire surrounding the bobbin A is about $\frac{1}{16}$ th of an inch in diameter, and is well covered with cotton; one end of the wire from the right hand bobbin is in contact with the screw G, which, by means of a metallic strap, is connected with the screw G' secured on the base of the apparatus; the other end of the wire on the left hand bobbin is in contact with another screw, D, supported by a strip of brass which is fixed to the base; from this brass plate there rises an upright stiff steel spring *d*, which presses strongly against a point attached to an insulated brass rod, *r*, screwed against the side of the case; on the opposite side of this rod is another point against which a second stiff steel spring, *d'*, presses; this spring is attached to a brass plate, E, terminated by a binding screw E'; E', therefore, is the screw terminal of the wire from the left hand coil. If G' and E' be now connected by a wire, W, the current will flow from G' through G into the right hand coil, out from the left hand coil to D, thence through *d r d'* to E, and from the terminal screw E', round the wire circuit, back to G'; and if the wire from G' proceed *up* a line of railway, and the wire from E' *down* the line, the circuit being complete throughout, the needle in the bobbin, A, will be deflected by a current proceeding from any station on the line, and thus signals will be communicated. Battery contact is broken and the direction of the current reversed by the action of the springs *d d'* in the following manner:—

B is a box-wood drum, moveable by a handle seen at H, in the front of the base of Fig. 415. Round either end of this drum are fixed the brass caps C and Z; the caps do not touch each other, a disc of box-wood being between them. Into these caps are screwed the steel projecting pieces C'Z', which become the poles of the battery, the Z' being connected with the zinc end, and C' with the copper, thus: a wire, C, from the copper end of the battery conveys the current, C'C', and a wire from the zinc end along Z, to a steel spring, which touches *z*, the continuation of the Z end of the box-wood cylinder. Now on moving the drum, by turning the handle, H,

Fig. 415, the steel spring *d* will be raised from its corresponding point on *r*; the circuit will thus become broken, but by continuing the motion of the drum, the wire C will come into contact with the spring below it, and thus there will be a battery pole at either end of the drum, and signals will thus be made on the dial, and on all the instruments connected with it. The connexions are made in such a manner, that when the handle is turned to the right the needle moves to the right. The exterior, or indicating needle is always placed with its N. pole upwards; that within the coil with its N. pole downwards; so that, in accordance with Oersted's fundamental law, looking at the face of the instrument, if we see the upper part of the needle moving towards the right, the spectator may be sure that the current is ascending in that half of the wire which is nearest to him.

Fig 419.

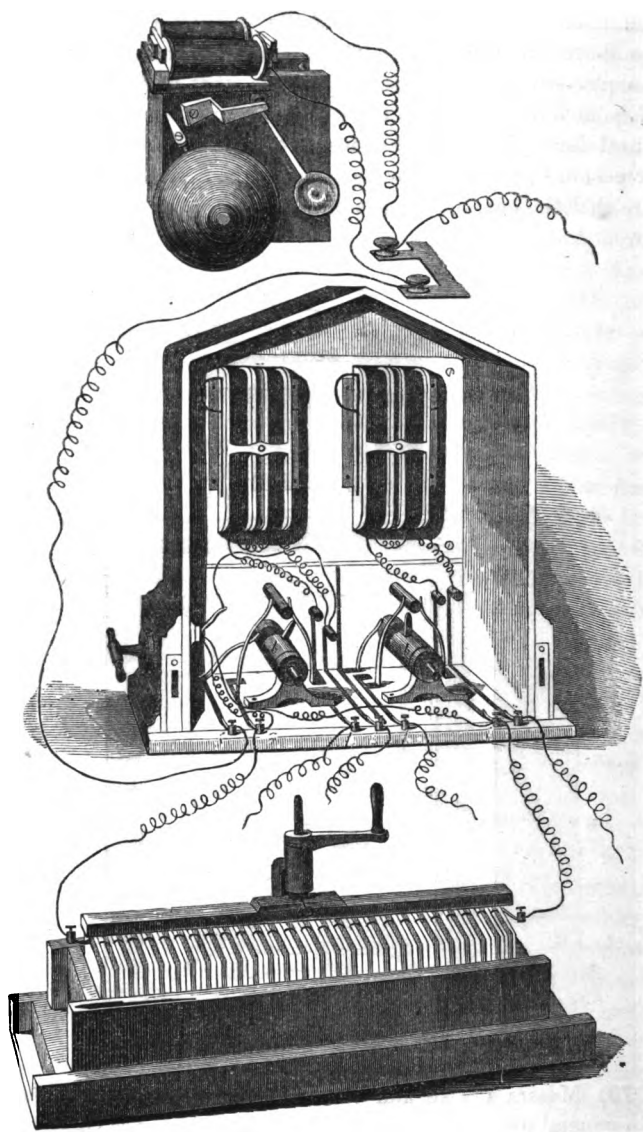


(1073) Messrs. Cooke and Wheatstone's double-needle telegraph, now in general use for railway service in this country, is shown in Figs.

3 D

419 and 420. On the top of the case is the alarum, A, which is worked by the handle, B. H H' are the handles by which the two needles are manipulated, and S is the "silent apparatus." The internal mechanism is precisely similar to that of the single-needle apparatus. The

Fig. 444.



letters of the alphabet are ranged from left to right, as in the ordinary mode of writing, in several lines above and below the points of the needles, the first series, from A to P, being above, and the second series, from R to Y, below. Each letter is indicated by one, two, or three movements. The following is the complete vocabulary and mode of correspondence:—

A. Two movements towards the left, by the left needle.

B. Three movements towards the left, by the left needle.

C, and the Fig. 1. Two movements of the left needle, the first to the left, and the second to the right.

D, and the Fig. 2. Two movements of the left needle, the first to the right, and the second to the left.

E, and the Fig. 3. One movement of the left needle to the right.

F. Two movements of the left needle to the right.

G. Three movements of the left needle to the right.

H. and the Fig. 4. One movement to the left of the right hand needle.

I. Two movements to the left of the right needle.

J is omitted, and replaced by G.

K. Three movements of the right needle to the left.

L, and the Fig. 5. Two movements of the right hand needle, the first to the right, the second to the left.

M, and the Fig. 6. Two movements of the right needle, the first to the left, the second to the right.

N, and the Fig. 7. One movement of the right needle towards the right.

O. Two movements of the right needle to the right.

P. Three movements of the right needle to the right.

Q is omitted, and K substituted for it.

R, and the Fig. 8. A single movement of both needles towards the left.

S. Two movements of both needles towards the right.

T. Three movements of both needles towards the left.

U, and the Fig. 9. Two movements of both needles, the first towards the right, the second towards the left.

V and O. Two movements of both needles, the first to the left, the second to the right.

W. One movement of both needles towards the right.

X. Two movements of both needles towards the right.

Y. Three movements of both needles towards the right.

Z is omitted, and replaced by S.

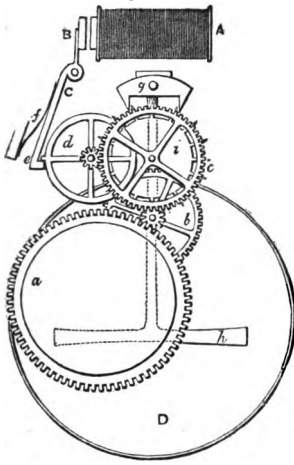
The sign +, indicating the termination of a word, is designated by a single movement of the left needle towards the left; the same signal is given when the receiver does not understand his correspondent's message. The exhibition of the letter E signifies that he *does* understand, and to denote the word *yes*. The signal for E is repeated twice, i. e., two movements of the left needle towards the right are made.

(1074) The words "*wait*," "*go on*," seen on the right and left side of the bottom of the dial plate are of great importance. Suppose, for example, the London clerk wishes to communicate with his correspondent at Dover, and that the latter is at the time engaged, he immediately signals the letter R, thereby intimating that he is not prepared to receive the London message; when he is at liberty, he directs his needles towards W, which means "*go on*," and the correspondence begins. It is also absolutely necessary to have a method whereby one station may signify to any individual station on the line that a message is proposed to be sent to it. Suppose, for example, that London wishes to communicate with Tonbridge; on the dial plate of Fig. 419 will be seen the names of the six stations of one of the groups on the South Eastern Railway, *viz.*, Reigate, Tonbridge, Ashford, Folkstone, London, and Dover; each of these stations is represented by a letter. Thus, London is designated by R, Tonbridge by E, Dover by W, and so on. The London correspondent signals E, and at the same time rings the bell at the station at Tonbridge; the Tonbridge clerk immediately returns the ring at London, thereby intimating that he is at his post. London now signals R, by which Tonbridge knows that it is London that wishes to communicate with him; he returns the signal R; London again rings the bell, and the correspondence commences,—Tonbridge signalling the letter E after every word if he understands, or the cross + if he does not. The message being finished, London deflects his left hand needle twice to the left; Tonbridge returns the signal, if he has no reply to make, and proceeds to transmit the message to its destination.

The numerals are indicated by certain letters; the letter H, followed by a cross +, intimating that figures and not letters are about to be shown. The letter W interposed between certain figures serves to group them: thus the letters HE W N might mean £43 7s., or 43 feet 7 inches, &c. Special signals are also devised for special purposes.

(1075) The mechanism of the alarum used on the telegraphic line of the South-Eastern Railway Station is shown in Fig. 421.

Fig. 421.

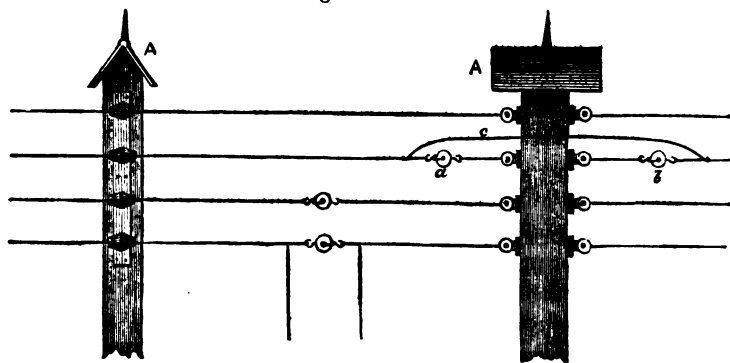


stop in the circumference of the wheel *d*, prevents it from moving. The armature is brought back to its normal position, when the attraction ceases by the small spring *f*, which presses against the long arm of the lever. Of the clock-work contained in the barrel, only the principal pieces are shown in the figure; the cog wheel *b* is connected by a pinion with the cog-wheel *a*, which works *i*, and this again gives motion to *d*, which carries the stop. The anchor escapement *g* works on the wheel *i*, and on the axis of the same wheel is placed the double-headed hammer, *h*. On completing the battery circuit, the armature, *B*, is attracted by the electro-magnet, the long arm of the lever, *C*, moves to the left, and the wheel *d*, being then set at liberty, the mainspring in the barrel, which is kept constantly wound up, sets it in motion, and the hammer is instantly put into rapid vibration, striking alternately the opposite sides of the bell, *D*; the ringing is kept up as long as the circuit is closed, but the moment it is broken the armature is detached by the spring *f*, and the catch is again pressed into its place on the wheel *d*. It is not the voltaic current that rings the bell, but the mainspring in the barrel; all that the Electricity does is to disengage the catch; and there is no greater difficulty, therefore, in ringing a large bell than a small one. It is easy to see that this principle may be modified in a variety of ways.

(1076) The batteries used to work our English telegraphs are composed of amalgamated zinc and copper plates, $4\frac{1}{2}$ inches long by $3\frac{1}{2}$ inches wide, the zinc being $\frac{1}{8}$ ths of an inch thick. The plates are cemented water-tight on to stout teak-wood or oak troughs, each trough being from 15 to 30 inches long, and $5\frac{1}{2}$ inches wide, and divided into

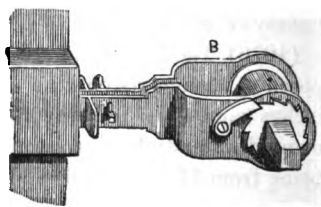
12 or 24 cells by partitions of slate. The plates connected together by copper slips, are placed across the slate partitions, and the cells are filled to within an inch of the top with siliceous sand, which is then saturated with a solution of 1 part of oil of vitriol in 15 parts of water. The numbers of cells used varies according to the distance between the stations : for short groups of 10 or 15 miles, 24 cells are employed, for distances from 40 to 60 miles double that number. The telegraphs on the South Eastern Railway of 180 miles and 47 stations are worked with 2,200 pairs of plates, and the whole telegraph system in the United Kingdom employs about 20,000 pairs. (Walker's "Electric Telegraph Manipulation," p. 9.) According to Mr. Walker's experience, new batteries, when carefully put together, will, with care, do duty for six or eight months, when the work is not very heavy ; and by washing the sand out with a flow of water, and refilling them, they frequently remain on duty ten or twelve months without being re-amalgamated. In America, for the registering telegraphs, Grove's battery is mostly in use, 30 cells of which are required for a distance of 150 miles. They require cleaning and replenishing about once a fortnight.

Fig. 422.



(1077) The modes of sustaining and insulating telegraphic wires adopted nearly universally in England are represented in Figs. 422 and 423. Wooden posts, from 15 to 30 feet high, are fixed firmly in the ground, at the rate of about 30 a mile ; the upper part of each post is 5 or 6 inches square ; it carries a wooden arm, which is separated from the post by discs or rings of brown delf-ware. The arm is secured to the post by an iron bolt and screw. On the face of the wooden arm, 4 hollow double earthenware or glass cones are fas-

Fig. 423.



tened by collars of iron ; through these the wires pass, and are thus effectually insulated. A similar system of wires passes on the opposite side of the post, and each post is provided with a small roof of earthenware or slate, on the top of which is a metallic point connected with the earth as a preservative against the effects of lightning. The contrivance for tightening the wires is seen at B. The posts on which this apparatus is placed are much stouter than the ordinary sustaining posts, and they are fixed at intervals of $\frac{1}{4}$ th of a mile apart. To the upper part of the post are attached as many iron screws as there are telegraph wires, and each screw carries a winder, consisting of a grooved drum with a wheel and ratchet attached ; the ends of the winder are insulated from the post by discs of earthenware ; *a* and *b* are two earthenware pulleys, or *shackles*, each furnished with two hooks insulated from each other. The winding post is thus seen to be out of the circuit, but the metallic continuity of the telegraph wire is secured by a thin wire, *c*, soldered to the outside of each shackle. The telegraph wire is of iron, about $\frac{1}{8}$ th of an inch in diameter : it is protected against the corroding action of atmospheric air and moisture by being passed through a bath of melted zinc, or *galvanized*, as it is called ; zinc being more positive than iron, combines first with oxygen ; the wire thus becomes coated with a thin layer of oxide of zinc, which acts as a coat of paint and effectually preserves the iron. In the neighbourhood of large towns, where great quantities of coal are daily burned, the sulphurous vapours arising from such fuel and passing over the oxide of zinc covering convert it into sulphate of zinc, which being soluble in water, is immediately melted by the rain and drops off. The wire thus deprived of its insoluble covering soon corrodes. Mr. Highton mentions ("Electric Telegraph," p. 117) that he has seen galvanized iron wires reduced in this way in less than two years from the diameter of $\frac{1}{8}$ th of an inch to that of a common sewing needle ; and he suggests that in the neighbourhood of large towns the wires should either be painted and varnished, or entirely cased in gutta percha.

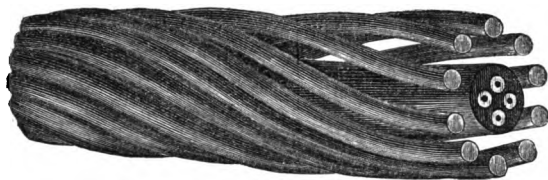
(1078) The insulator employed on the "Morse" line from New York to Washington, is simply a glass knob with 2 rings, between which the wire is wrapped. It is said to be very imperfect (Turnbull on the "Electro-magnetic Telegraph," p. 176), the wire losing its insulation almost entirely in wet weather, and the instruments working with difficulty upon even the slightest shower. It has been found also, that with this form of insulator, the atmospheric Electricity cracks the glass in two pieces, just as if it had been cut with a diamond. In the "House" line of telegraph (American) the glass cap, which is

covered with lac varnish, is screwed into a bell-shaped iron cap, which is filled with much care to the top of the post, and well painted and varnished, the telegraph wire is fastened to the top of the cap by projecting iron points. This plan, though decidedly superior to Morse's, is objectionable on the score of expense, and very inferior to the method adopted in England. In Germany, the wires are insulated by passing through porcelain caps, in the shape of a reversed cup, placed on the summit of the posts, which are thus covered with roofs. It is said to be very perfect. The posts in France are from 20 to 30 feet long, and are driven into the ground to a depth of from 30 to 60 inches, the buried parts being preserved by injection with sulphate of copper. The insulators, which are either bell-shaped or double oblique cones, are, as in England, fixed to the side of the post by screws, and sealed with sulphur in the interior; the conducting wire passes through a ring support fixed in the interior of the cone, so that the wire only passes on a point sheltered by the mass of the support.

When the conducting wires have to pass underground, they are usually made of copper, and are either covered with gutta percha or with cotton saturated with tar, and collected in leaden pipes in groups of three or four; the leaden pipes are covered with a pitched cord, and the whole placed in an iron pipe.

(1079) When the wires have to pass under water, as in the submarine telegraphs, great care is required for their insulation and protection. The first wires for the submarine telegraph between England and France were sunk in the British Channel, in August, 1850. The wire was 30 miles long, simply covered with gutta percha, and sunk to the bottom of the sea by leaden weights; it soon, however, became useless, being cut to pieces by attrition against the rocks. In the September of the following year, a submarine cable was constructed by Messrs. Newall and Co., and on the 18th of October, an electric communication was established between Dover and Calais, a distance of 21 miles. The plan adopted in the manufacture of this cable was as follows (Highton on the "Electric Telegraph"): A copper wire, No. 16, was first carefully covered with gutta percha; upon this a second covering was laid—the wire was thus thoroughly insulated. Four of these were then bound together with spun-yarn and hemp saturated with tar. This bundle of insulated wires with its hempen covering was then surrounded by 10 galvanized iron wires, each wire being $\frac{1}{4}$ ths of an inch in diameter. The insulated wires thus formed the core of a large continuous wire rope (Fig. 424), which was wound into a coil 30 feet in diameter. It was 24 miles long, and weighed 180 tons.

Fig. 424.



(1080) The "paying out" of this enormous cable commenced Sept. 25th, 1851. Steam tugs were placed by the Admiralty at the service of the Company. The *Blazer*, on which the cable was shipped, was towed from Dover to the South Foreland, and one end of the rope conveyed on to the English shore; after this, the vessel was towed in the direction of Cape Grinez. The distance between the two coasts is 20 miles, and though to allow for undulations and sinuosities 24 miles of cable had been constructed, the end of the rope was found to fall short of its destination by half a mile; another mile of cable was made, and spliced to the end of the first; and on the 18th of October, the communication was found to be perfect. The cost of this cable is said to have been £20,000, and the expenses to the Company to have been no less than £75,000. The success of this experiment stimulated Messrs. Newall and Co. to attempt a still greater enterprise, *viz.*, that of connecting telegraphically England and Ireland, by extending a submarine cable between Holyhead on the Welsh, and Howth on the Irish coast. This they effected in June, 1852, but from some unascertained cause (probably from its being too light, the cable enclosing only a *single* wire, and weighing only *one ton* a mile—the Dover and Calais cable weighing seven tons), after working well for three days, it became imperfect, and a great portion has been taken up. Nothing daunted by this failure, Messrs. Newall and Co. constructed a cable measuring seventy *miles* in one unbroken length, and with it, on the 6th of May, 1853, the first electric telegraphic communication was established between Belgium and England. This cable contains 6 wires, insulated by gutta percha, and laid into a rope with prepared spun yarn; it is covered with 12 thick iron wires, of a united strength equal to a strain of 40 to 50 tons—more than the proof strain of the chain cable of a first-rate man-of-war (Lardner on the "Electric Telegraph," p. 157). It weighed 7 tons a mile, its total weight being 500 tons; its cost was £37,000.* The great success which has hitherto attended submarine telegraphing has given rise to a project for the deposition of an

* For a graphic illustration of the manner in which this enormous cable was coiled in the hold of the vessel; also for the way in which it was deposited, see *Illustrated London News*, May 14, 1853.

electric cable across the Atlantic, so as to put the Old World into instantaneous communication with the new, a distance (between the nearest point of British America and the west coast of Ireland) of about 1,600 miles. Whether the curious phenomenon of the arrest of the Electricity supplied by voltaic battery, and the charging of the submerged or buried wire elsewhere described (316), would interfere with the realization of this project is a question which must be left for time and further experience to determine. It should, however, be mentioned that the Magneto-electric Telegraph Company, who have nearly 900 miles of underground wire in operation, report that they sometimes pass their signals, without any difficulty, through 500 miles of underground wire without any break or delay in the circuit. (Lardner on the "Electric Telegraph," p. 172.)

(1081) *The Earth Circuit*.—It had long ago been shown by Watson and others (10) that a Leyden phial could be discharged through a circuit, one half of which consisted of moist earth. It appears that Steinheil was the first to employ the earth to act the part of a conducting wire in an electro-telegraphic circuit. The two extremities of the wire of his telegraph, constructed at Munich in 1837, were attached to two copper plates, which were buried in the earth. He attributed the transmission of the current to the direct conductivity of the earth. It was proved on a larger scale in 1841, by Messrs. Cooke and Wheatstone, by experiments on the Blackwall Railway, that the earth may be employed successfully to replace one half of the conducting wire, or for the *return* circuit. In fact, they state that so excellent a conductor is the earth, and so little resistance does it offer to the transmission of Electricity, that the same pile will work a much greater distance with a circuit half wire and half earth than when altogether wire.

(1082) Whilst prosecuting some experiments with an electro-magnetic sounding apparatus, in the year 1841, Mr. Bain found that if the conducting wires were not perfectly insulated from the water in which they were immersed, the attractive power of the electro-magnet did not entirely cease when the circuit was broken. With a view of ascertaining the true cause of the phenomenon, Mr. Bain, in conjunction with Lieutenant Wright, made a series of experiments on the Serpentine river in Hyde Park, and after verifying their former observations relative to the remnant of power in the electro-magnet when contact with the battery was broken, the electro-magnet being on one side of the river, and the battery on the other, the wires passing *through* the river; and after making other experiments, in which the water and the moist earth formed part of the circuit, and wire the remainder, it occurred to Mr. Bain, that if a

positive metal were attached to one end of the conducting wire, and a negative metal to the other, and if the two metals were then placed in water, or buried in the moist earth while the connecting wire was properly insulated, a current might be generated. This was found to be the case, for when a large surface of copper was placed within Kensington Gardens at the one end of the river, and within Hyde Park at the other end a similar surface of zinc, and the metals connected by a wire, in the circuit of which was a galvanometer, a current of considerable intensity was found to be passing. The experiment was next tried on a more extended plan; a surface of zinc was buried in the moist earth of Hyde Park, and at rather more than a *mile distant*, a surface of copper was buried, and the metals were connected by a wire suspended on the railings; when the plates were large, Mr. Bain not only obtained the usual electro-magnetic effects in an enhanced degree, but also succeeded in the performance of electrotype operations; for in the course of a few minutes he coated a half-crown with copper. Subsequent experiments showed that if the metals are thus buried, and connecting wires are employed, electrotype depositions may be effected, and electro-magnetic apparatus worked for a great length of time.

(1083) Signor Ch. Matteucci made in the year 1844, numerous experiments on the conductivity of the earth for the electric current, (*Comptes Rendus*, June 3rd, 1844). He made the current from a single Bunsen's element (371) circulate in a copper wire, 9,281 feet long, and through a bed of earth of the same length; and he found the diminution which occurred in the intensity of the current to be such, that the resistance of the bed of earth must not only be regarded as nothing, but that further, the resistance of the copper wire entering into the mixed circuit must be considered as less than that presented by the same wire when it enters *alone* into the circuit. Experiments were made to ascertain whether this extraordinary fact was due to the passing of a voltaic current between the buried plates, but on closing the circuit with the earth and the wire *without* the pile, a deviation not exceeding 1° was obtained, and this shortly disappeared. It then occurred to Matteucci, that an explanation might possibly be given by having recourse to a current derived from Ampère's terrestrial currents. The battery current in the first experiments passed along the wire from E. to W.; he now reversed the current, causing it to pass from W. to E.; the deviation of the galvanometer, however, remained the same, as was also the case when the current was caused to pass from N. to S. or from S. to N. These experiments were afterwards repeated on greater lengths at Milan, and their results confirmed Matteucci in the conclusion to which he

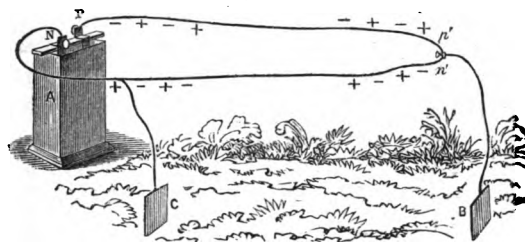
had previously arrived, viz., that when a current is transmitted by a circuit composed in parts of a long copper wire and of a long bed of earth, the diminution suffered by this current from the resistance of this mixed circuit, is less than that which it would have suffered by the resistance of the copper wire alone. Matteucci regards the earth as all other conducting bodies, its great volume making up for its inferior conductivity; he quotes the following experiment (*Comptes Rendus*, Jan. 12th, 1846), as conclusive against the hypothesis that the two electric charges liberated at the extremities of the pile always find means of diffusing themselves into the earth, which being a universal reservoir, succeeds in neutralizing their charges with its natural fluid, decomposed by the free fluid of the pile.

Experiment : The circuit of a pile of 10 Bunsen's elements, was established by plunging the two poles in two wells 160 metres apart; a galvanometer being in the circuit to ensure the passage of the current. In this interval were two other wells almost in a straight line with the two extreme wells. The distance between these two wells was 30 metres; they were distant from the two extreme wells, one, 80 metres, the other, 50. The extremities of a good long wire galvanometer were plunged into the two intermediate wells: the current was then passed in the long circuit, when a deviation of 35° or 40° was instantly obtained; on reversing the direction of the current in the long circuit, that of the *derived* current was likewise inverted. This, remarks Matteucci, is precisely what ought to be the case, if we admit that the electric current is transmitted in the ordinary manner, whilst it cannot be conceived under the other hypothesis.

(1084) The improbability of the earth's acting as a mere conductor in these cases, is strikingly shown by the following experiments made by M. Breguet, on the telegraph line between Paris and Rouen (Moigno's "*Télégraphe Electrique*," p. 259,) one of the poles of the Paris battery was soldered to a large metal plate, which was plunged into a well, the other pole communicated with the line wire to Rouen, and was there fastened to a similar metal plate, which was also plunged into a well; the circuit was thus half earth and half metal, or the circuit could be made metallic throughout. Similar arrangements were made at Rouen. Two zinc galvanometers, in every respect similar and working together with great uniformity, were employed to measure the electric forces at the two stations. The mean of twenty-eight experiments showed that when the current was half metal and half earth, the intensity was *twice as great* as when it was metallic throughout, that is, a circuit of 40 miles earth and 40 miles wire presented the same resistance as a circuit of 40 miles wire; the earth, in fact, offering no resistance at all. The intensity at Paris, of the current

transmitted through a copper wire to Rouen, and from Rouen back to Paris, through the earth was $56^{\circ} 8'$; that of a current sent and returned through a copper wire $29^{\circ} 1'$, or nearly one-half. At Rouen, the mean relative intensities were the same being $35^{\circ} 5'$ and $17^{\circ} 8'$. Moigno and Gauss both regard the earth as a reservoir or drain in which the positive Electricity on the one side, and the negative on the other are absorbed and lost. Thus let A (Fig. 425) represent the

Fig. 425.



cell of a voltaic battery, P and N being its two poles united by a metallic conductor; according to the theory of Ampère, the Electricity set free at the positive pole, meeting

with a resistance in the conducting wire, decomposes the neutral Electricity of the nearest molecule, attracting the negative and repelling the positive; the positive fluid of the first attracts the negative Electricity of the second, and repels its positive; this again acts on the neutral Electricity of the third, and so on, the decomposition proceeding step by step; the positive Electricity of the last molecule, p , being neutralized by the negative Electricity emanating from the N. pole of the battery. Immediately succeeding the first series of decompositions is a second series of recompositions, the last negative molecule, $-n$ being separated from its associated positive molecule, and thus becoming free, now combines with the positive molecule which precedes it, the negative molecule of which combines with the positive immediately behind it, and so on step by step. Suppose now the metallic circuit to be broken, between two free molecules, $+ p'$ on the positive side, $+ - n'$ on the negative, and that a communication be made with the earth through the metallic plates, B and C. The positive molecule will be brought into contact with an enormous reservoir, into which it will flow without meeting with any resistance; it will not, therefore, exercise any decomposing action, being in fact simply absorbed. The preceding negative molecule being again set free, will immediately combine with the contiguous positive molecule, and the same will happen at the negative end of the battery. A double series of decompositions and recompositions thus takes place, and this only in one-half of the circuit; the resistance is consequently reduced one-half, that is, the intensity of the current is doubled.

(1085) It must be admitted that there is some difficulty in this theory of the "drinking up" of Electricity by the earth, and that the

question is still open to investigation ; but whatever may be the true explanation of this remarkable function of the earth, its discovery has been a great boon to electro-telegraphy, and the fact that the earth absolutely offers no resistance whatever to the circulation of the electrical force, is taken due advantage of on all telegraphic lines. "Of all the miracles of science," observes Lardner ("The Electric Telegraph," p. 123), "surely this is the most marvellous. A stream of electric fluid has its source in the cellars of the Central Electric Telegraph Office, Lothbury, London ; it flows under the streets of the great metropolis ; and, passing on wires suspended over a zigzag series of railways, reaches Edinburgh, where it dips into the earth and diffuses itself upon the buried plate. From that it takes flight through the crust of the earth and *finds its own way* back to the cellars at Lothbury !" But this is not all ; though offering less resistance to the circulation of the electrical force than the *best* of all conductors, it at the same time acts as the most perfect insulator. Of this the following striking illustration is given by Mr. Walker ("Electric Telegraph Manipulation," p. 35) : "Ten wires enter the London office, each going to one side of the galvanometer ; the other sides of the galvanometers are connected respectively by ten wires with a long slip of brass, which brass is connected with the water-pipes ; so that, in point of fact, the wires, notwithstanding all our care and cost to keep them insulated from each other throughout their course along the railway,* are actually *one and all clustered together*, and connected into one common bundle, as soon as they have passed the galvanometer. Notwithstanding this *oneness* of the wires, provided all is clear along the line, a current can be sent along any one of the ten, without any portion being distributed among the other nine. Take the case of two wires only as an example. They

* The difficulty of obtaining perfect insulation of the wires is one of the greatest impediments to the establishment of telegraphic communication. The difficulty is increased when wires forming short circuits are placed in close proximity to those of long circuits. Under these circumstances, if the wires are not protected by an insulating coating, there is frequently in a damp state of the atmosphere, an escape of Electricity from the long wire to the short one, and a consequent diversion of the Electricity from its intended course ; for although the low intensity of voltaic Electricity may in experiments on a limited scale effectually prevent it from passing through a thin stratum of moist air, it must be remembered that each iron wire from London to Liverpool exposes a surface of not less than 45,000 square feet, and between several surfaces of that extent only 6 inches apart, a large quantity of Electricity may be transferred and lost. The escape of Electricity from telegraph wires, in the manner now alluded to, was first brought under the notice of telegraphic engineers by Mr. Bakewell. ("Bakewell on Electric Science," p. 157.)

are united, and are joined to the earth wire before they enter the London instrument. They are kept carefully apart from London to Dover, but after passing the Dover instrument, they are again united, and are joined to the earth wire, so that they form a continuous loop; and yet the current intended for one wire always takes the earth as the *return half* of the circuit, and no part of it finds its way into the companion wire. But if by any accident the earth wire is divided, the case is widely altered, and the current tells its own tale by its reverse action on the galvanometer, for it now accepts the companion wire, which before it entirely rejected."

(1086) The necessity of paying the utmost attention to the insulation of the line wire, involves the introduction of a difficulty of another kind, and which has to be carefully guarded against; that, viz., arising from the action of atmospheric Electricity, both induced, and in the form of direct strokes of lightning. "More damage," observes Mr. Highton ("The Electric Telegraph," p. 11), "is often done to the telegraph in a second by a single thunder storm, than by all the mischievous acts of malicious persons in a whole year." Posts are split in pieces, coils of wire are fused, needles are demagnetized, and permanent Magnetism given to soft iron electro-magnets. In the year 1846, the electric telegraph on the St. Germain's Railway was visited by an attack of atmospheric Electricity, the following account of which was communicated by M. Breguet to M. Arago ("Year-Book of Facts," 1848): "About five o'clock in the afternoon, during a heavy fall of rain, the bells of the electric telegraph at Le Vesitret began to ring, which led the attendant to suppose that he was about to receive a communication. Several letters then made their appearance, but finding they conveyed no meaning, he was about to make the signal "*Not understood*," when suddenly he heard an explosion, similar to a loud pistol-shot, and at the same time a vivid flash of light was seen to run along the conductors placed against the sides of the shed. The conductors were broken into fragments, their edges being fused. The wires of several electro-magnets were also broken, and the attendant who was holding the handle which moves the needle sustained all over the body a violent concussion, and several workmen standing about him also experienced severe shocks." At the other end of the line, at the Paris station, nothing was broken, and nothing remarkable occurred, excepting that several of the bells were heard to ring. At the Oundle station of the London and North-Western Railway considerable mischief was done in 1846, several of the coils being burst open, and the wires fused; and at the Chilham station, on the South-Eastern Railway, a flash of lightning destroyed, in August,

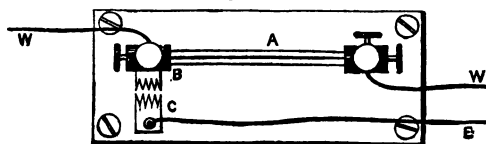
1849, the wire of the bell coil and both the galvanometer coils. In India, which is occasionally visited with storms of lightning such as we never witness in this country, the damage done is often much more severe; and in America, the disastrous consequences resulting from the same cause, soon after the establishment of the first line of telegraph by Morse, in 1844, rendered it imperatively necessary to devise some means for the protection of the operators and instruments.

(1087) Numerous forms of lightning conductors have been invented and adopted. Actual lightning flashes are warded off by the points visible above the posts (Fig. 421), which are connected with the earth by a wire. Highton's plan, which he states to be so effectual that since its adoption not a coil has been injured, is very simple. He surrounds the wire for 6 or 8 inches before it enters a telegraph instrument with bibulous or blotting paper, and passes it through a deal box lined with tin plate in connexion with the earth; the box is then filled with iron filings. All high tension Electricity collected by the wires will at once dart through the air in the bibulous paper to the myriads of points in the iron filings, which carry it safely to the earth. Walker's "protector" consists of a small hollow metal cylinder connected with the earth. The line wire in its passage from the railway to the telegraph passes within this cylinder, traversing which, it is first presented to the inner surface in the form of a thick wire furnished with spurs whose points are in the closest possible proximity to the cylinder without being in actual contact; it is then continued on, and presented as a short coil of very fine wire (finer, in fact, than that of the instrument coils) wound on a bobbin, the outer convolution of the coil being very close to the cylinder. Thus a better means of escape is presented to the lightning than is found in any part of the instrument; consequently it always escapes by this conductor, either by the points or by burning the fine wire. It is found to be perfectly effectual. In Steinheil's method the line wire extending over the station is divided, each end being fastened to a copper plate 6 inches in diameter; the plates are brought close together, but prevented from touching by a silk cloth; then coils of wire pass down from the corners of each plate to the telegraph instrument. The galvanic current is thus enabled to pass; but an atmospheric discharge would break through the small obstacle between the copper plates in preference to passing out of its way through the thin spiral of wire. Since the introduction of this protector in 1846, no derangement of the apparatus is stated to have occurred even with the most vivid flashes of lightning.

(1088) On the Brunswick State Telegraphs, the main wire, well

protected by gutta percha, is passed through pipes underground, and fastened to a copper plate in the telegraph room. From this plate a small insulated wire is extended to the signaling instrument, and through the battery to a second copper plate in connexion with the earth. The two copper plates are screwed together, but insulated from each other by pieces of ivory. The two thin wires, which are covered with silk, are twisted together, but separated near the telegraph apparatus, to the screws of which they are attached. The galvanic current passes through the main wire to the first plate, through the thin wire to the apparatus and electro-magnet, through this to the galvanic battery and the second plate, over this by the stronger insulated wire to the ground, making a perfect circuit. But a discharge of atmospheric Electricity would pass between the two copper plates rather than through the long thin wires, and the telegraph apparatus is thus effectually protected. Various forms of lightning protectors are used in America, the simplest and best seems to be that of Bulkley, which consists of two brass plates with serrated edges, one of which is fixed to a board, the other adjustable by means of a screw to any required proximity to the first; the line wire is connected with the fixed plate, and the moveable one is in communication with the earth; the plates are brought as near together as possible without touching, so that any Electricity of tension may meet with as little resistance as possible in its passage from the line wire to the earth.

(1089) Breguet's *paratonnerre* used on the French telegraph lines, is shown in Fig. 426.



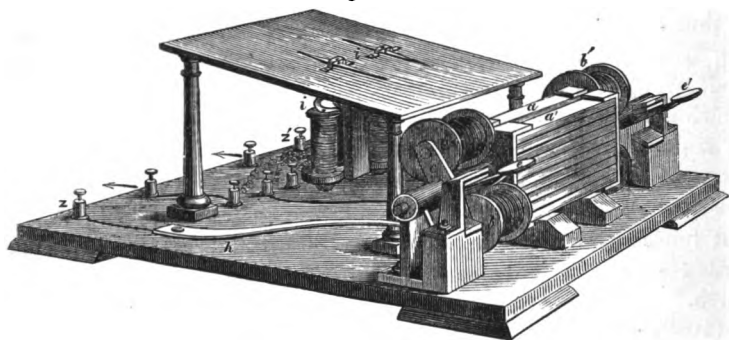
The line wire is connected with a very fine iron wire placed in a glass tube, capped at both ends with brass

and screwed on to a board. To the side of one of the brass caps is fastened a serrated piece of metal, B; immediately opposite and as close as possible to which is a similar serrated piece of metal, C, in communication with the earth by the wire E, so that if the wire of the line should become charged with atmospheric Electricity, it may discharge itself by these points to the earth; and in the event of a flash of lightning striking the line wire, the thin iron wire A would be fused, and the telegraph instrument protected.

(1090) *The Magneto-electric Telegraph*.—In this instrument, patented by Mr. Henley in 1848, the motions of the needles are actuated by the electric currents momentarily induced in electro-magnetic coils when moved in proximity to the poles of a permanent steel magnet. This

telegraph is adopted, with certain improvements, by the English and Irish Magnetic Telegraph Company, through a length of line above 2,100 miles; by it messages are now passed between Liverpool and Dublin direct, a distance of about 420 miles; the line of communication extending *via* Port Patrick and Belfast; and signals can be interchanged when necessary between London and Dublin, a distance by the wire of 660 miles, without any break of circuit, or renewal of the magnetic circuit: the whole length of wire in use is about 13,900 miles, of which 6350 miles are laid underground, and about 7,500 above ground. This telegraph, the simplest and the most economical yet invented, merits a detailed description. For the following particulars we are indebted to the kindness of Mr. B. Bright, the secretary of the above company.

Fig. 427.



(1091) The original apparatus of Mr. Henley is shown in Fig. 427. Two compound bar magnets, *a a'*, are fixed parallel to each other, so that their opposite poles are in juxta-position. At each end of the magnets are arranged a pair of electro-magnetic coils, *b b'*, which are connected together at the back by a soft iron armature, *c*; each pair is attached to a separate axle and finger key, *e e'*, and are perfectly independent of each other, so that by their motion they can communicate magneto-electric currents to the two line wires, *z z'*. In order to avoid the friction that would ensue on the motion of the coils, if their soft iron centres were in actual contact with the poles of the permanent magnets, the axles upon which the coils are fixed are so adjusted as to bring the ends of the soft iron cores to within about the $\frac{1}{16}$ th part of an inch from the magnets. When the *sending* part of the apparatus is at rest, a spring, *h*, keeps the coils so disposed that the centre of one is before one pole of the magnet, and the other before the other pole. This answers a double purpose; the iron cores and armatures of the coils act as a keeper to the magnets when the apparatus is not in use, and the position at the same time

is such that the maximum of inductive effect is obtained upon the motion of the coils. The finger key attached to the axle, on being depressed, reverses the position of the coils in relation to the poles of the magnets; the alteration in the polarity of the soft iron cores which thereupon ensues, occasions by induction a revulsion in the electric condition of the convolutions of wire forming the coils, and the current induced flows from one terminal wire of the pair of coils, through the indicating portion of the apparatus, *i*, in one direction to the earth, and from the other terminal wire in the opposite direction through the line wire. On the return of the finger key to its original position, the polarity of the cores is again reversed, and currents are induced in the opposite direction to those previously generated. The operation of the one current is to deflect, and of the other to bring back to zero the indicating needles of the apparatus, and of the instruments, at the various stations to which the currents may pass. The motion of the other finger key leads to similar effects being produced in connexion with the other line wire; and the combinations of movements of the two indicating needles constitute the alphabet.

(1092) The indicating portion of the apparatus consists of a pair of small electro-magnetic coils coupled together by an armature; the soft iron cores project beyond the coils, and are terminated by semi-circular horns of soft iron. This elongation of the cores was found necessary in order to prolong the polarization of the coil, as the great intensity of the induced current would not occasion during its passage through the coil a sufficient amount of polarity in the iron to move the magnet of the indicating needle unless its effects were, so to speak, thus temporarily fixed. On the return of the finger key to its original position, an amount of residual Magnetism is left in the horns of the indicating coils sufficient to hold the needle in its position at zero when the instrument is at rest. By this arrangement what is technically termed a "dead beat" of the needle is produced, and the needle at the same time is in perfect equilibrium upon its axle,—conditions which conduce greatly to the rapidity and invariability of the needle's motion, and to the accurate interpretation of the signals. The magnets used to generate the induced currents are tempered in a particular manner, and retain their polarity for years. They are easily remagnetized when required, by bringing their poles for a short time into contact with a powerful electro-magnet.

(1093) *Recoil Currents from Underground Lines.*—The Magnetic Telegraph Company have adopted, to a very great extent, the underground system. In 1851, they laid a line between Liverpool and Manchester; they afterwards extended the system from London

through Birmingham to Manchester, Liverpool, and the various towns in the Lancashire districts, northwards to Scotland, with a submarine cable linking up underground wires laid to Belfast and Dublin. They have been enabled to accomplish this through the great perfection to which the insulation of wire by successive coatings of gutta-percha has been brought by Mr. Statham. It was found upon communicating a charge to a great length of underground wire, that after the withdrawal of the excitation (whether galvanic or magnetic Electricity was employed), an *electrical recoil* immediately took place at the end of the wire to which the current had been previously communicated. The nature of this phenomenon has been explained by Faraday (316 *et seq.*); its existence was soon found to interfere very materially with the working of telegraphic apparatus, nor does it appear that up to the present time, any adequate remedy as regards the galvanic system has been applied. The nature of the interference will be at once understood, when it is mentioned that, with a letter-printing telegraph, the surplus current has the tendency to carry the machinery on farther, and to make other letters than those intended. With the chemical and other recording telegraphs, the surplus flow of Electricity will continue nearly a minute, entirely confounding the marks, and representing one letter with the next; and with the needle telegraphs, a beat more is made by the back current than intended with every letter formed.* Another remarkable feature to be noticed in connexion with the underground system, is the small comparative velocity with which the electrical impulse is communicated through each conductor in long circuits. Through a circuit of 480 miles, Messrs. Bright found that the difference of time between the communication of the electrical impulse and its arrival at the other end of the wire, amounted to rather more than a third part of a second, which would give as the rate of transmission of the galvanic or magnetic fluids through such conductors, only about 1,000 miles per second. It has been shown by Faraday (316 *et seq.*) that this retardation does not arise from any resistance of the conducting medium, but is the consequence of a *lateral* induction whereby the wire becomes charged *statically* with Electricity,—becomes in fact an immense Leyden arrangement.

(1094) On applying the magneto-apparatus above described to the underground system, it was found impossible to work it without making some provision against the effects of the recoil currents, for when the needle had been deflected and brought back to zero, by the two successive currents generated by the instrument, the recoil

G. B. Bright, "Shaffner's Telegraph Companion."

current flowing in the opposite direction to the last current sent, again threw the needle over, so that each time a signal was transmitted, instead of two beats of the needle being given, *three* occurred, disorganizing the series of signals employed, and leaving the indicating needles of the sending instrument in such a position as to render the answering signal (given after every word) unintelligible; for of the two currents employed in sending the answering signal from the other end, only the second showed any effect; the first serving to keep the needle against the stop pin, where the recoil current had left it. Moreover, the continual recurrence of two currents in one direction, and only one in the other, for each movement of the finger-key, a residual excess of one kind of polarity accumulated in the indicating coils; and thus after a short time, the effects of currents from the other end were neutralized, and the communication of signals rendered impossible.

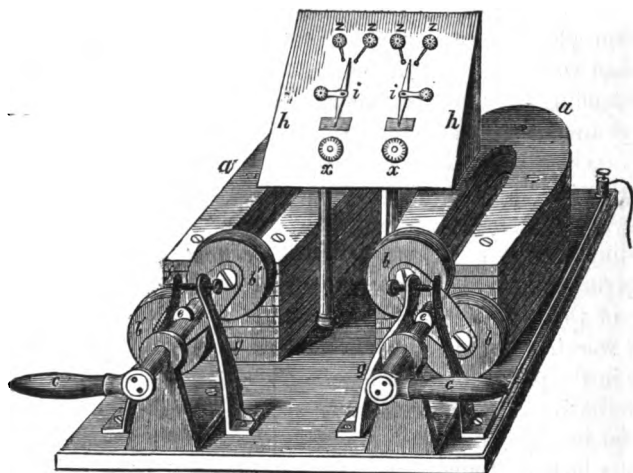
As the reciprocity of two instruments working in a circuit together is almost a *sine qua non* for correct transmission of signals, and constitutes the most valuable feature of excellence in the English system, it was at once seen that if underground wires were to be worked, this difficulty must be overcome.

(1095) *Messrs. Bright's Improved Magnetic Telegraph.*—It was first sought to obviate the effects of the recoil currents by placing the charged wire into direct connexion with the earth at the instant that the exciting current ceased, so as to prevent the flow of the recoil current from passing through the indicating apparatus, which was again placed in communication with the line wire when the handle had recovered its place of rest. It was found, however, that upon extending the line, the time required for the recoil current to discharge itself increased also; Messrs. Bright then applied another method. The indicating apparatus was altogether disconnected from the action of the sending currents, and only brought into connexion with the line wire at their termination. In this plan, instead of shutting off the recoil current it was permitted to pass through the receiving coils at the close of the sending currents, and the connexions of the apparatus were so arranged that it conducted to the efficient working of the apparatus by keeping the needles at zero, so as to be in the proper position for receiving signals from the opposite ends of the line. A compensating apparatus was also introduced having for its object: 1st, the obviating the effects of the deflecting currents which continually pass through telegraph wires, more or less, and in different directions, and which arise from variations of terrestrial Magnetism, and during aurora borealis and other atmospheric electrical disturbances (311 *et seq.*); and 2nd, the

neutralizing any excess of residual Magnetism that might be engendered in the horns of the coils by the recoil current; this excess varies with the difference in the length of the circuit worked, and requires a *constant* compensation to be maintained. The apparatus consists of a permanent magnet of much greater strength than the magnet within the horns of the indicating-coils, fixed upon an axis, at such a distance from the lower pole of the indicating needle, that the poles of the compensating magnet may be made to describe a circle intersecting the lower pole of the indicating magnet, but being in a plane slightly removed from it, so as not actually to come into contact. By an external regulator, the compensating magnet can be adjusted, so that the influence of either of its poles can be brought to exercise a definite influence of attraction or repulsion upon the receiving magnet, and upon the soft iron horns of the coils by which it is moved, and thus to negative an excess of polarity in either direction. Since this contrivance has been adopted not the least inconvenience has been suffered from the greatest electro-terrestrial disturbances, even when to such an extent as to deflect a galvanometer needle at right angles; nor does the strongest return current from the most extended circuit impede in the least the efficient transmission of signals.

(1096) The magnetic telegraph as thus improved and with which the underground wires are now worked, is shown in Fig. 428;

Fig. 428.



a a, compound horseshoe magnets, formed of steel plates screwed tog.

b b, induction coils attached to axles moved by the handles *c c*;

one of the wires terminating each pair of induction coils is connected to an insulated metallic *cam*; the other end of each pair of coils is conducted directly to the earth.

c c, the metallic *cams*; they are insulated from the axles to which they are attached by ivory plates.

ff, two springs connected with the line wires, and resting against the screws of the bearings *g g*.

g g, two bearings, or bridge-pieces, in connexion with the indicating portion of the instrument.

h h, the outside of the dial; *ii*, the indicating needles moved by magnetic needles inside on the same axles.

x x, thumb-screws by which the magnet regulators are adjusted.

z z z z adjusting pins between which the needles beat.

The internal arrangement of the indicating apparatus is not shown in the figure. When at rest, the spring *f* is in contact with the bridge-piece *g*, and the line wire is in direct communication with the indicating part of the instrument, and the electric currents from other stations pass from the line wire through the indicating coils, and thence to the earth, producing in their passage the required signals. When, however, the handle is depressed, the metallic *cam* or stud attached to the axle presses the spring away from the bearing *g*, and the current of Magneto-electricity produced in the induction coils by their change in position, as regards the pole of the permanent magnet, passes direct to the line wire; this current deflects the needles of other stations from zero. Directly the downward motion of the handle is arrested, and during its return to its original position, a current in the opposite direction is induced, and flows through the line wire, bringing the indicating needles of the other stations back to zero, but not affecting its own indicating apparatus, owing to the connexion between the spring and the bearing being still incomplete. The moment the spring is again in contact with the bridge-piece, on the cam setting it at liberty, the line wire, in which a portion of the last current has been *fixed*, as it were *in transitu*, seeks to gain its equilibrium, and the recoil current passes through the indicating portion of the instrument (now in circuit again), and holds the needles to zero, in the proper position to be actuated by currents from the other stations.

(1097) *Messrs. Bright's Acoustic Telegraphic Apparatus*.—Under the ordinary system of telegraphing, it is necessary to employ a transcriber to write down the words as interpreted from the visual signals, and dictated to him by the receiving operator, whose eyes being fixed on the rapidly moving needles, could not be engaged in conjunction with his hands in writing. It was found that owing to

the frequent occurrence of words of nearly similar sound, the transcribers sometimes unavoidably misunderstood the meaning of the receiving operator's, and altered the sense of the despatch by writing the wrong word. Such words as "two," "too," "to," "four," "for," "hour," "our," may, for instance, be very easily confounded. Messrs. Bright have sought to remedy this inconvenience by transferring the manifestation of the effects of the current from the eye to the ear. Their apparatus is shown in Figs. 429 and 430.

Fig. 429.

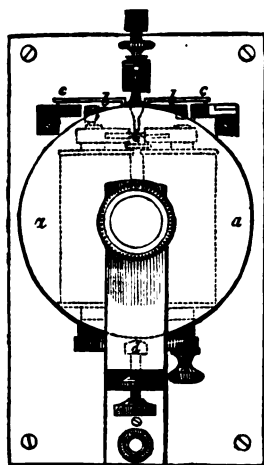
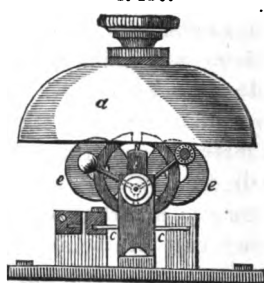


Fig. 430.



a is the bell; *b*, the hammer; *b'*, the muffer to deaden the sound, and stop the vibration after each stroke; *c*, the contact maker and breaker, by which the local battery is put on and

shut off; *d*, a fixed muffer; *e, e*, Fig. 429, the electro-magnetic coils through which the local current is passed, and which actuates the magnet *i*, from the axle of which extend arms bearing the hammer and muffer *b b'*.

There are usually a pair of these bells together, one bell differing half an octave in tone from the other, and one being fixed to a wooden partition, one on one side, and the other on the other side of the operator. From the number of beats, and the difference in tone, the letters and words are formed in the same manner as with the needle telegraph.

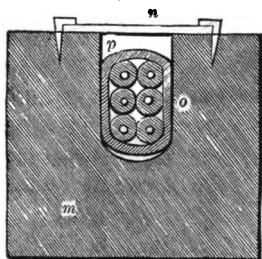
(1098) Besides the saving in staff and in mistakes, any injury to the eyes of the clerks is prevented, and an appeal is made to an organ far better capable of endurance and accurate interpretation; and it is found that a greater speed can be attained than by the old plan of telegraphing by needles, and the prompt attention of the operator is at once directed to the instrument, by the sounds given, upon a call being made. It is worthy of note, that while to read by a visible signal a movement of at least the eighth part of an inch is necessary for accuracy, the local current of the acoustic apparatus produces the full sound by the slightest movement, even the $\frac{1}{160}$ th part

of an inch of the magnet actuated by the primary current proceeding from a distant station. The idea of assisting the telegraphic operator in interpreting visual signals, by releasing the detent of a train of clockwork, and so producing intonation of an alarm to mark out the number and period of the beats of the needle more distinctly, appears to have been suggested in this country about twelve years ago, but practical difficulties at that time prevented its application. A similar plan without, however, the employment of local currents, was proposed in Germany in the early days of electro-telegraphing, but it was not successfully carried out. We are informed, however, that some of the most busy circuits in connexion with the English and Irish Magnetic Telegraph Company are now worked by this method at the rate of from 30 to 40 words per minute, received and written down by the *same* operator.

(1099) The following details of the system of underground wires have been kindly furnished by Mr. Bright:—

It was evident that the integrity of the insulating coatings of gutta percha could not be preserved long without some external protection throughout the length of each line, as the mere compression of the soil, gravel, and stones would at once have injured it, and in opening the roads for repairs, they would experience still further damage; after discussing the merits of various plans of protection, it was finally decided that the wires throughout towns should be laid in cast iron piping, divided longitudinally, so that the wires might be laid in quickly, without the tedious and injurious operation of drawing them through, as was the case with the old system of street work, where the wires were laid in ordinary gas piping; and that along the country roads, which were comparatively little liable to disturbance from the construction of sewers or laying of gas or water pipes, the wires should be laid in *creasoted* wooden troughs, of about 3 inches scantling, cut in long lengths, so as to be little liable to disturbance upon any partial subsidence of the soil, which not unfrequently occurs in districts where mining operations are carried on. The tops of the troughs are generally protected by fastening to them a galvanized iron lid.

Fig. 431.



The tops of the troughs are generally protected by fastening to them a galvanized iron lid.

Fig. 431 shows a section of one of the troughs: *m* being the trough; *n*, the galvanized iron lid; *o*, the gutta perchaed; and *p*, a lapping of tarred yarn. The trough is deposited at a depth of 2 feet from the surface of the road. The iron piping used in towns is about 2½

inches in diameter. The lower halves are first laid, socket into socket, in the trench, and the wires are then rapidly reeled off, and deposited in the lower halves from a drum drawn over the trench. The upper halves are then laid on, and attached to the already laid portions by clamps or bolts fastening through ears cast in the sides of the pipes. So well has this mode succeeded that in Liverpool the whole lengths of the streets from Tithebarn railway station to the office in Exchange Street East were laid down in a single night ; and in Manchester, the line of streets from the railway station in Salford to Ducie Street by the Manchester Exchange, in 22 hours.

(1100) In the overground system, the wires are arranged upon insulators attached to arms of different lengths, so that if a wire breaks and falls off it does not come into contact with those below, so as to impede the transmission of signals, but falls clear. The insulators are of glass or earthenware, of the form shown (side view and section in Figs. 432 and 433). The

wires pass through a groove in the top of the insulator, and are secured there by a small peg and lapping of binding wire.

(1101) Froment's French alphabetic tele-

Fig. 432.

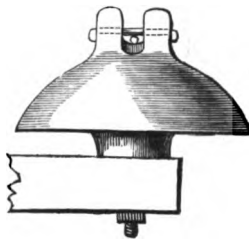


Fig. 433.

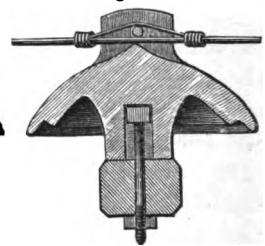
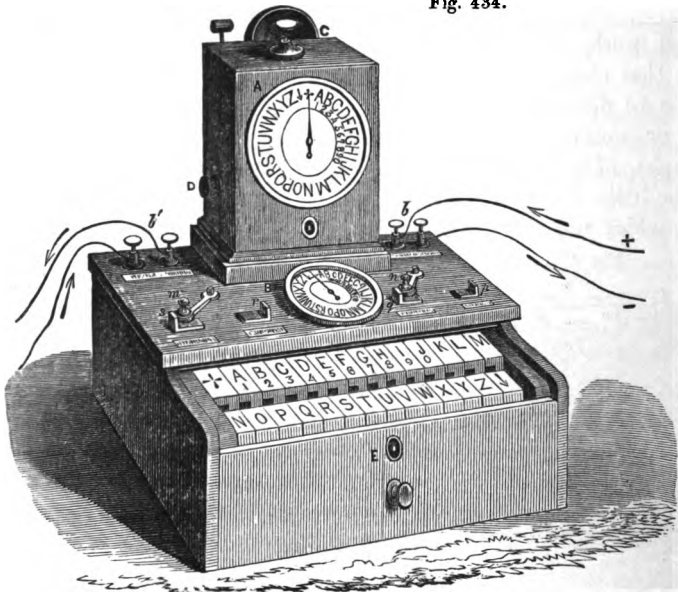


Fig. 434.



graph shown in Fig. 434 is an exceedingly elegant piece of apparatus. In external form it resembles a small pianoforte without the black keys. There are 28 keys : 26 representing letters, 1 a cross, and 1 an arrow ; by pressing down any key its corresponding letter is shown on the dial, and at the same time on the dial of a similar apparatus at the distant station. Suppose, for example, the apparatus figured in the text to be at Paris, the current from the pile enters the apparatus at *b* and leaves it at *b'* ; it proceeds thence to the distant station—say Rouen—where it traverses and works a precisely similar apparatus.

(1102) The mechanism of the internal part of the apparatus will be understood from a slight consideration of Figs. 435 and 436.

Fig. 435.

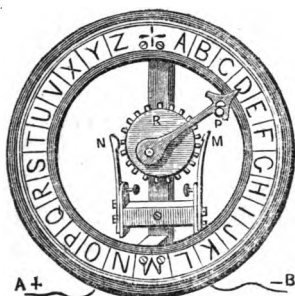
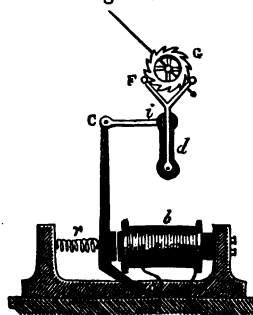


Fig. 436.



Fig 435 is the *manipulator*, or the instrument for giving signals ; Fig. 436 is the *receiver*. The current from the battery enters through A, Fig. 435, passes up the brass spring N, which is in contact with the wheel R, and from this through the second notched spring M, out by the wire B, and on along the line wire to the telegraph at the distant station. There the current traverses the bobbin of an electro-magnet, not seen in Fig. 435, but exhibited separately in Fig. 437. This electro-magnet is fixed horizontally at one extremity,

Fig. 437.



the other being left free to operate on the soft iron armature *a*, which forms part of a bent lever, moveable round the pin *o* ; the lever is restored to a vertical position when the electro-magnet is no longer active by the action of the spring *r*. The moment the electrical current traverses the bobbin, the lever at C is attracted, and the motion is imparted to a second lever *d*, through the shank *i*. This second lever is fixed on a horizontal axis, and is united to the fork F. When the current is interrupted the spring pulls back the lever, and

thus a step by step movement is given to the fork, which it transmits to the wheel G carrying the index.

(1103) The manner in which the battery current is interrupted and renewed will be understood by referring to Fig. 435. The wheel R carries 26 teeth; on turning it by the button P, while the plate N is, from its curved form, in constant contact with the teeth, the plate M, being crooked, has its contacts broken and renewed every time it passes over a tooth, and at the same time the battery current is thrown off and on. Suppose the pointer P is advanced 4 letters, then the current between N and M will be 4 times made and 4 times broken, and the armature of the electro-magnet at the distant station will be 4 times attracted and 4 times pulled back by its spring; but these 4 attractions will give 4 movements to the wheel G, and the pointer will pass over the same number of letters in the dial of Fig. 436, the *receiver*, as in that of Fig. 435, the manipulator. At the top of the case of the instrument is the alarm, which is worked by a special electro-magnet. Referring now to Fig. 434, we see in front of the apparatus a series of 28 ivory keys, the first being marked with a cross, the last with an arrow, and the intermediate 26 with the letters of the alphabet; the first 10 letters carrying also the 10 numerals. Immediately in front of the keys, on a horizontal platform of mahogany, is the dial B and 2 small metal pieces, *m n*, which are moveable, and which by means of a handle may be brought into contact, *m* with *s* or *r*, and *n* with *q* or *p*. The dial B is the verifier; its index must always point to the same letter as that last signalled; if it does not, it shows that the apparatus is not in proper working order. When *m* is in contact with *s*, the apparatus is in a condition to send signals from Paris to Rouen. When in contact with *r*, it is in a condition to receive a signal from Rouen to Paris. In like manner when *n* is in contact with *q*, the alarm may be sounded at Rouen; when in contact with *p*, the machinery is in a state to receive a notice from Rouen.

(1104) *Electro-magnetic Clocks*.—Mr. Bain, who has patented several applications of Electricity to useful purposes, exhibited in the spring of 1841, at the Polytechnic Institution, an electro-magnetic clock, the principle of which will be clearly understood by an inspection of Figs. 438 and 439.

B, Fig. 438, is a back view of an ordinary clock, with a pendulum vibrating seconds; *C*, a plate of ivory affixed to the frame of the clock, in the middle of which is inserted a slip of brass in connexion with the positive pole of the battery. To the pendulum is attached a very light brass spring, *F*, in such a manner, that every vibration of the pendulum brings the free end of the

spring into contact with the strip of brass, thus completing the electric circuit, which is broken as soon as the spring touches the ivory. A series of *electric clocks* may be connected, by means of the wires, with this clock, and if a voltaic battery be included in the circuit they will all go together.

(1105) Fig. 439, is a back view of one of the electric clocks : *a* is

Fig. 438.

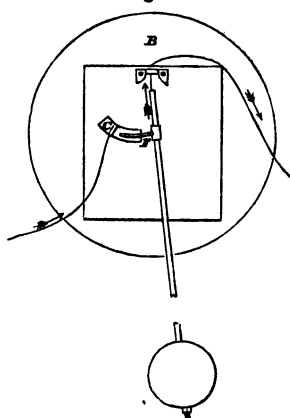
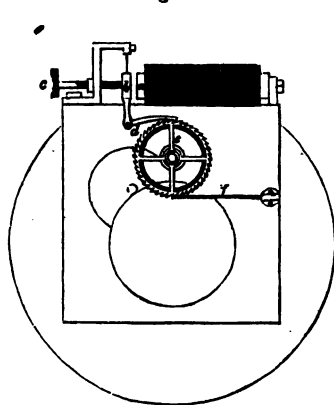


Fig. 439.



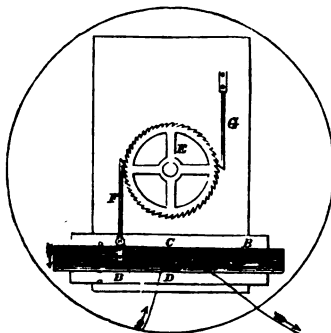
an electro-magnet, and *b*, its feeder, suspended by a spring pendulum-fashion ; *c* is a small screw to regulate the distance of the feeder from the electro-magnet. At the lower end of the feeder is jointed a light click lever, *d*, falling into the teeth of a ratchet wheel *e* ; *f* is a spring to keep the ratchet wheel steady. When the pendulum of the clock sends an electric current through the conducting wire, the feeder is attracted by the magnet, and the click lever *d*, takes over 1 tooth of the ratchet wheel ; upon the current being arrested (by the spring *F* of the pendulum, leaving the slip of brass in the primary clock), the feeder falls back into its former position, and causes the click lever to draw the ratchet wheel 1 tooth forward. The arbor of the ratchet wheel carries the *seconds' hand*, which is thus taken forward 1 degree every second, corresponding to the vibration of the clock *B*. A pinion on the ratchet arbor gives motion to other simple wheel-work, which carries the minute and hour hands. When a large number of clocks is to be worked, the ratchet wheel is placed on the arbor of the *minute hand*, and is moved every minute instead of every second. An ivory circle, with slips or studs of metal, inserted flush with its face, corresponding to the number of clocks or group of clocks intended to be worked, is fixed on the face of the regulating or primary clock ; in the centre of this circle is placed

the arbor of the seconds' hand of the clock, upon which is fixed a slight metal spring with its free end in contact with the ivory circle. The conducting wire from the positive pole of the battery is in connexion with the framework of the clock; every time, therefore, that the seconds' hand passes over a metal stud in the ivory circle, an electric circuit is completed and a current transmitted to the clock or group of clocks in connexion with that particular stud. As the seconds' hand passes over every portion of the circle once in each minute, the whole number of clocks thus connected with the regulating clock will be moved forward 1 degree every minute. By this means a large proportion of electric power is saved, for the battery has only a single clock or a small group of clocks to work at the same instant of time.

(1106) Mr. Bain has also invented an apparatus for making ordinary clocks keep correct time; also a method of working the electric clock by the deflection of the wire coil. In conjunction with Mr. Barwise, he took out a patent for these inventions, which was sealed 8th January, 1841. On the 28th of March, his clock was exhibited at the Polytechnic Institution.

Fig. 440, shows the method adopted by Mr. Bain for working the electric clock by the deflection of the *wire coil*, instead of the attractive power of the electro-magnet. *A* is a coil of insulated copper wire, freely suspended on centres. *B* is a compound permanent steel magnet, immovably fixed within the coil. *C C* are two spiral

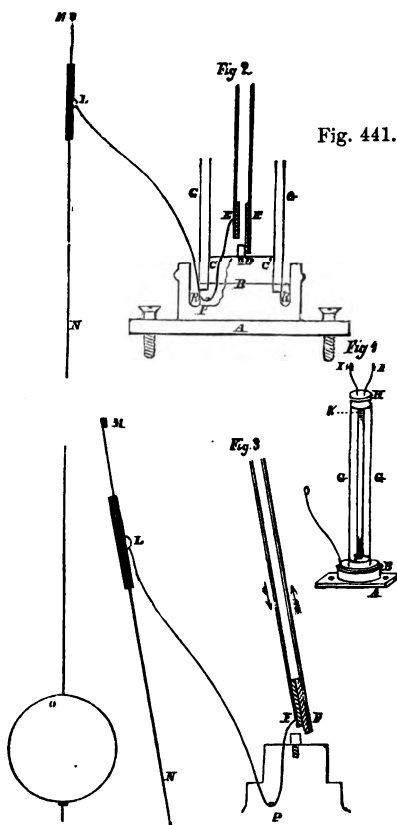
Fig. 440. •



springs, one on each side, for the purpose of conveying the electric current from the stationary conducting wire *D*, to the moveable coil. *F* is a click lever attached to the coil. *E* is a ratchet wheel fixed upon the minute-hand arbor of the clock, and *G* a wheel to keep the spring steady. The regulating clock transmits the electric current to the wire coil, upon which the left hand end is instantly depressed, and the

clock lever *F* draws the wheel *E* forward 1 tooth. When the flow of Electricity from the regulating clock is discontinued, the wire coil resumes its original horizontal position by the action of the spring *C*. If the clock receives an electric current once in every second, the wheel *E* is placed on the arbor of the seconds' hand; but if the Electricity is only transmitted once in each minute, then the wheel *E* must be placed on the spindle of the minute hand.

(1107) The Rev. F. Lockey's contact-former for the electro-magnetic clock is shown in Fig. 441. Fig. 1 shows the contact-former entire; in each figure similar letters refer to similar parts. On the base board *A* (about 3 by 2 inches) is fixed the circular box or trough *B*. Fig. 2 exhibits a section of this box-wood trough wherein is turned the channel *R R*, and the central part, *C C*, is left as a solid cylinder on which to place rather firmly the glass tube *G G*. This tube, of which *G G* in Fig. 2 shows the section, rests on a rim or shoulder just below the rim at *B*, which shows the level to which mercury is poured into the channel *R R*, for the purpose of closing the bottom of the tube, and preventing all access of dust to its interior. The glass tube is surmounted by an ivory cap, *H*, Fig. 1, cemented thereon; through the ivory cap pass the two wires *I I*, furnished with screw connecting pieces for the purpose of uniting them with the *p* and *n* wires of the galvanic battery. The lower end of these wires terminates in two very thin and flexible copper springs, of which the lower portions are seen in Fig. 2, *E F*; they are tied together at *K*, Fig. 1, a piece of ivory being interposed to prevent metallic contact, as well as to place them parallel to each other in the tube; they are tipped with platinum foil at *E* and *F*, and one of them is a little longer than the other. The spring *F* is so set as to have a slight tendency to advance towards *E*, but it is prevented from doing so by the ivory stud *D*, Fig. 2. Part of the central cylinder *C C* is supposed to be broken away in Fig. 2 to show the lever (formed of iron wire No. 18) bent somewhat in the form *E C P L*, the fulcrum *P* being beneath the end of the tube, and the part *E C P* working freely in a slit in the cylinder *C C*. If this contact-breaker



is intended to work an electro-magnetic clock, it is so placed at the side of the central or regulating clock, as that the pendulum MNO , just before it swings into a perpendicular position, shall begin to act on the lever at L . During the remaining half of its vibration towards the right hand (in the figure), as well as during the first half of its returning vibration towards the left hand (see Fig. 3) it will *maintain contact* between the free or platinum ends of the springs E and F ; during the other two halves of its vibrations, the lever is unacted upon, and the springs returning to their parallelism, contact is broken, and the battery current ceases. Such an instrument does not impede the action of the clock to which it is applied; Mr. Lockey's had been upwards of six months in continuous use, and acting with unfailing accuracy, when the author first saw it.*

(1108) Mr. Wheatstone's electro-magnetic clock, which was exhibited and explained at the Royal Society, 25th November, 1840, is thus constructed: all the parts employed in a clock for maintaining and regulating the power are entirely dispensed with. It consists simply of a face with its second, minute, and hour hands, and of a train of wheels which communicate motion from the arbor of the seconds' hand to that of the hour hand, in the same manner as in an ordinary clock train; a small electro-magnet is caused to act upon a peculiarly constructed wheel placed on the seconds' arbor, in such a manner that whenever the temporary Magnetism is either produced or destroyed, the wheel, and consequently the seconds' hand, advance $\frac{1}{60}$ th part of its revolution. On the axis which carries the scape wheel of the primary clock, a small disc of brass is fixed, which is divided on its circumference into 60 equal parts; each alternate division is then cut out and filled with a piece of wood, so that the circumference consists of 30 regular alternations of wood and metal. An extremely light brass spring, which is screwed to a block of ivory or hard wood, and which has no connexion with the metallic parts of the clock, rests by its free end on the circumference of the disc. A copper wire is fastened to the end of the spring, and proceeds to one end of the wire of the electro-magnet; while another wire attached to the clock frame is continued until it joins the other end of that of the same electro-magnet. A constant voltaic battery, consisting of a few elements of very small dimensions, is interposed in any part of the circuit. By this arrangement the circuit is periodically

* The cost of working an electro-magnetic clock, according to Mr. Tylee's observations, is under a penny per week, the battery employed being one on Smee's construction, platinized silver, $3\frac{1}{2}$ inches square, and the exciting fluid, water with $\frac{1}{10}$ part of sulphuric acid. Such a battery Mr. Tylee finds will work his clock for 14 days without being interfered with.

made and broken, in consequence of the spring resting for one second on a metal division, and the next second on a wooden division. The circuit may be extended to any length, and any number of electro-magnetic instruments may be thus brought into sympathetic action with the standard clock. It is necessary to observe, that the force of the battery and the proportion between the resistances of the electro-magnetic coils and those of the other parts of the circuit, must, in order to produce the maximum effect with the least expenditure of power, be varied to suit each particular case.

(1109) The next step in the progress of the invention of electric clocks, was the application of the electric power to work single clocks, so that no winding might be required, and the common clock dispensed with altogether. Mr. Bain's arrangements for effecting this are shown in Figs. 442, 443.*

Fig. 442 is a representation of an electric pendulum, suspended from a metal bracket, *h*; the bracket being firmly fixed to the board AA, which is, in a finished clock, the back of the clock-case. The pendulum-rod is of wood. B the bob of the pendulum, is composed of a reel of insulated copper wire, having (merely to improve the appearance) a brass covering; the ends of the wire are carried up the rod, and terminate in two suspension springs, *i* and *j*, which serve the double purpose of suspending the pendulum, and conveying Electricity to and from the wire in the bob B. *m* are two brass tubes fixed to the sides of the case, and facing each other. *a b c f g* is an apparatus called the *break*, for letting on and cutting off the electric current to and from the wire in the pendulum B, and performing the same office for clocks in distant places. Z is a plate of zinc buried in the ground. C is a plate of copper, or what is equally good, a quantity of carbon (common coke or wood charcoal). In private houses and other establishments in town, the ground underneath the floor of the coal-cellar, or the flags of the area, is a suitable position for sinking the plates, or in any place where free access may be had to the moist soil. In country establishments there will be no difficulty, as the plates may be sunk as above, or in any part of the garden. D and D' are wires connecting the zinc and carbon with the pendulum. These wires should be entirely insulated, and for this purpose gutta percha covering is the best material; thus protected, they may be carried to any distance in any manner most convenient. The zinc and carbon should be buried in the soil, at least 3 feet deep, and should not be less than 4 feet apart. To unite the wire D with the zinc plate, it must be simply soldered; but in uniting the wire D' with the carbon, a piece of platinum wire

* History of Electric Clocks, by Alexander Bain.

must be soldered to the end of the copper wire, and the other end of the platinum wire tied firmly round a small piece of the carbon,

Fig. 442.

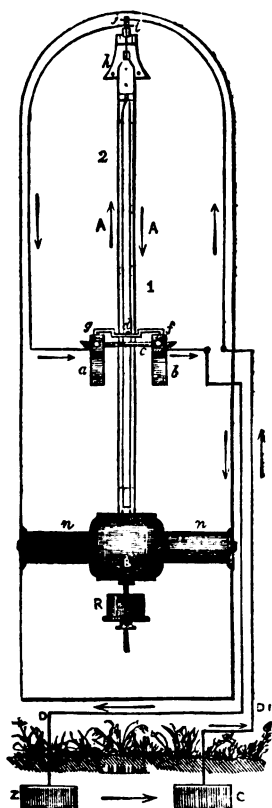


Fig. 443.

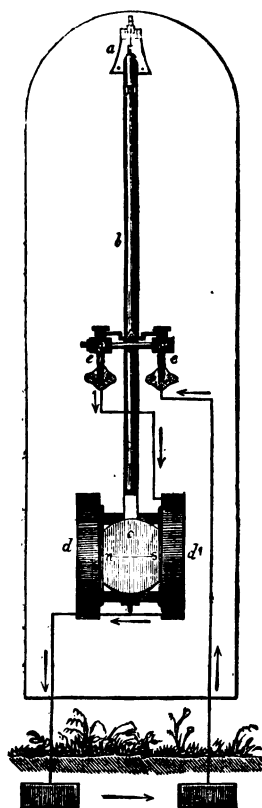
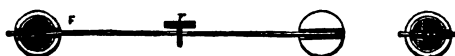


Fig. 444.



and placed in the centre of the mass. Especial attention must be given to this, as it has been found, in every instance, that if the copper wire come into contact with the carbon it will inevitably corrode. Another plan equally good, is to drill a small hole in a piece of the carbon, and drive in a plug, likewise made of carbon, with the end of the platinum wire. If the plate C be composed of copper, it will simply be necessary to solder the copper wire to it. The break is composed of two metal standards, *a* and *b*, fixed to the back of the case; *c* is a wooden or ivory bar, fixed (but easily move-

able) in the standards, by means of binding screws. On the surface of the end of the wood or ivory bar *f*, is inserted a strip of gold, concave on the upper surface, as seen at F, Fig. 444, which is in metallic contact with the standard *b*. At the end *g*, of the bar, is inserted (bound in a metal ring) a small piece of agate, and a piece of gold, both semicircular, represented by Fig. 444; the light part being the gold, the dark part the agate, with a shallow groove cut in the surface of each, similar to that in the gold at F, in fig. 444. In the grooved part of the agate, and perfectly flush with the surface, is inserted a plug of gold. The plug of gold is in metallic connexion with the bracket *a*. The semicircular piece of gold is to form the connexion with other clocks at a distance. *f g* represents the thin-kneed bar, the ends of which rest and slide freely in the grooves or concave parts already described. R is the regulating weight, which brings the pendulum to time. The opening in the interior of the reel B is large enough to permit the pendulum to vibrate freely, without the liability of touching the tubes *n n*. The suspension spring *j*, being connected by a wire with the carbon, if the end of the kneed bar rest on the gold plug in the agate, the electric circuit will be complete, and the course of the current may be thus described. The current is supposed to begin at the plate of zinc in the ground, thence through the moisture of the earth (a sufficient conductor) to the carbon, then through the wire D', as shown by the arrows to the spring *j*, through the spring down a wire, to the coil of insulated wire in the bob B, which it permeates, and thence, by the wire 1, to the spring *i*, to the bracket *a* of the break, through the gold plug in the agate, to the point *g* of the bar *g f*, then through the bar to the bracket *b*, and returning by the wire D to the zinc plate, as shown by the arrows.

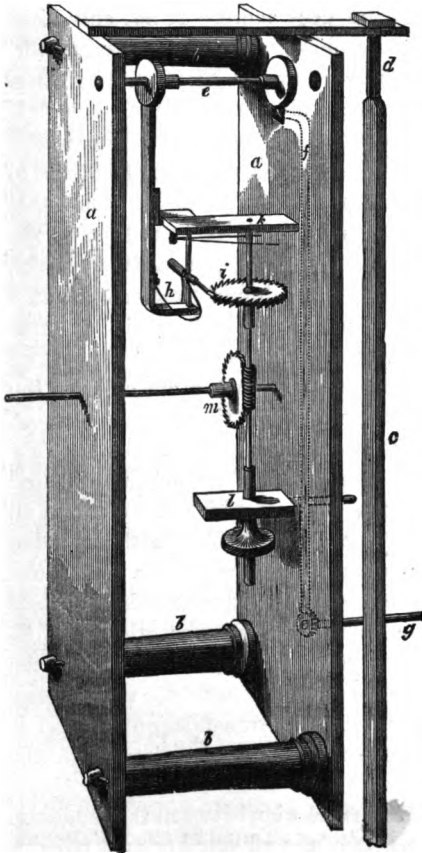
(1110) The mechanism and the means of establishing the galvanic power being thus explained, the manner of its operation remains to be shown. While the Electricity is thus passing, it renders the coil of wire in the bob B magnetic, that is, it gives it all the properties of a magnet with dissimilar poles, N. and S. In the diagram, the N. pole is to the right hand, and the S. to the left. Now, the permanent magnets having their N. poles inwards next to the coil, it is evident, by the well known law of Magnetism, that the N. pole of the left hand magnet will attract the S. pole of the coil, while at the same instant the N. pole of the right hand magnet will repel the N. pole of the coil, and by these means the pendulum will receive an impetus towards the left. It cannot under these circumstances hang perpendicular, but if the galvanic current is broken (which can be done by sliding the bar *g f* a little to the left,

till the point is off the gold plug), the coil being no longer magnetic, the magnet will have no further effect upon it; the pendulum is therefore free to go back in the contrary direction. The pendulum itself gives motion to the sliding bar, by means of the pin *d*, which projects from the rod, and acts in the kneed part of the bar. If we now take hold of the pendulum with the hand, and move it to the right, till the point of the bar is on the gold plug, and then let it swing back, it receives an impulse from the magnets, as just explained. When it arrives at the end of its excursion to the left, it will of itself push the sliding bar off the gold plug; the power will then cease, and it is free to return to the right hand by its own momentum, until it pushes the sliding bar again on to the gold plug—and thereby receiving another impulse, will continue its vibrations, which will increase in length, till the point of the sliding bar is carried beyond the surface of the plug on the right, and partly on to the agate, this action cutting off a great portion of the electric current, and if the vibration further increase in the smallest degree, the power during one vibration is entirely cut off. In this way the pendulum is kept precisely at one given arc of vibration, however variable the electric current may be, provided only that there be always sufficient. It may be here remarked, that the lower the break is placed with reference to the pendulum, the greater will be the accuracy of its vibration. This governing principle of the break is a most important feature in the invention, and is accomplished without any extra work or friction. For large church clocks an apparatus termed a mutator is employed, which, instead of cutting off the current, changes its direction, so that the pendulum receives its impulse, both from right to left, and left to right, but it has the same governing principle as the break just described.

(1111) Fig. 443 is a representation of another pendulum, with its earth-battery and connecting wires. In this arrangement the permanent magnets are in the bob of the pendulum, and the coils of wire are fixed to the case; or, in other words, the permanent magnets move, and the temporary magnets, viz., the coils of wire *d, d*, are fixed. *b* is the pendulum-rod, suspended in the ordinary way by a single steel spring to the bracket *a*. *c c* are two semicircular permanent steel magnets, having N. poles pointing to the left, and S. poles pointing to the right. *d, d* are two oblong coils of insulated copper wire, fixed to the back of the case, the opening in the coils being large enough to allow the bob of the pendulum to move freely without the liability of touching; the break in this case is the same in principle and action as that already explained, but the connecting parts are covered with brass caps to exclude the dust, and the brackets are more ornamental. The

action is as follows : When the galvanic current is let on, the coil *d* attracts the N. poles of the magnets of the pendulum-bob, at the same time the coil *d'* repels the S. pole; the pendulum thus gets its impulse to the left, and the current being cut off by the break, as explained in Fig. 442, the pendulum is free to return by its own momentum, and the motion is thus perpetuated. It will be observed that these pendulums are moved not by mechanical means, which involve friction and wear, but by magnetic power, in which there is none of either, and even that power is applied, *at the utmost*, in every second vibration, though in actual practice it is not in full force more than once in every fifth vibration, the only friction (which is very slight) being the sliding of the bar *g f*, of the break; it may, therefore, be safely inferred that these are the most detached pen-

Fig. 445.



dulums ever yet contrived. They are regulated to time in the ordinary way, by raising or lowering the weight R, or by raising or lowering the bob itself.

(1112) Fig. 455 represents the mechanism by which motion is given to the hands; there are but two wheels in the train, besides the dial-wheels, and as these are moved in the ordinary way, they are not shown in the figure. *a a*, are the frames, fitted to each other in the usual manner; fixed to the top of the frames is a cross bar to which the pendulum may be suspended (Mr. Bain, prefers suspending it as shown in Fig. 455); *c* is the top portion of the pendulum-rod, which is suspended at *d*; *f* is the crutch, shown by two dotted lines, having its axis at *e*—on the same axis is the arm

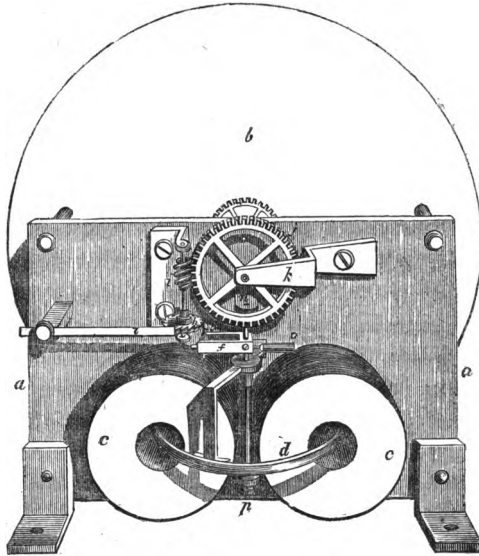
h, which carries the click *i*; *k* and *l* are projections from the inner part of the back frame; these are the bearings of a spindle, which carries the ratchet-wheel at *i*, and a worm which works into the teeth of the wheel *m*, the arbor of the wheel projecting through the front frame. The action takes place as follows: the pendulum-rod, in its excursion to the left, comes against the projecting pin *g*, which is fixed in the lower end of the crutch, and pushes it aside; this action gives similar motion, through the crutch and axle *e*, to the arm *h* and click *i*: this causes the point of the click to slip over one tooth of the ratchet-wheel. Now, when the pendulum takes its excursion to the right hand, the crutch follows by means of its own weight (or a small weight attached to it), and the click *i* pushes the ratchet-wheel forward the space of one tooth, the worm gives motion to the wheel *m*, and this gives motion to the dialwork and hands in the usual manner.

(1113) But the electric pendulum does more. It not only gives motion to the clock, or rather indicator, which is in the case with it, by mechanical action, but it lets on currents of Electricity to other clocks or indicators at any distance; and this important object it accomplishes without any extra wear or tear, and without any friction; for it will be perceived in the previous explanation of the break, that when the point *g* of the bar is off the gold plug which is in connexion with the pendulum, it is moved on to the gold grooved plate which is connected with the distant clocks, thus letting on the current to the pendulum and clocks at a distance alternately. By this arrangement there is a great economizing of electric power, as when the current is cut off from the clocks it is working the pendulum; when cut off from the pendulum it is working the clocks; and thus there is no moment when the electric current is not in practical operation.

(1114) Fig. 446 represents the mechanism of one of the affiliated or companion clocks. *a a* is a brass plate to which the dial and all parts of the mechanism are fixed; *c c* are reels filled with insulated copper wire; *d* is a semicircular permanent steel magnet, a similar one being on the other side. These magnets are fixed to an axle by means of arms, poles of the same name being opposite each other, viz., N. to N., and S. to S., and the poles vibrate freely in the interior of the coils. These coils are joined to, and form part of, the electric circuit with the parent clock, and by the transmission of electric currents from thence the magnets *d* vibrate in unison with the pendulum.

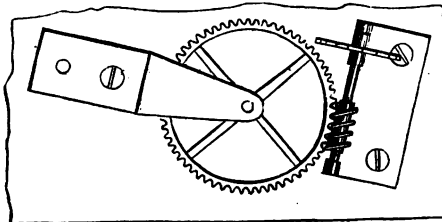
(1115) Having thus obtained uniform motion between the pendulum of the parent clock and the magnets of the affiliated ones, it remains

Fig. 446.



to be shown how motion is given to the hands of the latter. *f* is a small frame, fixed on the same axle as the magnets. This frame carries the little click *g*, which acts in the teeth of the ratchet-wheel *k*; this wheel is carried by the spindle *i*, on which is a screw or worm working in the teeth of the wheel *n* more clearly shown in Fig. 447; the axle of this wheel projects through the plate *a a*, and gives motion to the hands in the ordinary way. *l* is a straight steel spring to keep the ratchet-wheel from going back with the click. *k* is a bearing for one end of the axle of the wheel *n*; the other bearing is in the plate *a a*. *b* represents the back of the dial-plate. Mr. Bain tested the correctness of this principle in 1846, by working

Fig. 447.



a clock at Glasgow, by an electric pendulum in the telegraph station at Edinburgh, a distance of 46 miles. The two clocks went accu-

rately together, the magnet of the companion clock at Glasgow vibrating in unison with the pendulum in Edinburgh.

(1116) *Shepherd's Electro-Magnetic Clock*.—In this beautiful apparatus, well known to the frequenters of the Great Exhibition in 1851, Electro-magnetism is the moving power. The pendulum is so arranged as to make and break an electric circuit, and consequently to make and unmake a horse shoe magnet at each vibration. Each time that the magnet is made it attracts an armature, which lifts certain levers; one of these is concerned in raising a weighted lever and causing it to be held up by a detent or latch; the magnet is then unmade in consequence of the pendulum breaking the circuit, and the armature is released, when the pendulum lifts the latch, and allows the weighted lever to fall, which in falling strikes the pendulum so as to give it an adequate impulse; then the circuit is again completed, the armature attracted, the levers moved, the weight raised and held up by the detent; another vibration breaks the circuit, and releases the armature, the pendulum then raises the detent, the weight falls, and in falling, its arm strikes the pendulum, and gives it an impulse, and so on.

(1117) But the pendulum at each vibration not only makes and breaks the electric circuit of the battery, which maintains its own action, but also, and simultaneously, that of a second battery, of which the duty is to make and unmake the electro-magnets belonging exclusively to the clock or clocks which are upon this circuit. These electro-magnets act upon the extremes of one or more horizontal bar-magnets, so as alternately to attract and repel their opposed poles, and which carry upon their axis the pallets, by the alternating motions of which to the right and the left, the ratchet wheel is propelled onwards at the rate of a tooth each second, and the axis of this ratchet wheel carries the pinion which moves the other wheels of the clock.

(1118) The circuit of the battery connected with the striking part of the clock is only completed once in an hour, and is connected with an electro-magnet, so arranged as by means of a proper lever to pull the ratchet wheel attached to the notched striking wheel 1 tooth forward every 2 seconds, and each tooth is accompanied by a blow on the electro-magnetic bell. The number of blows depends upon the notched wheel, the spaces on the circumference of which are adapted to the number to be struck, and when this is complete, a lever falls into the notch, and so doing cuts off the electric current, which is not re-established through the striking electro-magnet till the next hour, when a peg upon the hour wheel pushes the striking

lever forward, so as to cause it to be depressed by a similar peg upon the minute wheel.

(1119) Shepherd's clocks are adopted in the extensive warehouse of Mr. Pawson, in St. Paul's Churchyard, where eight dials are maintained in action by an electro-magnetic pendulum in the counting-house; they are also used at the Greenwich Observatory, at the Tunbridge station of the South Eastern Railway, &c.; indeed, the time is probably not far distant when clock power will be applied to all the principal cities and towns in Europe, as water and gas are at the present day.

CHAPTER XXI.

DIAMAGNETISM.

Action of Magnetism on Light—Action of Magnets on the Metals—Action of Magnets on Air and Gases—The Magne-Crystalline Force—Diamagnetic Polarity—The Polymagnet—Diamagnetic Conditions of Flames and Gases—Magnetic Conducting Power—Atmospheric Magnetism.

(1120) *Action of Magnetism on Light.*—On the 27th of November, 1845, Professor Faraday communicated to the Royal Society a memoir, in which he made known the interesting fact, that when the “line of magnetic force” (by which he understands that exercise of magnetic power which is exerted in the lines usually called “magnetic curves”) is made to pass through certain transparent bodies parallel to a ray of polarized light traversing the same body, the ray of polarized light experiences a rotation. The experiment was made in the following manner. A ray of light from an argand lamp polarized by reflection was passed through a Nicol’s eye-piece,* revolving on a horizontal axis. Between the polarizing mirror and the eye-piece the poles of an electro-magnet, each of which would sustain from 28 to 56 pounds, were arranged. The poles were separated from each other about 2 inches in the direction of the line of the ray, and so placed that, if on the *same* side of the polarized ray it might pass near them, or if on the *contrary* side, it might go between them, its direction being always parallel, or nearly so, to the magnetic lines of force. A piece of *silicated borate of lead* glass was placed between the poles, so that the polarized ray should pass through its length. The eye-piece was now turned in such a position that the image of the ray was invisible. On now causing the electric current from a Grove’s battery of 5 cells to circulate the iron, the image of the lamp-flame became visible, and continued so as long as the iron continued magnetic, but on stopping the current, the light instantly disappeared. The force impressed upon the *diamagnetic*† was one of rotation, as the light could be extinguished

* The arrangement known as “Nicol’s prism” consists of a rhombohedron of *calcite* (doubly refracting spar) split into two wedge-shaped portions by a plane passing through two opposite solid angles, and perpendicular to the principal plane, which passes through the same angles; the two wedges are cemented together with Canada balsam, which, while it allows one of the doubly refracted rays to be transmitted, banishes the other ray altogether from the field of vision.

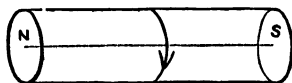
† By “diamagnetic” is meant a body through which lines of magnetic force are passing, the same not being magnetic like iron.

and again rendered visible by the revolution of the eye-piece to the right or to the left. When the N. pole was nearest the observer, the rotation of the ray was right-handed; when the S. pole was nearest, it was left-handed. Common magnets acted in the same manner as electro-magnets, though more feebly.

(1121) The law of the action is this: "If a magnetic line of force be *going* from a N. pole, or *coming* from a S. pole, along the path of a polarized ray, coming to the observer it will rotate that ray to the right-hand." Thus, supposing Fig. 448

Fig. 448.

to represent a cylinder of glass, the line joining N and S is the magnetic line of force, and if a line be traced round



the cylinder with arrow heads on it to represent direction, as in the figure, such a simple model held up before the eye will express the whole of the law, and give every position and consequence of direction resulting from it. The amount of rotation was in proportion to the extent of the diamagnetic through which the ray passed, and the power of the rotation was in proportion to the intensity of the magnetic force. The interposition of non-magnetic metals between the poles had no influence on the result; but iron, by diverting the direction of the lines of force, affected the results materially. That the phenomenon is directly connected with the magnetic form of force is proved by the circumstance, that the brightness of the polarized ray is developed *gradually*, the iron requiring some little time (a couple of seconds) to acquire its full magnetic intensity after throwing on the current.

(1122) All transparent bodies do not possess this power in the same degree, and some have it not at all; but in those in which it exists, whether solid or liquid, or however opposed in chemical character, the law of rotation is the same. The best substance is silico-borate of lead; both *flint* and *crown glass* give it, as do water, alcohol, ether, and, in fact, every liquid substance that has been tried; but Faraday was unable to find the power in rock crystal, Iceland spar, sulphate of baryta, carbonate of soda, or ice.

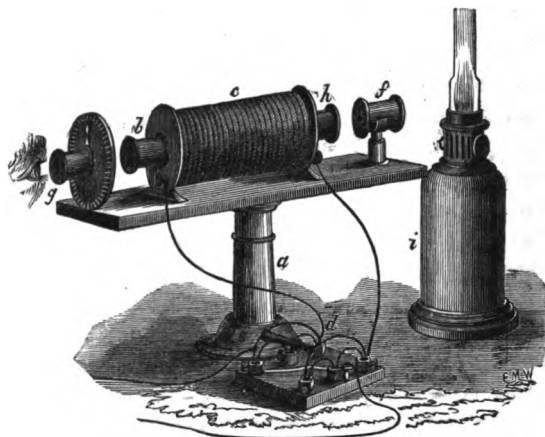
(1123) The following experiment is quoted by Faraday as clearly demonstrating that a ray of light may be electrified, and the electric forces illuminated. A tube was filled with distilled water and introduced as a core into a long helix or coil 65 inches long, and containing 1,240 feet of wire; it was placed in the line of the polarized ray, so that by examination through the eye-piece the image of the lamp-flame produced by the ray could be seen through it. Then the eye-piece was turned until the image of the flame disappeared, and afterwards the current of 10 pairs of plates was sent through the helix;

instantly the image of the flame reappeared, and continued as long as the electric current was passing through the helix; on stopping the current the image disappeared; the light did not rise gradually as in the case of electro-magnets, but instantly; when the current was sent round the helix in one direction, the rotation induced upon the ray of light was one way; when the current was changed, the direction of rotation changed likewise.

In this experiment the apparent deflection of the ray of light is by many believed to be occasioned by an alteration in the refracting power of the medium through which the ray passes, and not to an influence exerted directly by Magnetism on the beam of light.

(1124) The apparatus shown in Fig. 449, was constructed by Professor Böttger (*Beiträge zur Physik et Chemie Drittes Heft*, p. 1) for the illustration of these novel phenomena: *a* is a stand sup-

Fig. 449.



porting a pair of achromatic Nicol's prisms, *g* and *f*, placed horizontally; between these there is placed a brass tube, some 2 or 3 lines in diameter, and from 6 to 8 inches long, closed at both ends by plates of glass; *b h*, the tube, filled with any double refracting fluid, for instance, tartaric acid, oil of turpentine, a solution of sugar candy ($\frac{1}{3}$ rd candy and $\frac{2}{3}$ ds water), &c., &c., is placed in the axis of a hollow helix, which is lined throughout its entire length with a thin cylinder of sheet iron, *c*; the projecting terminals of the helix are brought by means of the commutator, *d*, into connexion with the poles of a Grove's battery of 6 or 7 pairs. On letting the light of an argand lamp, *i*, pass through the hindermost Nicol's prism, and thus causing a ray of polarized light to traverse the saccharine

solution in $h\bar{b}$, it will be observed that a certain position may be given to the front moveable prism, g , in which the field is dark; if, now, by completing the circuit, the galvanic current be caused to traverse the helix c in such a manner that it enters the right-handed helix, where the polarized ray enters the refracting liquid, the longitudinal magnetic axis coinciding with the axis of the ray, or in other words, the magnetic N. pole being at $\bar{b}$, and the S. pole at n , there will instantly be indicated a rotation of the plane of polarization to the left, the field no longer remaining dark, but becoming of a reddish hue, the phenomenon remaining constant as long as the circuit is closed. On inverting the current by means of the commutator, so that the N. pole is brought to h and the S. pole to $\bar{b}$, the plane of polarization becomes inverted to the right, the field at the same time becoming of a bluish green tint.

(1125) Taking the natural rotating force of a specimen of oil of turpentine as a standard of comparison, Faraday obtained the following numbers, a powerful electro-magnet being employed with a constant difference of $2\frac{1}{2}$ inches between its poles :—

Oil of turpentine	11.8
Heavy glass	6.0
Flint glass	2.8
Rock salt	2.2
Water	1.0
Alcohol	less than water.
Ether	less than alcohol.

—the different substances being corrected by calculation to one standard length. That light and the magnetic and electric forces have a direct relation and dependence is further shown by the following experiment :* Place side by side a certain quantity of water in a helix, and a tube containing oil of turpentine. If the oil possesses right hand rotation, pass an electric current through the helix so as to give rotation to the right; the water in the tube will acquire a rotatory power to the right, and the two liquids will possess the same mode of action. Leaving now the tubes, the helix, and the current in the state just described, pass the polarized ray in the contrary direction through the tubes, and observe at the opposite extremity of the tube. The oil of turpentine will be still seen to turn the ray to the right, but it will not be the same with the *water*, which will turn the ray to the left; the rotation being absolutely connected with the direction of the electric current which moves in the circuit,

* Faraday, *Comptes Rendus*, January 16, 1846.

and which, seen through this extremity, passes to the left. If, instead of water, oil of turpentine be in the helix, and if the electric current be sufficiently intense to produce on the luminous ray a rotation equal to that determined by the oil, its rotatory power, observed on a ray passing in a certain direction, will appear double; while, examined by a ray passing in the contrary direction, it will be reduced to zero. It thus appears, that it is only through the intervention of matter that the direct relations of the magnetic force and light become manifest; that different matters possess the property in different degrees; and that as the substances between the magnetic poles, though clearly affected by the magnetic force, are not rendered magnetic in the sense of iron, their molecular condition, while in this state, must be *new*, and the force must be a *new magnetic force*.

(1126) The rotatory power superinduced by magnetic action is quite independent of that which the substance possesses of itself. In oil of turpentine, for instance, whichever way a ray of light (polarized) passes through this fluid, it is rotated in the same manner, and rays passing in every possible direction through it *simultaneously* are all rotated with equal force, and according to one common law of direction, *i. e.*, all right handed, or else all to the left. This is not the case with the rotation superinduced on the same oil of turpentine by the magnetic or electric forces; it exists only in one direction, that is in a plane perpendicular to the magnetic line, and being limited to this plane, it can be changed in direction by a reversal of the direction of the inducing force. The direction of the rotation produced by the natural state is connected invariably with the direction of the ray of light, but the power to produce it appears to be possessed in every direction, and at all times, by the particles of the fluid; the direction of the rotation produced by the induced condition is connected invariably with the direction of the *magnetic line*, or the *electric current*, and the condition is possessed by the particles of matter, but strictly limited by the line or the currents changing and disappearing with it.

(1127) *The General Magnetic Condition of Matter*.—The first substance submitted by Faraday to the action of the magnetic forces was heavy silicated borate of lead glass. A bar of this substance, 2 inches long and $\frac{1}{2}$ an inch wide and thick, was suspended centrally between the poles of a powerful electro-magnet; when the effect of torsion was over, the current was thrown on; the bar immediately moved, and took up a position *across the magnetic line of force* (equatorial).* On being displaced, it returned to it, and this happened

* Let N and S, Fig. 450, represent the poles of a horse-shoe magnet looking down

many times in succession. The reversal of the poles of the electro-magnet caused no difference. The bar went by the shortest course to the equatorial position. The power that urged the bar into this position was so thoroughly under command, that it could be either hastened in its course into it, or arrested as it was passing from it,

by seasonable contacts at the voltaic battery. If the bar was in the direction of the axis, or *magnetic line of force*, it did not move on making battery contact, neither did it if it was originally in the equatorial position; but if it was in the least oblique, its obliquity increased till it became equatorial. Here, then, was a magnetic bar pointing E. and W. instead of N. and S.

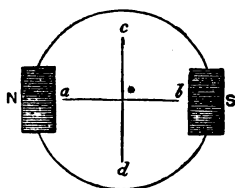
(1128) If the bar was suspended nearer to one pole than the other, it was repelled from the nearer pole; and if it was equidistant from both poles, but in the *axial* line, that is in the line from pole to pole, it pointed *equatorially* on being moved a little on either side of the axial line from which it was apparently repelled. If two bars were suspended each near the opposite poles, both were *repelled* by their respective poles, and thus appeared to *attract* each other; so also when two bars were hung equatorially on either side of the axial line, both receded from that line, apparently repelling one another.

When a cube was employed, the effect was repulsion from both poles, and recession from the magnetic axis on either side. The tendency was to move from a *stronger* to a *weaker* place of magnetic force, and this is the cause of the pointing of any oblong arrangement. When one or two magnetic poles are active at once, the courses described by the glass form a series of curves, which Faraday calls *diamagnetic curves* in contradistinction to the lines called *magnetic curves*. In these experiments we have magnetic repulsion apparently without polarity.

(1129) A very great number of other substances, both solid and liquid, were then submitted to the action of the magnet, the liquids being enclosed in small glass tubes hermetically sealed. The results are given in the following table:—

upon them; the space between the poles is called "the magnetic field;" the line, *a b*, parallel to which a *magnetic* body, such as a bar of iron, would take up its position, is called the "*axial line*;" the line, *c d*, at right angles to *a b*, and parallel to which a *diamagnetic* body, such as a bar of bismuth would set, is called the "*equatorial line*."

Fig. 450.



POINTED EQUATORIALLY (DIAMAGNETIC).		POINTED AXIALLY (MAGNETIC).
Rock crystal.	Nitric acid.	Paper.
Sulphate of lime.	Sulphuric acid.	Sealing wax.
Sulphate of baryta.	Muriatic acid.	Fluor spar.
Sulphate of soda.	{ Solution of alka- line and earthy salts. }	Peroxide of lead.
Sulphate of potassa.		Plumbago.
Sulphate of magnesia.		China ink.
Alum.	Glass.	Berlin porcelain.
Muriate of ammonia.	Litharge.	Red lead.
Chloride of lead.	White arsenic.	Sulphate of zinc.
Chloride of sodium.	Iodine.	Shell lac.
Nitrate of potash.	Phosphorus.	Silkworm gut.
Carbonate of soda.	Sulphur.	Asbestos.
Iceland spar.	Resin.	Vermilion.
Oxalate of lead.	Spermaceti.	Tourmaline.
Tartrate of potash and antimony.	Caffeine.	Charcoal.
Tartaric acid.	Cinchona.	
Citric acid.	Margaric acid.	
Water.	Wax from shell lac.	
Alcohol.	Olive oil.	
Ether.	Oil of turpentine.	
Sugar.	Jet.	
Starch.	Caoutchouc.	
Gum arabic.	Dried beef.	
Wood.	Dried blood.	
Ivory.	Fresh blood.	
Dried mutton.	Leather.	
Fresh beef.	Apple.	
	Bread.	

(1130) Phosphorus appears to stand at the head of all diamagnetic substances; its pointing could be verified between the poles of a common magnet. If a man could be suspended between the poles, he would point equatorially, for all the substances of which he is made possess this property. The reason why *blood* which contains iron is not magnetic, is, probably, because it is diamagnetic in a greater degree; and the latter force neutralizes and predominates over the former.

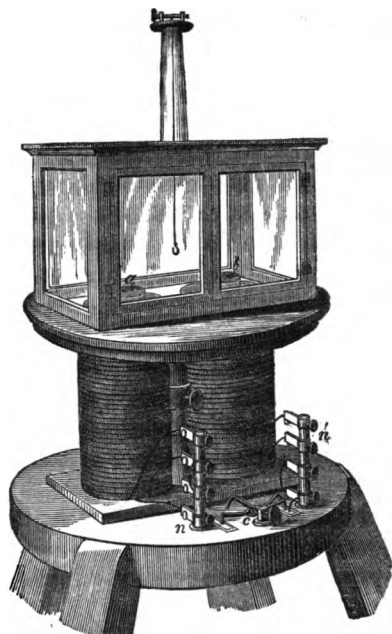
By these new facts, forces directly the opposite of those existing in magnetic bodies are proved to have an existence; for, whereas the latter produce *attraction*, the former produce *repulsion*. The former

cause a body to set in the *axial* direction, but the latter make it take an equatorial position.

(1131) *Action of Magnets on the Metals.*—The metals were examined as to Magnetism by

Fig. 451.

suspending them in pieces of about 2 inches long in the magnetic field of the electro-magnet. The apparatus employed by M. Plücker (a philosopher who has followed up these inquiries with great ability and success) is shown in Fig. 451. The electro-magnet *a b* is surrounded with 4 coils of thick silk-covered copper wire, each wound separately around its 2 branches, and communicating with 2 metallic conductors *n n'*. The current from the battery is thrown on and off, and changed in direction, by means of a commutator *c*. The poles of the magnet are surmounted by a glass case with a suspension thread, so that different substances may be submitted to the action of the magnet in a still atmosphere, or in atmospheres more or less charged with various vapours and gases.



(1132) The following metals, when thus tried, were either not magnetic, or if so, to so small an amount as not to destroy the results of the other force:—

Antimony.	Bismuth.	Cadmium.	Copper.
Gold.	Lead.	Mercury.	Silver.
Tin.	Zinc.		

The following were magnetic in the sense of iron:—

Cobalt. Nickel. Platinum. Titanium. Palladium.

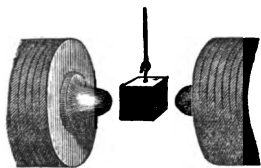
Of all the metals, *bismuth* was found to be the most eminently diamagnetic, excelling in this property even heavy glass and phosphorus; and it is, therefore, specially adapted for showing the various phenomena. Its movements were, however, complicated, and demanded careful analysis; but they all resolved themselves into their

simple elementary origin; the ruling principle being that each particle of the metal tends to go from the *stronger* to the *weaker* points of the magnetic field. When bismuth powder was sprinkled upon paper and laid over the horizontal circular termination of the vertical pole of a bar electro-magnet, it retreated in both directions, inwards and outwards, from a circular line just over the edge of the core, leaving the circle clear, and at the same time showing the tendency of the particles of bismuth to move in all directions from that line; and when the pole was terminated by a *cone*, a clear line could be traced through the powder, by drawing the paper on which it was sprinkled over the cone.

(1133) Copper (in consequence, as Faraday believes, of its excellent conducting power for electric currents) exhibited some remarkable phenomena. When suspended between the poles it first advanced towards the axial line, as if it were magnetic; it then suddenly stopped, and took up a new position, from which it could only be removed by the application of some force. Even when swinging with considerable momentum, it could be caught up and retained at will. If after the Magnetism had been sustained for two or three seconds the electric current was suddenly stopped, there was instantly a strong action on the bar, and it began to revolve; on again renewing the current it was again arrested as before. Some other metals, viz., silver, gold, zinc, cadmium, tin, mercury, platinum, palladium, lead, and antimony exhibited in a greater or smaller degree the same phenomena.

In order to form a sufficient idea of the arresting power of these

Fig. 452.



induced currents, take a lump of solid copper, approaching to the cubical or globular form, weighing from a $\frac{1}{4}$ to $\frac{1}{2}$ a pound, suspend it by a long thread, give it rapid rotation, and then introduce it, while spinning, into the magnetic field of the electro-magnet,—its motion will be instantly

stopped, and on trying further to spin it whilst in the field it will be found impossible.

(1134) Faraday next submitted various metallic salts to the action of the magnet: all salts and compounds containing iron in the *basic part* were found to be magnetic both in the form of crystals and when in solution; yellow and red prussiate of potash were however both diamagnetic; pure sulphate and chloride of nickel, both in crystals and in solution, were magnetic; oxide of titanium, oxide of chromium, and chromic acid were magnetic, as were also

the salts of manganese and chromium; the compounds of lead, platinum, palladium, and arsenic pointed equatorially, as was also the case with chromate of potash. An interesting set of results was obtained by filling tubes with ferruginous solutions of different degrees of strength, and suspending them in similar ferruginous solutions, also of different degrees of strength, between the poles of the electro-magnet. When the solution in the tube was stronger, or contained more iron than that in the glass in which it was suspended, it pointed *axially*; when it was weaker, or contained less iron than that in the glass, it pointed *equatorially*; and when the solutions in both tube and glass were of the same degree of strength, the tube was indifferent. Let *n*, Figs. 453 and 454, represent a thin

Fig. 453.

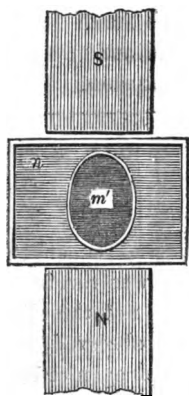
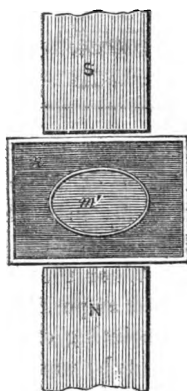


Fig. 454.



glass trough, filled with a solution of 16 grains of crystallized protosulphate of iron in each cubic inch of water, the trough being placed between the poles of a powerful magnet; let *m'* be an oblong glass trough, containing a solution of 8 grains of protosulphate of iron to each cubic inch of water, the latter will set *across* the magnetic field as in Fig. 454, like a bar of bismuth, because it contains less iron than the liquid in which it is suspended. Let the exterior trough be filled with the weaker solution, and the interior tube with the stronger, the latter will now set as shown in Fig. 453, that is, axially, as it would do in air. Iron and nickel, when heated to a degree far above that required to render them insensible to an ordinary magnet, still pointed axially between the poles. By multiplying these experiments the following *order* of metals in their relation to the magnetic force was obtained (0° is the medium point or condition of a metal or substance indifferent to the magnetic force):—

MAGNETIC.

Iron.
Nickel.
Cobalt.
Manganese.
Chromium.
Cerium.
Titanium.
Palladium.
Platinum.
Osmium.

DIAMAGNETIC.

Bismuth.
Antimony.
Zinc.
Tin.
Cadmium.
Sodium.
Mercury.
Lead.
Silver.
Copper.
Gold.
Arsenic.
Uranium.
Rhodium.
Iridium.
Tungsten.

0°.

(1135) *Action of Magnets on Air and Gases.*—Common air, sealed hermetically in a glass tube, and placed between the poles, pointed feebly towards the equatorial position, the effect being due to the glass. When the air round the tube was rarefied, and finally exhausted as far as possible by a good pump, not the slightest difference in the pointing of the tube could be observed, neither could there when the tube was surrounded with hydrogen or carbonic acid; there seems, therefore, no difference between dense air and rare air, or between one gas and another. On the other hand, the air tube pointed axially when subjected to the magnetic forces whilst submerged in water, alcohol, turpentine, and mercury; the action of the air in the fluids being the same as the action of a magnetic body in air. Various gases and vapours and a vacuum pointed *equatorially* when surrounded with air, but *axially* when surrounded with liquids; the equatorial pointing being due to the glass only, but the axial pointing depends upon the relation of the contents of the tube to the surrounding air. It appears, therefore, that gases and vapours occupy a medium position between magnetic and diamagnetic bodies; and that however marked the diamagnetic character of a body may be, it loses all traces of this character when it becomes vaporous. Taking air and a vacuum as the neutral point, the following table represents a general list of certain substances in their relation to the magnetic force:—

Iron.		Bismuth.
Nickel.		Phosphorus.
Cobalt.		Antimony.
Manganese.		Heavy glass.
Palladium.		Flint glass.
Crown glass.	Air and vacuum.	Mercury.
Platinum.	0°.	Water.
Osmium.	Middle of the series.	Gold.
		Alcohol.
		Ether.
		Arsenic.

(1136) This position, intermediate between magnetic and diamagnetic bodies taken by air; its exhibiting no change in its relations by rarefaction; its taking a place exactly in the middle of a great series; and lastly, the fact that all gases and vapours are alike, seems to point to the fact that air must have a great, and perhaps an active part to play in the physical and terrestrial arrangement of magnetic forces. The whole of these extraordinary discoveries prove that the magnetic force presides over matter as universally as the gravitating, the electric, the chemical, and the cohesive forces, and that substances arrange themselves into two great divisions, the *magnetic* and the *diamagnetic*, which are in the same general *antithetical* relation to each other as *positive* and *negative* in Electricity, or as *northness* and *southness* in polarity, or as the lines of electric and magnetic forces in magnetic Electricity. Neither was this remarkable power (the diamagnetic), given to bodies for nothing. "It doubtless," says Faraday, "has its appointed office, and that, one, which relates to the whole mass of the globe. For, though the amount of the power appears to be feeble, yet, when it is considered that the crust of the earth is composed of substances of which by far the greater portion belongs to the *diamagnetic* class, it must not be too hastily assumed that their effect is entirely overruled by the action of the magnetic matters, whilst the great mass of waters and the atmosphere must exert their diamagnetic action uncontrolled." Faraday found that it required more than 48·6 grains of crystallized protosulphate of iron to neutralize the diamagnetic power of 10 cubic inches of water, and it is not, therefore, at all unlikely that many of the masses which form the crust of our globe may have an excess of diamagnetic matter and act accordingly. He throws out the notion that it may not hereafter prove impossible to construct an instrument for measuring one of the conditions of terrestrial Magnetism, on the principle that a pound of bismuth or of

water estimated at the equator, where the magnetic needle does not dip, ought theoretically to weigh *less* than in latitudes where the dip is considerable, whilst a pound of *iron* or *nickel* ought under the same change of circumstances to weigh more.

(1137) *The Magne-crystallic Force*.—In his experiments on bismuth, Faraday had noticed some very embarrassing results: *e. g.*, taking at random from a quantity 4 small cast cylinders of the metal, and suspending them horizontally between the poles of the electro-magnet, the first pointed *axially*; the second, *equatorially*; the third, *equatorial* in one position, and *obliquely equatorial* if turned round on its axis 50° or 60° ; the fourth, *equatorially and axially* under the same treatment; whilst all of them were repelled by a single magnetic pole, thus showing their strong and well-marked diamagnetic character. The cause of these variations he succeeded in tracing to the regularly crystalline condition of the metallic cylinder. On suspending between the poles a carefully selected group of crystals of bismuth, and sending the current on, the metal vibrated strongly about a given line, into which at last it settled; and if moved out of that position, it returned when at liberty into it, pointing with considerable force, with its greatest length *axial*. The position taken up by the metal had nothing to do with its shape, but was entirely dependent on its crystalline condition, and the effect occurred with a single pole. Now, bismuth being eminently a diamagnetic body, and as such tending to pass from a stronger to a weaker place of magnetic force, it would have no tendency to point at all in a field of uniform force (such as between the rounded poles of an electro-magnet); the crystalline group, however, *does* point in such a field, the tendency being that the line joining two opposite solid angles of the crystalline group, should take up an *axial* position. The impelling force is therefore distinct, both from the magnetic and the diamagnetic, and is called by Faraday the *magne-crystallic force*.

(1138) It was further noticed that the *cleavage* of the bismuth was not made with equal facility at the four solid angles, and that *two*, or more frequently *one* of the planes produced by cleavage were brighter and more perfect than the others. When the crystal was suspended in the magnetic field with its bright plane *vertical*, it pointed with considerable force with the plane towards either the one or the other magnetic pole, so that the magne-crystallic axis appeared now to be *horizontal*, and acting with its greatest power; when, however, the crystal was suspended with its bright plane *horizontal*, so that the magne-crystallic axis was *vertical*, it did not point at all; the law of action appearing to be, "that the line or axis of magne-crystallic force tends to place itself parallel, or as a tangent to the

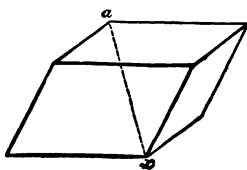
magnetic curve or line of magnetic force, passing through the place where the crystal is situated." It does not require very powerful magnets to exhibit these remarkable phenomena; they may be verified with common horseshoes, with a lifting power of under 2 pounds. Neither is bismuth the only metal in which they are observed; Faraday having succeeded in obtaining magne-crystalline action with antimony, arsenic, zinc, titanium, and with the sulphates of nickel and iron.

(1139) The most remarkable property of this force is its not possessing a dual or *antithetical* character, *both* poles of the crystal having like characters; but Faraday has shown by the following experiment that a crystal of bismuth is able to re-act upon and affect a magnet *at a distance*. He suspended a small magnetic needle perpendicularly by a single cocoon filament, and placed near its lower pole a crystal of bismuth with the *magne-crystalline axis* in a horizontal direction, the whole being left for two or three hours; the effect was small but distinct, the result being, that if the direction of the magne-crystalline axis made an angle of 10° , 20° , or 30° , with the line from the magnetic pole to the middle of the bismuth crystal, *then the pole followed it*, tending to bring the two lines into parallelism, and this it did whichever end of the magne-crystalline axis was towards the pole, or whichever side it was inclined to. It thus appears that a crystal of bismuth is able to react upon and affect a magnet at a distance. This new force Faraday believes to be one *induced* under the magnetic and electric influences, and not an original force inherent in the crystal; for the crystal can take away nothing from the magnetic fluid, neither is it affected by the earth's Magnetism; it is, however, a most peculiar one, the body possessing it being moved without having any attractive or repulsive powers.

(1140) Whilst engaged in the study of the diamagnetic properties of organic bodies, Plücker was induced to submit various crystalline bodies to the action of the magnet, and he made the following remarkable discoveries Taylor's "Scientific Memoirs," vol. 5): "When any crystal having a single optic axis* is placed between the

* In all crystals which possess the property of double refraction, there are one or two directions in which the splitting of the ray does not take place; these directions are called the *axes* or the *optic axes* of the crystals. Those crystals, the interiors of which present only one direction of indivisibility, are called *uniaxial*; those with two directions of indivisibility are called *binaxial*. As an example of an uniaxial crystal, Iceland spar may be taken, the primitive form of which is a rhombohedron (Fig. 455), that is, a crystal of this substance, whatever its form may

Fig. 455.



two poles of a magnet, this axis is *repelled* by each of the two poles. If the crystal has two optic axes, each of these two axes is repelled by each of the two poles with the same force. The force which produces this repulsion is independent of the magnetic or diamagnetic condition of the mass of the crystal; it diminishes *less* as the distance from the poles of the magnet increases, than the magnetic or diamagnetic forces emanating from these poles and acting upon the crystal. M. Plücker suspended a green plate of

be, is to be regarded as made up of an infinite number of molecules symmetrically arranged side by side, each being a rhombohedron. The line $a x$ joining the obtuse summits of one of these rhombohedrons is called its *crystallographic axis*. It has been proved experimentally to be a law without exception that in an *uniaxial* crystal, the axis of double refraction, or the *optic axis*, *coincides* with the *crystallographic axis*. It has further been found that in some crystals the ray of extraordinary refraction is inclined *from* the axis, and in others *towards* it, more than the ordinary ray. The former are said to have a *negative* axis, the latter a *positive*. Uniaxial crystals may, therefore, be arranged in two classes, as in the following table (Pouillet's "Elements of Physics"):

NEGATIVE UNIAXIAL CRYSTALS.

Iceland spar.
Carbonate of lime and magnesia.
Carbonate of lime and iron.
Tourmaline.
Rubellite.
Corindon.
Sapphire.
Ruby.
Emerald.
Hydrochlorate of lime.
Hydrochlorate of strontia.
Subphosphate of potash.
Sulphate of nickel and copper.
Cinnabar.
Mellite.
Molybdate of lead.

Beryl
Apatite.
Idocrase (Vesuvian).
Wernerite.
Mica (certain varieties).
Phosphate of lead.
Arseniophosphate of lead.
Hydrate of strontia.
Arsenate of potash.
Octohedrite.
Prussiate of potash.
Phosphate of lime.
Arsenate of lead.
Arsenate of copper.
Nepheline.

POSITIVE UNIAXIAL CRYSTALS.

Zircon.
Quartz.
Oxide of iron.
Tungstate of zinc.
Stannite.
Boracite.
Apophyllite.

Sulphate of potash and iron.
Subacetate of copper and lime.
Hydrate of magnesia.
Ice.
Hyposulphate of lime.
Diopase.
Red silver.

It was discovered by Fresnel that in binaxial crystals there is no *ordinary* ray properly so called; neither of the rays into which the light becomes resolved obeying the usual law of refraction or the *law of sines*, as it is termed (the sines of the angles of incidence and refraction *not* being in a constant ratio.) The following table (Brewster) contains the names of a few binaxial crystals with the inclination of their optic axes to each other.

tourmaline, the longitudinal direction of which corresponded with the direction of its optic axis, between the poles of an electro-magnet in the apparatus shown in Fig. 451, in such a manner that the direction of the thread corresponded with the direction of the optic axis; the plate being magnetic, arranged itself between the poles, the direction of its breadth coinciding with a straight line connecting the poles, as any other magnetic body of the same form would have done. But when the plate was suspended in such a manner that the direction of its *breadth* coincided with that of the silk thread, so that the optic axis could now oscillate freely in a horizontal plane, it assumed that position which a *diamagnetic* body of the same form would have done: i. e., with its axial and longitudinal direction perpendicular to the line of the apices of the poles. On again suspending the plate so that it could oscillate horizontally, it took up the same position as a diamagnetic body of the same form would have done. The direction of its breadth being in the line of the apices of the poles, and its longitudinal and axial direction perpendicular to it. By opening and closing the circuit in each of the three positions of suspension, the tourmaline could be turned round and retained in exactly the opposite position.

(1141) Plücker then took a dark brown crystal, having the form of a six-sided prism, and suspended it between the poles, the latter being so close together that the crystal had just room to oscillate freely. Under these circumstances, the magnetic attraction caused

A, Principal Axis,—Positive.		B, Principal Axis,—Negative.	
Substances.	Inclination.	Substances.	Inclination
Sulphate of nickel . . .	3° to 42° 1'	Nitrate of potash . . .	5° 20'
Biborate of soda . . .	28° 42'	Carbonate of strontia . .	6 56
Sulphate of baryta . . .	37 42	Talc	7 24
Spermaceti	37 40	Carbonate of lead . . .	10 35
Henlandite	41 40	Mica (certain varieties)	14 0
Sulphate of soda and magnesia	46 49	Sulphate of magnesia . .	37 24
Brazilian topaz	49 50	Carbonate of ammonia . .	43 24
Sulphate of strontia . . .	50 0	Sulphate of zinc	44 28
Sulphate of lime	60 0	Sugar	50 0
Nitrate of silver	62 16	Phosphate of soda . . .	55 20
Scottish topaz	65 0	Tartrate of potash . . .	71 20
Sulphate of potash	67 0	Tartaric acid	79 0
Potassiotartrate of soda . .	80 0		

Uniaxial crystals include all those crystals belonging to the pyramidal and, rhombohedral systems; *binaxial* crystals include those belonging to the prismatic *oblique*, and *amorphic* systems.

the tourmaline to assume such a position that the axis of the prism, which is also its optic axis, coincided with the line of the apices of the poles. The poles were then gradually separated from each other, and as they receded, the force tending to keep the crystal in its first position became less and less intense, and when their distance amounted to 80 millimetres (about $\frac{1}{3}$ ths of an inch), the crystal rotated 90° , as if it became diamagnetic, so that its axis was now perpendicular to the line of the apices of the poles. On the further separation of the latter, the force which retained it in the position just described increased, and in this, it continued distinctly to remain after the apices of the poles had been entirely removed. At a sufficient distance from the poles, therefore, the repulsive action overcomes the magnetic attraction.

(1142) A crystal of calcareous spar, a decidedly diamagnetic body, was then suspended between the poles, so that its axis should oscillate horizontally. On charging the magnet, the *axis* became placed exactly *equatorially*, the crystal assuming a position in which neither a magnetic nor a diamagnetic mass of the same form would have rested when acted upon by the magnetic and diamagnetic action of the poles of the electro-magnet. Various other magnetic crystals, viz., rock crystal, opaque crystallized quartz, a square octohedron of zircon, two yellowish-green transparent crystals of emerald, a black idocrase, and a large corundum, exhibited the same deportment, as did also the following *binaxial* crystals (crystals having two optic axes), mica, a magnetic body; topaz, sugar, arragonite, nitre, and sulphate of soda—diamagnetic bodies. All these, when suspended so that the planes of their two optic axes could oscillate horizontally, took up the equatorial position.

(1143) These experiments appeared to Plücker to disclose a relation between the forms of the ultimate particles of matter and the magnetic forces, and to lead to the remarkable result that we can determine crystalline forms by the magnet. He thought, moreover, that they showed the existence of a relation between the forces which are in action during crystallization and the magnetic forces. According to Faraday's view, the new force discovered by Plücker is an *optic axis* force exerted in the equatorial direction, and therefore existing in a direction at right angles to that which produces the magneto-crystalline phenomena; both forces, however, have relation to the force conferring the condition of crystalline structure, and Faraday is of opinion that they have one common origin and cause.

(1144) The more recent experiments of Tyndall and Knoblauch (*Phil. Mag.*, vol. xxxvi. p. 178, and vol. i., N. S., p. 1) lead, however, to a different view of the matter. These physicists have investigated

Plücker's phenomena with great ability. They have shown that the action of a crystal so far from being independent of the Magnetism or Diamagnetism of its mass, as announced by Plücker, is totally changed by the substitution of a magnetic constituent for a diamagnetic. In determining whether the optic axis will be repelled or not, their plan was to take a thin rhomb, cloven from the crystal, and having ground it into the shape of a disc, it was suspended between the poles, when, if it belonged to a class whose optical axis is repelled, the line bisecting the acute angles of the rhomb set itself axial, if of the other class, the same line set itself equatorial. Their method of examining crystals was to pound them in an agate mortar, and then to make them into a paste with distilled water, which, when dry, they suspended between the poles. On experimenting with gutta percha, Messrs. Tyndall and Knoblauch found that a circular disc of this substance always arranged itself with the direction of the fibre *axial*, and a parallelogram, $\frac{2}{3}$ ths of an inch long and $\frac{1}{2}$ an inch wide, with the fibres crossing it transversely, set stiffly *equatorial*. This they consider to be owing to the facility with which the magnetic force can act in the direction of the fibre. The same phenomena were produced with ivory, which could be made to stand either axially or equatorially by cutting it in a particular way. They consider that Plücker's explanation of Faraday's experiment is incorrect, and that the *setting* of a crystal in the magnetic field is dependent on the amount of magnetic or diamagnetic force in the direction of the lines of cleavages.

(1145) The experiments of Messrs. Tyndall and Knoblauch are irreconcilable with Plücker's statement, that the position of the optic axis is independent of the Magnetism or Diamagnetism of the crystal; nor does their extensive examination of crystalline bodies confirm the law announced by the German philosopher, that "there will be either repulsion or attraction of the optic axes by the poles of the magnet, according to the crystalline structure of the crystal—if the crystal is a *negative one* there will be repulsion, if it is a positive one there will be attraction;" in some cases they found this law to hold good, but in many others the results were opposed to it.

(1146) Messrs. Tyndall and Knoblauch quote the following experiment to show that the deportment of crystalline bodies in the magnetic field may be explained without assuming the existence of an "optic axis" force: Take a slice of apple, rather thicker than a penny piece, stick through it, in a direction perpendicular to its flat surface, some bits of iron wire, and hang it in the magnetic field; it will set itself *equatorial*, *not by repulsion*, but by the attraction of the iron wires. Substitute bits of bismuth wire for the iron, the

apple will now set *axial*, not by attraction, but by the repulsion of the bismuth. Now, arrangement is conceivable amongst the particles of a magnetic or a diamagnetic body capable of producing similar effects, and if the magnetic and diamagnetic forces be associated with the particles of matter, the inference is not unreasonable that the closer these particles are aggregated, the less will be the obstruction offered to the transmission of the respective forces among them. As regards Magnetism, different directions through the same body may represent good and bad conductors in Electricity, the line of preference being that of closest contact among the material particles. If some fine bismuth powder be kneaded into a paste with gum-water, and then made into a roll, about $1\frac{1}{4}$ inch across, it will point *equatorially* between the magnetic poles, but if it be squeezed flat it will point *axially*, even though its length be ten times that of its breadth; again, if a similar roll be made of pounded carbonate of iron, it will point *axially*, but after being squeezed, it will recoil violently between the poles, and point *equatorially*. The cause of these phenomena is evident. The line of closest contact is perpendicular in each case to the surface of the plate, a consequence of the pressure in this direction; and this perpendicular stands axial or equatorial, according as the plate is magnetic or diamagnetic. This sort of action must exist in all non-homogeneous masses, and there must be an election of a certain line by the force operating, and this line they call *the line of elective polarity*.

(1147) Messrs. Tyndall and Knoblauch imitated Faraday's experiments with crystals of sulphate of iron by substituting for them a model of powdered carbonate of iron with gum-water, made into a paste, and compressed and arranged so that the line of "elective polarity" through the model was perpendicular to the length. With this they obtained corresponding results; the model, though magnetic, and strongly attracted by the magnet, actually receded from it when made to stand between the flat-faced poles obliquely. In the same way, by using bismuth powder, they imitated Faraday's experiments with a plate of bismuth. Now, as by reducing the substances to powder, all symmetry of crystalline arrangement is annihilated, and the force among the particles which makes them cohere in regular order, rendered ineffective, it would seem that Magnetism and Diamagnetism are clearly modified by mechanical arrangement. They enunciate the general principle in the following terms: "*If the arrangement of the component particles of any body, be such as to present different degrees of proximity in different directions, then the line of closest proximity, other circumstances being*

equal, will be that chosen by the respective forces for the exhibition of their greatest energy. If the mass be magnetic, this line will stand axial; if diamagnetic, equatorial." Both experiment and speculation seem, indeed, to concur in pronouncing the line of closest proximity among the particles to be that in which the magnetic and diamagnetic forces will exhibit themselves with peculiar energy, thus determining the position of the crystalline mass between the poles.

(1148) It had been announced by Plücker as a law that the magnetic attraction decreases in a quicker ratio than the repulsion of the *optic axis*. By this law he accounted for the following fact. On setting a small rhomboid of Iceland spar, with its optic axis horizontal, between the pointed poles, brought together as closely as possible, it sets equatorially, the optic axis coinciding with the magnetic axis; on now separating the poles $\frac{1}{4}$ or $\frac{3}{4}$ of an inch from each other, the rhomboid turns through 90° , and sets with its optic axis equatorial, and its greatest length axial. In the first instance the diamagnetic force overcame the optic axis force; in the second the optic axis force was the strongest. Tyndall and Knoblauch imitated these phenomena exactly with a *model* rhomboid, made by dissolving pure Iceland spar in hydrochloric acid, precipitating by carbonate of ammonia, and making with this precipitate a dough with gum-water, which they squeezed in one direction, so that the line of compression through the model coincided with that which represented the optical axis. Between the *near* points of the magnet the artificial optical axis stood from point to point; between the *distant* points it stood equatorially. They also constructed models of magnetic crystals from emery sand-paper; some of these, where magnetic layers of emery were perpendicular to its length, acted in the magnetic field precisely like a *prism of beryl*; between the near points both stood axial, between the distant points equatorial. From these and many similar experiments, these intelligent philosophers came to the conclusion that both classes of phenomena have a common origin; and that from the deportment of crystalline bodies between the poles of a magnet, no direct connexion between light and Magnetism can be inferred.

(1149) *Constancy of Differential Magne-Crystalline Force in Different Media.*—It had been observed by Faraday in his earlier experiments on *magne-crystalline* action, that with respect to bismuth the relation between the magnetic force in the axial and equatorial directions was unchanged by varying the surrounding medium from water to a solution of sulphate of iron. In his Thirtieth Series of Experimental Researches (Nov. 15th and 25th, 1855), he makes this condition the subject of further and special investigation. The

method employed to compare the possible variation of force produced by different circumstances, was to suspend the magne-crystal by a torsion fibre or wire, to place it in the magnetic field, to adjust the torsion index so that it should be at zero when the crystal had taken its position of stable equilibrium; then to put on *right-handed* torsion until the crystal had attained the point of unstable equilibrium, or the upsetting point on that side; and after having noticed the torsion required, to reverse the motion, and put on *left-handed* force, until the upsetting point on the opposite side was attained. Either of these forces, *minus* the deflection, is the measure of the upsetting force, and therefore the sum of these two observations, *minus* the number of degrees through which the crystal has moved in passing from one upsetting point to the other, may be considered as expressing the force which solicits the crystal to retain its stable position of rest.

(1150) The magnet employed was that great one constructed by Logeman, and sent to the Exhibition of 1851. It could sustain a weight of 430 pounds, and is very constant in power. The sliding poles pieces were of square iron, and presented either pointed terminations towards each other, or two flat faces 1·7-inch square, which could be brought up to the opposite sides of the troughs or vessels containing the different fluids or media required for the experiments. These vessels were of various sizes and kinds; but the outer ones were usually of copper, with flat sides, that the pole pieces might bear against them, and be thus preserved in their position during the progress of a single experiment, or a series of comparative results. The torsion suspender was about 24·5 inches in length, and was either a fine platinum wire, of which 28·5 inches weighed 1 grain, or a finer wire of silver, or a bundle of cocoon silk fibres. The torsion wire terminated below, by a hook, made out of a flat piece of copper foil, intended to receive on its edge a corresponding hook attached to the object submitted to experiment. The crystal was held by one turn of a fine copper wire which was continued upward for 5·7 inches, and terminated by a flat hook, like that just described. A horizontal bristle was fixed to each loop, and this, by its position, not only showed the place of the crystal beneath, but being retained between moveable stops associated with a horizontal scale, it indicated when the crystal was approaching the upsetting point, and being held within, and governed by the stops, allowed them, through it, to govern the crystal. The balance was enclosed by glass, to obviate the effects of currents of air.

(1151) With this apparatus Faraday experimented with *bismuth*, *tourmaline*, *protocarbonate of iron*, and *red ferroprussiate of potassa*,

in various media. With a bismuth crystal, in the form of an octagonal prism, suspended perpendicularly between the flat faces of the sliding poles, so that its magne-crystallic axis was horizontal, the up-setting torsion force in *air* was 2250°; in *absolute alcohol*, 2269°; in *water*, 2230°; and in saturated solution of *protosulphate of iron*, 2234°. In another experiment at a higher temperature, viz., 160° Fahr., the torsion force in *water* was 1945°, and in melted *phosphorus*, 1950°. With tourmaline the following numbers were obtained, the fine silver torsion wire being employed: *water*, 1082°; *olive oil*, 1085°; *alcohol*, 1081°; *air*, 1079°; saturated solution of *protosulphate of iron*, 1081°. A rough octagonal prism of native *protocarbonate of iron* (a highly paramagnetic substance) being suspended between the poles, opened to the full extent of the magnet, viz., 4.7 inches; the torsion force in *water* was 542; in *air*, 543; and in *protosulphate of iron*, 542. Lastly, a crystal of *red ferroprussiate of potash*, gave a torsion force in *air*, 314; and in *camphine*, 316.

(1152) These results point to the conclusion that there is no experimental difference in the proportion of the force developed in different directions in a magne-crystal, by the action of induction, whatever be the nature of the medium surrounding it, and whatever the difference in the paramagnetic and diamagnetic character of the crystals, or the media employed,—crystals differing as much as bismuth and carbonate of iron, and media differing as greatly as phosphorus and saturated solution of protosulphate of iron having been employed. The aptitude of a magne-crystal, when in the magnetic field, to assume a maximum conductive state in a given direction, makes it similar in action to a permanently magnetized sphere; and magne-crystals may be employed in experiments to measure magnetic force just as needles are; indeed, they are in some points of view philosophically more accurate, being equal in quality in all their parts, taking up precisely the same state under the same inductive force; having no coercitive or retentive faculty, and being independent of the surrounding medium.

(1153) As the setting force of a crystal remains constant for any surrounding medium, the possibility existed of finding a magne-crystal and a medium so related that the attraction and repulsion of the crystal as a whole, should be convertible terms depending upon the position of the crystal in regard to the lines of force. This case Faraday realized with the paramagnetic red ferroprussiate of potassa and a solution of sulphate of iron, and also with the diamagnetic crystal, carbonate of lime, and diluted alcohol. He also sought for a crystal amongst the ferrocarbonates of lime having this relation to

the assumed natural zero presented by a vacuum, or carbonic acid ; but this case was not realized.

(1154) *Action of Heat on Magne-crystals.*—When magne-crystals subjected to the same constant magnetic force, were raised or lowered to different temperatures, it was found that the setting force was affected ; and at all temperatures, from 0° Fahr. upwards, the force diminished as the temperature became higher. Thus the torsion force of a crystal of bismuth at 92° being 175° , was at 279° diminished to 82° ; that of a tourmaline, by passing from the temperature of 79° to 289° , was so far diminished, that the power at the lower temperature was nearly double that at the higher. A like result occurred with carbonate of iron, and also with compressed bismuth. In all these cases the bodies resumed their first full power on returning to lower temperatures, nor was there any appearance of magnetic *charge* in any part of the range of observations. Between 32° and 300° the force of bismuth appeared to alter by equal, regular degrees ; but with tourmaline and carbonate of iron the change was greatest for an equal number of degrees at the lower temperatures. At a full red heat, however, both tourmaline and calcareous spar retained a portion of their magne-crystalline force or condition, and so did carbonate of iron up to that temperature at which it was decomposed. A crystal of ferrocarbonate of lime had its magnetic condition absolutely reversed by change of temperature ; at low temperatures the optic axis pointed axially, and at high temperatures equatorially.

(1155) *Effect of Heat upon the Absolute Magnetic Force of Bodies.*—At temperatures varying from 30° to 288° the inductive force in *iron* appears to undergo no change, having obtained and kept its maximum degree ; with *nickel* there is a diminution of force at the upper temperature, which is in accordance with the general effect of heat ; with *cobalt*, on the other hand, there was an *increase* of power with elevation of temperature. Faraday thinks it probable that in passing to lower temperatures than those employed, a particular temperature would be arrived at for nickel and iron, presenting the maximum magnetic induction for each, and below which their inductive force would diminish—a view which adds much additional interest to the relation between heat and Magnetism.

(1156) *Diamagnetic Polarity.*—By the following experiment, Weber (*Pogg. Ann.* Jan., 1848) considers the polarity of bismuth to be proved : A strong horseshoe magnet is laid upon a table in such a position that the line joining its two poles is perpendicular to the magnetic meridian, and to be considered as prolonged on one side ; in that line, and near the magnet, is to be placed a small

powerful magnetic needle, suspended by a cocoon silk, and on the other side of it, the pole of a bar magnet, in such a position, and so near, as exactly to counteract the effect of the horseshoe magnet, and leave the needle to point exactly as if both magnets were away. Then a mass of bismuth being placed between the poles is said to react upon the small magnet needle, causing its deflection in a particular direction, and is supposed to indicate the polarity of the bismuth under the circumstances, as it had no such action when the magnets were away. A piece of iron, in the place of the bismuth, produces a contrary deflection of the needle. This experiment may be variously modified, but in every case the force of the bismuth must be observed upon other magnet poles than those which determine the diamagnetic condition of the bismuth, and they all concur (according to Weber) in confirming the assertion that bismuth constantly acts upon such poles in an opposite manner to iron in its place, that it consequently repels where iron attracts, and attracts where iron repels; in short, that at other magnet poles than those which diamagnetize the bismuth we as frequently observe attractive as repulsive forces of the bismuth.

(1157) In order to remove every doubt as to the diamagnetic force being really nothing else than the magnetic fluids, or their equivalents Ampère's currents, Weber proceeded to examine whether, agreeably with the laws of induction discovered by Faraday, an electric current can be induced in a neighbouring conductor by rotating a diamagnetic body under the influence of a powerful magnet. The following was the arrangement adopted: An iron nucleus, 600 millimetres * in length, coated several times with thick copper wire, was used as the electro-magnet. To the circular terminal surface, 50 millimetres in diameter, of this iron nucleus, was fixed the annular conductor, which consisted of copper wire, 300 metres long, and $\frac{1}{3}$ of a millimetre thick, well spun with silk, and coiled upon wooden cylinders. The space included in this annular conductor, in which the bar of bismuth was to be placed, was 140 millimetres in length, and 15 millimetres in breadth; the bar of pure precipitated bismuth was somewhat thinner. The extremities of the annular conductor were connected with a commutator, as were also the extremities of the multiplier of a very sensitive galvanometer, the magnet needle of which was provided with a mirror, in which the image of the distant scale was observed by a telescope directed towards it. The galvanometer was, moreover, provided with so effective a damper that it was scarcely possible to observe any vibration of the needle.

* 1 millimetre = 0.03937 English inch; 1 metre = 39.37 English inches.

Now, whilst a very powerful and constant galvanic current passed through the thick wire of the electro-magnet, the bar of bismuth was withdrawn from the annular conductor, the commutator changed, and the bar of bismuth again inserted, the commutator again changed, and the bar of bismuth withdrawn, &c. During this experiment, continued for about *one minute*, the state of the galvanometer was read off at intervals of about 10 seconds.

A second series of experiments was now made, but with this difference, that the commutator assumed that position, on *withdrawing* the bar of bismuth which it had occupied in the first series on *inserting* the bismuth, and *vice versa*.

(1158) The results were these: The commutator being in the position A, whilst the bismuth was withdrawn, the galvanometer *rose* 2.62; the commutator being in the position B, whilst the bismuth was withdrawn, the galvanometer *fell* 2.10. The extreme end of an *iron* bar being substituted for the bismuth, the induced current was too powerful to be measured; the direction of the needle could alone be observed. The position of the commutator being A, whilst the iron bar was removed, there was a *decrease* in the deflection of the galvanometer; and the position of the commutator being B, there was an *increase* in the deflection of the needle on removing the iron bar, and these results being exactly the reverse of those obtained with the bismuth, prove, (according to Weber,) the induction of electric currents by the diamagnetization of the bismuth, the direction of these currents being constantly the reverse of those induced by iron under the same circumstances, precisely as it should be if the bismuth contained magnetic fluids, or their equivalents (Ampère's currents,) which are set in motion, or rotated under the influence of powerful magnets in exactly an opposite direction to that of iron.

(1159) The apparatus employed by Faraday for the determination of this question is thus described (*Phil. Trans.*, part i., 1850): "A straight wooden lever, 2 feet in length, was fixed by an axis at one end, and by means of a crank and wheel made to vibrate in a horizontal plane, so that its free extremity passed to and fro through about 2 inches. Cylinders of metal, or other substances, $5\frac{1}{4}$ inches long, and $\frac{3}{4}$ ths of an inch in diameter, were fixed in succession to the end of a brass rod, 2 feet long, which itself was attached at the other end to the moving extremity of the lever, so that the cylinders could be moved to and fro in the direction of their length through a space of 2 inches. A large cylinder electro-magnet was also prepared, the iron core of which was 21 inches long and 1.7 inch in diameter; but one end of this core was made smaller for the length of 1 inch, being in that part only 1 inch in diameter. On to this

reduced part was fixed a hollow helix, consisting of 516 feet of fine covered copper wire; it was 3 inches long, 2 inches external diameter, and 1 inch internal diameter; when in its place, 1 inch of the central space was occupied by the reduced end of the electro-magnet core which carried it, and the magnet and helix were both placed concentric with the metal cylinder above mentioned, and at such a distance that the latter in its motion would move within the helix, in the direction of its axis approaching to, and receding from the electro-magnet in rapid or slow succession. The least and greatest distances of the moving cylinder from the magnet during the journey, were $\frac{1}{8}$ th of an inch and 2.2 inches. The object, of course, was to observe any influence upon the experimental helix of fine wire which the metal cylinders might exert, either whilst moving to or from the magnet, or at different distances from it.

“The extremities of the experimental helix wire were connected with a very delicate galvanometer, placed 18 or 20 feet from the machine, so as to be unaffected directly by the electro-magnet; but a commutator was interposed between them. This commutator was moved by the wooden lever, and as the electric currents which would arrive at it from the experimental helix, in a complete cycle of motion, or to-and-fro action of the metal cylinder, would consist of two contrary portions, so the office of this commutator was, sometimes to take up these portions in succession, and send them on in one consistent current to the galvanometer, and at other times to oppose them and to neutralize their result; and, therefore, it was made adjustable, so as to change at any period of the time or part of the motion.

“With such an arrangement as this, it is known, that however powerful the magnet, and however delicate the other parts of the apparatus, no effect will be produced at the galvanometer as long as the magnet does not change in force, or in its action upon neighbouring bodies, or its distance from, or relation to, the experimental helix; but the introduction of a piece of iron into the helix, or anything that can influence, or be influenced by the magnet, can, or ought to show a corresponding influence upon the helix and galvanometer. ‘*The apparatus,*’ observes Faraday, ‘I should imagine to be almost the same in principle and practice as that of M. Weber, *except that it gives me CONTRARY RESULTS.*’”

To insure steadiness, the machine, the magnet and helix, and the galvanometer stood upon separate tables on a stone floor laid upon the earth, the table carrying the machine being carefully strutted to neighbouring stone work. No iron was employed in any of the moving parts, and great care was taken to prevent the core while in

motion from disturbing in the least degree the experimental helix and magnet. The magnet was excited by a current from 5 pairs Grove's plates, and was then very powerful.

It was observed that on connecting the magnet with the battery, and then the experimental helix with the galvanometer (a very delicate instrument by Ruhmkorff), a current appeared at the latter, which continued a varying time, and which seemed to come from the battery. This current, which it was necessary in these delicate investigations to guard against, was traced to the *time* occupied by the iron core in attaining its maximum magnetic condition. It disappeared after the magnet had been excited a short time, and no experiment was proceeded with till it had entirely ceased.

(1160) On proceeding to experiment with this apparatus, Faraday found that when magnetic metals were used as cores, and such a velocity given to the machine as to cause five or six approaches and withdrawals of the core in one second, the direction in which the needle of the galvanometer moved was consistent with the effect of a magnetic body; but when *diamagnetic* metals were used, the deflection of the needle was in a contrary direction, *but the deflection was not the greatest for the most diamagnetic substances; indeed, the effect with bismuth, antimony, and phosphorus was scarcely appreciable. The effects were proportionate to the conducting power of the substance for Electricity*; and after minutely examining into all the circumstances, and varying the experiments in many ways, Faraday came to the conclusion that they were due to *induced currents* moving through the masses of the diamagnetic substances, and not to any polarity correspondent in its general nature (though opposed in its direction) to that of iron.

(1161) Referring to Reisch's experiments as described by Weber, according to which both N. and S. poles, when they act at the same time on the same side of a piece of bismuth, by no means repel it with the *sum* of the forces which they would individually exert, but only with the *difference* of these forces; Faraday says, that he repeated it "carefully and anxiously, but could never obtain the slightest trace of action with the bismuth." He obtained action with the iron, but in those cases the action was far less than if the iron were applied outside between the horse-shoe magnet and the needle, or to the needle alone, the *magnets being entirely away*; with weak magnetic substances, he did not find the arrangement at all comparable for readiness of indication or delicacy, with the use of a common or an astatic needle.

Faraday also refers to an experiment of Plücker, which at first seems to indicate strongly the polarity of bismuth or phosphorus. If

a bar of either of these substances be suspended horizontally between the poles of the electro-magnet, it will go to the equatorial position with a certain force, passing from stronger to weaker places of action. If a bar of iron of the same size be fixed in the equatorial position, a little below the plane in which the diamagnetic bar is moving, the latter will proceed to the equatorial position with much greater force than before, and this is considered as due to the circumstance that on the side where the iron has N. polarity, the diamagnetic body has S. polarity, and that on the other side the S. polarity of the iron and the N. polarity of the bismuth also coincide.

(1162) It is, however (says Faraday), very evident that the lines of magnetic force have been altered sufficiently in their intensity of direction, by the presence of the iron, to account fully for the increased effect. For, consider the bar as just leaving the axial position and going to the equatorial position,—at the moment of starting its extremities are in places of stronger magnetic force than before, for it cannot be doubted for a moment that the iron bar determines more force from pole to pole of the electro-magnet than if it were away. On the other hand, when it has attained the equatorial position, the extremities are under a much weaker magnetic force than they were subject to in the *same* places before, for the iron bar determines downwards upon itself much of that force which, when it is not there, exists in the plane occupied by the bismuth. Hence, in passing through 90° , the diamagnetic is urged by a much greater difference of intensity of force when the iron is present than when it is away; and hence, probably, the whole additional effect. . . . The effect does not (Faraday thinks) add anything to the experimental proof of diamagnetic polarity, nor can he find any evidence of such a state either in his own experiments or in those by Weber or Reisch, and the actions represented or typified by iron, by copper, and by bismuth remain at present distinct.

(1163) A series of memoirs have recently been published by Von Feilitsch (*Pogg. Ann.*), in which he endeavours to prove that diamagnetic bodies possess a polarity the *same* as that of iron; and in this uncertain state of the subject some admirable experiments were undertaken by Dr. Tyndall, the results of which were laid before the Physical section of the British Association at Liverpool in 1854. That the repulsion of a diamagnetic body depends not alone on the magnet operating upon it, but upon the joint action of the magnet and diamagnet, is proved by the fact that the repulsive force increases not simply in proportion to the strength of the magnet, but to the

square of the strength.* Tyndall confirms the observation of Reisch, that the condition, whatever it may be, which is evoked in a bar of bismuth by one magnetic pole is neutralized by the other; that each pole evokes a condition peculiar to itself, for when a bar of that metal was suspended between the poles of two bar electro-magnets it was repelled when the poles were alike, but remained motionless when the poles were of different names. The most perfect antithesis was observed in all cases between the deportment of a *normal* diamagnetic bismuth bar (a bar in which the planes of principal cleavage are parallel to the length of the bar) and a bar of soft iron; the electric and magnetic forces, which caused a deflection of the former from right to left, produced a deflection of the latter from left to right. The whole of the experiment seemed to justify the presumption, that whatever be the nature of the influences evoked in magnetic bodies by the action of currents or magnets, or of both combined, to an influence of the same nature but antithetical in its manner of distribution, the deportment of diamagnetic bodies is to be referred.

(1164) The following experiment is described by Tyndall as pointing to the conclusion that, whatever the ideal magnetic distribution in iron may be, a precisely opposite distribution occurs in bismuth; or, in other words, that the diamagnetic force is a polar force, but that the polarity is the reverse of magnetic polarity. Two helices were so placed that the end of the soft iron cores which fitted into them, were about 6 inches apart from centre to centre; the helices were at opposite ends of the plane which touched the ends of the cores. A helix of copper wire was introduced, and within it a bismuth bar, $6\frac{1}{2}$ inches long, and four-tenths of an inch in diameter,

* This mark of distinction between those bodies which have their power of exhibiting magnetic phenomena conferred upon them by the magnet, and those whose actions are dependent upon some constant property of the mass, was pointed out by Tyndall and Poggendorff in 1851. It may be illustrated thus: Let M represent the Magnetism of either pole of a magnet, and let M' be the Magnetism of the opposite pole of a very hard steel bar, then their mutual attraction at a given unit of distance is expressed by the product MM' . If now the power of the pole of the magnet be increased to nM , the mutual attraction will be nMM' , provided, that is, that the steel bar is hard enough to resist magnetization by influence; hence, when a variable magnetic pole acts on an opposite one of constant power, the attraction is proportional to the strength of the former. But, if instead of a hard steel bar, a piece of soft iron (M') be taken, the Magnetism of which will increase in the same ratio as that of the influencing pole of the magnet, then on increasing the power of the latter from M to nM , the attraction expressed by the product of both will be n^2MM' ; that is to say, the attraction of a body magnetized by influence, and whose Magnetism varies as the strength of the influencing magnet is proportional to the *square of the strength* of the latter.

was freely suspended, so that the ends of the bar were opposite to those of the soft iron cores. A current being sent through the helix, if the bismuth bar within it were excited by the current, it was probable that the nature of the excitement would manifest itself in the action of the magnets upon the diamagnetic body. By working delicately, the most perfect mastery was obtained over the suspended bismuth: when the current through the helix flowed in a certain direction, the ends of the diamagnetic bar were repelled by the electro-magnets; when the current flowing through the helix was reversed, the same ends were attracted by the magnet. The same effect was obtained when instead of reversing the helix current, the polarity of the two magnets was reversed. On comparing the deflections with those of soft iron, it was found that they were *perfectly antithetical*. The excitement which caused the ends of the iron bar to be attracted, caused the ends of the bismuth bar to be repelled; while the excitement which caused the ends of the iron bar to be repelled, caused those of the bismuth bar to be attracted.

(1165) If it be true that the polarity of the bismuth bar is the reverse of magnetic polarity, its two ends must, when the current circulates round it, be in different states; but if this is the case, then, if we make the two poles acting upon the ends of the bar *alike*, we ought to have attraction at one end and repulsion at the other; the result of these opposing actions being that the bar must remain undeflected. Tyndall made this experiment, and the result was in accordance with this conclusion. Two magnets with poles of the same name were brought to bear on a bismuth bar, the direction of the force emanating from the two poles being the same, the repulsion of one end and the attraction of the other tended to deflect the bar; two other poles of the same name, but of opposite names to the former two, were then caused to act upon the bar, *i. e.*, four magnets were employed—the two poles to the left being of the same name, and the two to the right of the opposite quality. The bar was promptly deflected, thus corroborating the view that diamagnetic bodies possess a polarity opposed to magnetic bodies.

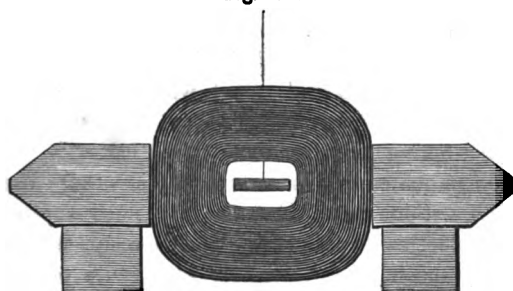
(1166) In the Bakerian Lecture for 1855, Dr Tyndall reinvestigates this interesting subject at great length, and adduces powerful experimental evidence in proof of the *duality* of diamagnetic excitement and of diamagnetic polarity. In experimenting with bismuth, the question of structure must be particularly attended to, for the “setting” of a bar of that metal between the magnetic poles will depend on the relation of the form of the mass to the planes of crystallization. A bar of bismuth whose planes of principal cleavage are throughout parallel to its length, suspended in the magnetic field

with the said planes *vertical*, will set its longest dimension at right angles to the line joining the poles—this is the normal department of diamagnetic bodies, and Tyndall, therefore, calls such a bar, a *normal diamagnetic bar*. On the other hand, a bar of compressed bismuth dust, or a bar of bismuth whose principal planes of crystallization are transverse to its length, will set axial in the magnetic field; such bars he calls *abnormal diamagnetic bars*.

Again, a bar of iron sets with its longest dimension from pole to pole; but a bar of compressed carbonate of iron dust, whose shortest dimension coincides with the line of pressure, sets its length equatorial; the former may, therefore, be called a *normal paramagnetic bar*, and the latter an *abnormal paramagnetic bar*.

(1167) The apparatus employed in examining the separate and joint action of a magnet and a voltaic current on these different bars, is shown in Fig. 456. A helix was formed of covered copper wire,

Fig. 456.



$\frac{1}{8}$ th of an inch thick; the space within the helix was rectangular, and was 1 inch long, 0.7 inch high, and 1 inch wide; the external diameter of the helix was 3 inches. Within the rectan-

gular space, the body to be examined was suspended by a fibre which descended through a slit in the helix. The latter was placed between the two flat poles of an electro-magnet, and could thus be caused to act upon the bar within it, either alone or in combination with the magnet. When a *normal*, paramagnetic bar was suspended in this helix, and a current sent through the latter, the bar set its longest horizontal dimension parallel to the axis of the helix, and consequently *perpendicular* to the coils. An *abnormal* paramagnetic bar suspended in a similar manner set its longest dimension perpendicular to the axis of the helix, and consequently *parallel* to the coils. A *normal* diamagnetic bar comported itself in the helix precisely as an *abnormal* paramagnetic bar; and an *abnormal* diamagnetic bar exactly as a *normal* paramagnetic bar.

(1168) In examining the conjoint action of the magnet and the helix, eight experiments were made with each particular bar; in the first four the *magnet* was excited first, and after the suspended bar had taken up its position of equilibrium, the deflection produced by the passage of a current through the surrounded helix was observed; in

the second four experiments the *helix* was excited first, and when the bar within had taken up its position of equilibrium, the Magnetism was developed and the consequent deflection observed. We give the results of the eight experiments with the *normal paramagnetic bar*. N S (Fig. 457) indicate the N. and S. poles of the electro-magnet; *a b* is the bar of iron; the helix within which the bar was suspended is shown in outline around it; the arrow shows the direction of the current in the *upper half* of the helix.

Fig. 457.



Fig. 458.



Fig. 459.



Fig. 460.



1°. *Magnet excited first*.—On exciting the magnet, the paramagnetic bar set itself parallel to the line joining the poles, as shown by the unbroken line *a b*. On now sending a current through the helix in the direction of the arrow, the bar was deflected towards the position dotted in the figure; interrupting the current in the helix and permitting the magnet to remain excited, the bar returned to its former position; the current was now sent through the helix in the direction of the arrow (Fig. 458), the consequent deflection was towards the dotted position. In Figs. 459 and 460, all other things remaining the same, the polarity of the magnet was reversed; the deflections of the bar on exciting the helix are shown by the dotted lines.

Fig. 461.



Fig. 462.



Fig. 463.



Fig. 464.



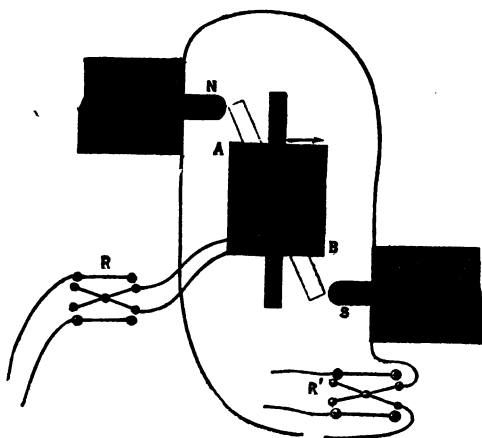
2°. *Helix excited first*.—On passing the current through the helix the bar immediately set its length parallel to the axis of the helix. On now exciting the magnet so that its polarity was that indicated by Fig. 461, the deflection was towards the dotted position. Inter-

rupting the current through both magnet and helix, and reversing the current through the latter, the bar came to rest as before, parallel to the axis. On exciting the magnet as in the last case, the deflection was that shown in Fig. 462. Preserving the same current in the helix, and reversing the polarity of the magnet the deflection was that shown in Fig. 463. Preserving the magnet poles as in the last experiment, and reversing the current in the helix the deflection was that shown in Fig. 464.

(1169) These experiments were repeated under precisely the same conditions with a *normal diamagnetic* bar; the deflections were in each of the eight cases the reverse of those indicated in the figures; they were next repeated with an *abnormal paramagnetic* bar, made of compressed carbonate of iron dust; the deflections were in each case the same with those with the normal diamagnetic bar; and lastly, an *abnormal diamagnetic* bar, consisting of a prism of bismuth, whose principal planes of crystallization were perpendicular to its length, was tested by a mode of experiment the same as that applied in the other cases, and the deflections were found to agree with those of the *normal paramagnetic* bar.

(1170) For examining the question of the "polarity" of diamagnetic bodies, the plan adopted by Tyndall was to cause fixed magnets to act upon a moveable bar of bismuth encircled by an electric current, and to note from the deflections of the bar the character of the force acting upon it. The bar was suspended with great delicacy in the axis of a helix of covered copper wire; opposite to either end of the bar was placed an electro-magnetic spiral, enclosing a core of soft iron. The spirals were so connected

Fig. 465.



together that the same current excited both, so that the same magnetic strength was developed in both poles, and by means of a reverser the polarity of the cores could be changed at pleasure; a current reverser was also attached to the helix enclosing the bismuth bar, so that the current from the battery could be caused to flow through

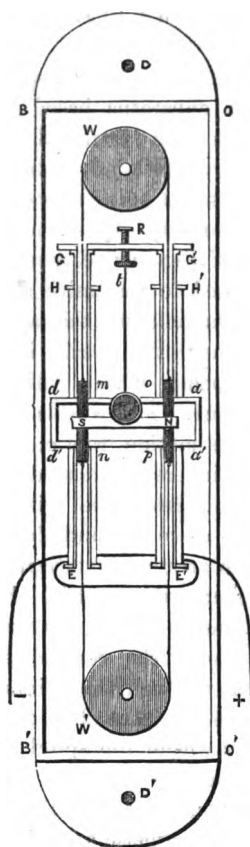
it in either direction. The arrangement will be at once understood by an inspection of Fig. 465. A B, the helix enclosing the bismuth bar; N S, the ends of the cores of the electromagnets; R', the current reverser of the spirals; R, the current reverser of the helix. On sending the current through the helix in the direction indicated by the arrow, the magnets being so excited that the pole N. was N. and the pole S., S.; the bar moved from its position, and came to rest in the dotted position, being manifestly *attracted* by the magnets. On reversing the poles of the magnets, the bismuth bar instantly loosed from the position it previously occupied, and receded from the poles; it was now repelled. On now changing the direction of the current through the helix, attraction was again manifested. "In all cases, when the bar was freely moving in any direction under the operation of forces acting upon it, the reversion, either of the current in the helix or the polarity of the cores, arrested the motion; approach was converted into recession, and recession into approach."

(1171) Tyndall has more recently (*Phil. Trans.*, 1856) again investigated this interesting subject with an apparatus based on different principles, and constructed (from a plan furnished by M. Weber,) by M. Leyser, of Leipsic. The diamagnetic bar, suitably excited, is permitted to act upon an astatic system of steel magnets; and from the deflections of the system the polarity of the bar is inferred. The instrument consists essentially of 2 spirals of covered copper wire, about 18 inches long, firmly attached to a massive slab of mahogany. The slab is attached by brass bolts to the solid masonry of the Royal Institution, so as to have the spirals in a vertical position. Above the spirals is a wooden wheel, with a grooved periphery, and below them a similar one. The wheels are united by an endless string, which communicates motion from one of them to the other. To this string the cylinders submitted to examination, are attached; and by turning the lower wheel with a suitable key, the cylinders can be caused to move up and down within the spirals. Two steel bar magnets are arranged astatically, connected by a rigid brass junction, and so suspended that the magnets are in a horizontal plane. The two magnets have the two spirals between them, their poles being opposite the centres of the spirals. When, therefore, a current is sent through the spirals, it exerts no more action upon the magnets than the central or neutral point of a magnet would do. If the bars within the spiral be perfectly central, they also will present these neutral points to the suspended magnets, and hence exert no action upon them. But if the key be so turned that the two ends of the diamagnetic bars shall

act upon the magnets, then, if these bars be polar, the intensity and character of their polarity will be indicated by the deflections of the magnets. Hence, we have not only the action of the earth neutralized, but a turning force is brought to bear upon the suspended system four times that which would come into play if only a single spiral and a single pole were made use of. The instrument is enclosed on all sides from external air currents; the magnets have a mirror attached to them which moves as they move, and which is observed by means of a telescope and scale placed at a distance of about 10 feet from the instrument.

(1172) The apparatus, and the working of its various parts, will be understood by reference to Fig. 466; B O B' O' is the outline of the rectangular case, the front of which is removed so as to show the apparatus within. D D' are the screw holes by which the box is

Fig. 466.



secured firmly to the wall; H E H' E' are the copper wire helices wound round 2 brass reels, the upper ends of which protrude from H to G and from H' to G'; W W' are the grooved wheels, to the string of which are attached the cylinders, *m, n, o, p*, of the body to be examined; G G' is a cross-bar of brass, through the centre of which the screw, R, passes, from which the astatic arrangement of magnets, S N, is suspended by silk fibres; the black circle in front of the magnet S N is a mirror, and the rectangle, *d a d' a'*, is the outline of a copper damper, which, owing to the currents induced in it by the motion of the magnets, soon brings the latter to rest, and thus expedites experiment.

(1173) When cylinders of bismuth, copper, antimony, heavy glass, marble, and many other substances were submitted to experiment with this apparatus, very marked deflections were produced. We quote one particular experiment performed by Dr. Tyndall in the presence of Professors Faraday, De la Rive, and Marcet. The bismuth cylinders were 3 inches long and 0.7 of an inch in diameter, and were chemically pure. A current from a single

cell of Grove's battery being caused to circulate in the helices, the cylinders remaining in their centres as in the figure, the cross wire of the telescope cut the number 650 on the scale. Turning the wheel *W'* so as to raise the cylinder *m n* and depress the cylinder *o p*, the magnet promptly moved, and after some oscillations took up a new position of equilibrium—the cross wire of the telescope then cutting 670 on the scale. Reversing the motion so as to place the cylinders again central, the former position 650 was assumed; on turning further in the same direction so as to depress *m n* and raise *o p*, the position of equilibrium of the magnet was at the number 630. Hence, by bringing the two ends *n* and *o* to bear upon the astatic magnet, the motion was from smaller to greater numbers, the position of rest being then 20 divisions *greater* than when the bars were central. By bringing the ends *m* and *p* to bear upon the magnet, the motion was from greater to smaller numbers, the position of rest being 20 divisions *less* than when the bars were central.

When the current was caused to flow through the helices in the contrary direction, an opposite result was obtained. The following was the experiment: The bismuth cylinders being in the centres of the helices, the cross wire of the telescope cut the number 482 on the scale. Turning the wheel so as to raise *m n* and depress *o p*, the cross wire cut 468; reversing the motion so as to place the cylinder again central, the former position of 482 was assumed, and on turning further in the same direction so as to depress *m n* and raise *o p*, the number became 493. In this case, therefore, the first motion was from greater to smaller numbers, and the last from smaller to greater.

(1174) In answer to the objection that has been urged against these experiments, that the deflections are due to induced currents aroused in the bismuth by its mechanical motion up and down within the spiral, Tyndall satisfactorily replies—1st, that the deflection produced is *permanent*, which could not be the case if the effect were due to induced currents, which vanish instantaneously. 2ndly, if the effect were due to induction, it would be shown in the most exalted degree by the best conductors. Now, antimony is less diamagnetic than bismuth, but it is a better conductor. The deflection produced by it, however, shows that it is its *diamagnetic* quality, and not its *conductive* quality which is effective; the amount of deflection being less than that of bismuth. Copper is fifty times a better conductor than bismuth, but its diamagnetic capacity is nearly *nil*; it produces no sensible action upon the magnets, which could not possibly be the case were the result due to induction.

Both paramagnetic and diamagnetic liquids have been included by

Tyndall in this examination, and the polarity of both has been established.

(1175) *Tyndall's Polymagnet*.—For the exhibition of the various phenomena of Diamagnetism and Electro-magnetism, the apparatus shown in Fig. 467, was devised by Dr. Tyndall. It consists of an

Fig. 467.

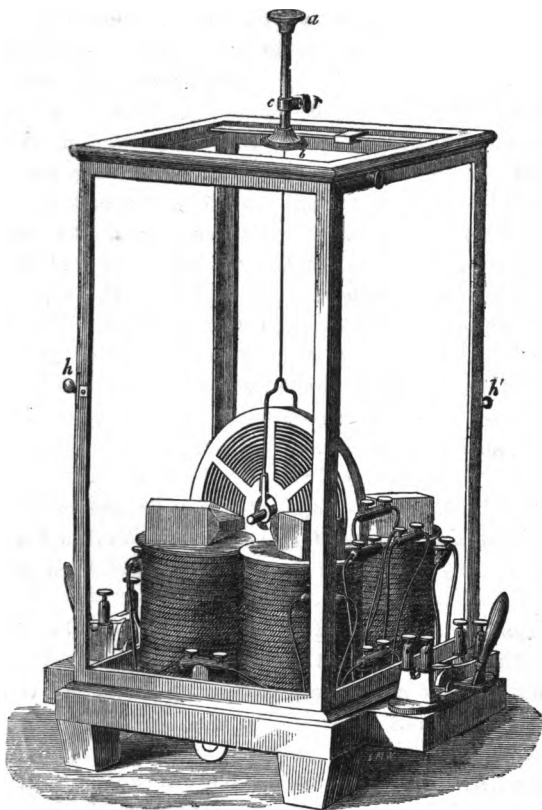
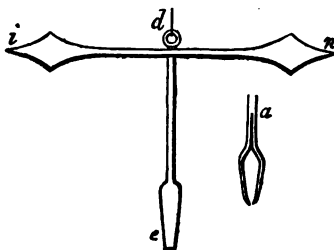


Fig. 468.



arrangement of two horseshoe magnets, a helix of covered copper wire disposed between them, and a suitable means of suspension. The diameter of the soft iron cores is 1.125 inch, and their distance apart from centre to centre 4.85 inches. The diameter of the covered copper wire surrounding the cores is 0.1 inch, and the weight of it which surrounds each limb of the magnet is 12 pounds. The helix placed between the two electro-magnets has an internal diameter of 1 inch, an external diameter of 8 inches, and measures along its axis 1.15 inch. The diameter of its wire is 0.065 of an inch, and its weight is 6 pounds. It is wound so as to form a double coil, and is held compactly together by radial strips of brass. A simple current reverser is fixed on the base-board of the instrument, which, to preserve a still atmosphere, is surrounded by a glass case. In the figure a bismuth bar is represented as suspended within the helix by several fibres of unspun silk attached to the central rod which passes through the top of the glass case. The bar is 6 inches long and .4 of an inch in diameter. When suspended so as to swing freely within the helix, its ends lie between the movable masses of iron which rest upon the electro-magnetic cores. Four poles are thus brought simultaneously to bear upon the bar of bismuth, and its action is thereby rendered both prompt and energetic. The two poles to the right of the bar must both be of the same name, and the two to the left of the bar of the opposite quality. If those to the right be both N., those to the left must be both S., and *vice versa*. On sending a current from 10 or 15 cells round the helix, and exciting the magnets by a battery of 4 or 5 cells, the current reversers place the deflections of the bar entirely under the control of the experimenter. By changing the direction of the current in the helix by means of its reverser, a change of deflection is produced. The same is effected if the polarity of the magnets be changed by the reverser which belongs to them.

All the experiments that are usually made with an upright electro-magnet may be made with this instrument, the various parts of which may with great facility be lifted separately out of the case; and numerous experiments will suggest themselves to those acquainted with what has been done of late years in Diamagnetism.*

(1176) *Diamagnetic Conditions of Flames and Gases*.—At the meeting of the Physical section of the Ninth Italian Scientific Congress in Venice, 21st of September, 1847, a memoir on the Universality of Magnetism was read by Padre Bancalari, Professor of Physics in the

* The instrument above described was constructed by Mr. Becker, of Newman Street, and the same ingenious mechanic has recently completed a very perfect and elegant apparatus of a similar nature for Mr. J. Strange.

Royal University of Genoa; and on the 27th of the same month it was announced by the reporter that it had been proved in the presence of several philosophers, "that on the interposition of a flame between the poles of an electro-magnet, it was repulsed at the instant the electric current was closed, to return to the first position the instant it was broken." This experiment was repeated shortly afterwards by Professor Zantedeschi, not at first with satisfactory results, but he afterwards fully confirmed Bancalari's experiments, "having," as he says, "constantly observed repulsion in the act of closing the circle, which lasted the whole time that the Magnetism was kept up, and when in the act of opening the circle, he saw the flame return to its primitive position."

(1177) A further study of the phenomena gave Zantedeschi the following results: He found that the phenomenon occurs with contacts of both solid and hollow soft iron, showing that the movement of the flame was not attributable to currents of air.

2nd. That the repulsion when it is quite distinct, and the flame quite pure and terminated in a well-shaped top, is accompanied by a depression.

3rd. That, *ceteris paribus*, the greatest effect takes place when the flame is touching the convex of the magnetic curves indicated by iron filings.

4th. That the action is null, or almost null, when the flame is placed in the centre of the interval which separates the two contacts.

5th. That in the manifestation of the effects it is not necessary for the contacts to be *entirely* separated.

6th. That there is a certain mass of the keeper pieces which is the most efficacious; beyond a limit, which can be shown by experiment, *increase* of the mass causes a *diminution* in the effect.

7th. That the movements of the flame increase with the number of the battery plates.

(1178) Faraday repeated Bancalari's experiment with the large electro-magnet belonging to the Royal Institution. The two terminal pieces of iron forming the *vertical* magnetic poles, were each 1·7 inch square and 6 inches long, but the ends were shaped to a form approaching that of a cone, of which the sides have an angle of about 100°, and the axis of which is horizontal, and in the upper surface of the pieces of iron. The apex of each end was rounded—nearly a *tenth* of an inch of the cone being in this way removed. When these terminations are brought near to each other, they give a powerful effect in the magnetic field, and the axial line of magnetic force is of course horizontal, and on a level nearly with the upper surface of the bars.

(1179) His results were as follows:—

When the flame of a wax taper was held near the axial line but on one side or the other, about one-third of the flame rising above the level of the upper surface of the poles, as soon as the magnetic

Fig. 468.



Fig. 469.



Fig. 470.



force was on, the flame was affected, and receded from the axial line, moving equatorially, until it took an inclined position, as if a gentle wind was causing its deflection from the upright position—an effect which ceased the instant the Magnetism was removed. The effect was not instantaneous, but rose gradually to a maximum. It ceased very quickly when the Magnetism was removed. The progressive increase is due to the gradual production of currents in the air about the magnetic field, which tend to be, and *are* formed on the assumption of the magnetic conditions in the presence of the flame.

When the flame was placed so as to rise truly across the magnetic axis, the effect of the Magnetism was to *compress* the flame between the points of the poles, making it recede in the direction of the axial line from the poles towards the middle transverse plane, and also to shorten the top of the flame (Fig. 468).

On raising the flame a little more, the effect of the magnetic force was to increase the intensity of the results just described, and the flame actually became of a *fish-tail shape* disposed across the magnetic axis (Fig. 469.)

(1180) If the flame was raised until about two-thirds of it were

above the level of the axial line, and the poles approached so near to each other (about 0.3 of an inch) that they began to cool and compress the part of the flame at the axial line, yet without interfering with its rising freely between them, then on rendering the magnet active the flame became more and more compressed and shortened, and as the effects proceeded to a maximum the top at last descended and the flame no more rose between the magnetic poles, but spread out right and left on each side of the axial line *producing a double flame with two long tongues* (Fig. 470).

When the magnet was thrown out of action, the flame resumed its ordinary upright form between the poles at once, being depressed and redivided again by the renewal of the magnetic action.

When a small flame only about $\frac{1}{3}$ rd of an inch high was placed between the poles, the magnetic force instantly *flattened it* into an *equatorial disc*.

(1181) Remarkable results are obtained with the dense stream of smoke rising from a blown-out green wax taper.

When the ignited wick is held about an inch below the axial line, the smoke rises vertically in one column until about $\frac{2}{3}$ ds of that distance is passed over, and then it divides, going right and left, leaving the space between the poles clear. As the taper is slowly raised, the division of the smoke descends, taking place lower down until it occurs upon the wick at the distance of 0.4 or 0.5 of an inch below the axial line. If the taper be raised still more, the magnetic effect is so great as not only to divide the stream but to make it *descend on each side* of the ignited wick, producing a form resembling that of the letter W; and at the same time the top of the burning wick is greatly brightened by the stream of air that is impelled downwards upon it. In these experiments the magnetic poles were only $\frac{1}{25}$ of an inch apart. Faraday has even succeeded in affecting the smoke from a small spark by a *good ordinary magnet*.

(1182) In searching into the cause of these phenomena Faraday began by examining the effect of *heat alone* in conducing to the diamagnetic condition of flame. For the burning taper he substituted a helix of fine platina wire, which could be placed in any position and ignited by a voltaic battery. When the helix was placed directly under the axial line, the hot air rose up between the poles freely, being rendered evident above by a thermometer, or by burning the finger, or even by scorching paper; but as soon as the magnet was rendered active, *the hot air divided into a double stream and was found ascending on the two sides of the axial line*; but a *descending current* was formed between the poles, flowing downwards

towards the helix and the hot air, which rose and passed off sideways from it.

(1183) This experiment showed that *hot* air is *more diamagnetic* than *cold* air, and by the following beautiful experiment Faraday proved that air artificially cooled is with relation to air at the natural temperature actually *magnetic*. A stream of air was conducted through a tube surrounded by a freezing mixture, and then directed downwards a little on one side of the axial line into a tube containing a delicate air thermometer, which of course immediately fell; on rendering the magnet active, *the thermometer rose*, but on bringing the tube *under* the axial line it again fell, showing that the cold current of air had been drawn inwards or attracted towards the axial line; i.e., had been rendered magnetic in relation to air at the ordinary temperature.

(1184) This extraordinary effect of heat in increasing the diamagnetic condition of bodies seems to be confined to gases and vapours, Faraday could not detect any distinct increase of the force by heating cylinders of copper and silver to redness.

(1185) Common air being thus shown to have a decided magnetic relation, Faraday proceeded to examine other gases and vapours for which he employed the following ingenious apparatus:—

A Woulf's bottle was provided, having three apertures *a*, *b*, *c*; into *a*, a wide tube was fixed descending within the bottle to the bottom, being open above and below; by this water could be poured into the bottle, and employed to displace the gas previously within it. Aperture *b* was closed with a stopper; aperture *c* had an external tube with a stop-cock fixed in it to conduct the gas to any place desired. To expel the gas and send it forward, a cistern of water was placed above the bottle, and its cock so plugged by a splinter of wood, that when fully open, it delivered only 12 cubic inches of fluid in a minute. This stream of water being directed into aperture *d*, and the cock of tube *c* open, 12 cubic inches of any gas within the Woulf's bottle were delivered in a minute of time, and this proportion was found not sufficiently great to *deluge* the magnetic field.

In order to deliver the gas at the magnetic poles, a piece of tube bent at one end nearly to a right angle was held by a clamp in a moveable position, so that its vertical part could be placed anywhere below the axial line; the aperture of this tube was about $\frac{1}{4}$ th of an inch in diameter. In the horizontal part, near the angle, was placed a piece of bibulous paper, moistened when necessary with strong solution of muriatic acid. If the gas to be employed as a stream was heavier than the surrounding medium, then the glass tube was so bent as to deliver its stream downwards, and over the axial line.

(1186) The next point was to detect and trace the course of these streams. This was effected by arranging upon little stands a set of tubes of thin glass, open at both ends, and about the size and length of a finger. These tubes could be readily adjusted at pleasure, either over or under the magnetic poles. When they were over the poles, three tubes were generally used, one *over* the axial line, and one at each side. When they were under the poles the low end was turned up a little for the purpose of facilitating observation.

Now, the gas issuing from the delivering tube had diffused through it a little invisible muriatic acid vapour, and to make it evident into which of the "catch" tubes it passed, a piece of bibulous paper moistened with ammonia was suspended in each, and it was evident at once by the *visible fume* formed at the top of one of the tubes, whether the gas delivered below passed up the one or the other tube, and which; and yet the gas was perfectly clear and transparent as it passed to the place of magnetic action. To preserve the air in a tranquil state, a little sheltering apparatus of mica was built up round the poles.

(1187) To try the working of the apparatus, *air* was sent in; the stream being directed by the axial line, the fume appeared in the *catch* tube above, whether the magnet was active or not, just as it should have done.

Nitrogen—When sent from below upwards, it passed by the axial line into the catch tube above; but when the magnet was made active a *fume appeared in the side tubes as well*. The jet was now arranged a little on one side of the axial line, so that without the magnetic action it still went into the middle tube; on making the magnet active a great portion of it was sent to the side catch tube, thus showing that in relation to atmospheric air nitrogen *is* at the same temperature *diamagnetic*.

Oxygen—When sent from above downwards through air between the poles, it descended vertically, whether the magnet was excited or not; when it was made to descend on one side of the axial line it was deflected and drawn *towards* the axial line, thus showing either that in common air oxygen *is magnetic*, or that it is less *diamagnetic* than a mixture of oxygen and nitrogen.

Hydrogen—In spite of its lightness it was deflected, and sent equatorially, proving it to be strongly diamagnetic.

Carbonic Acid—In air it was *diamagnetic*; its course was traced by a glass containing lime water placed beneath the lower end of the catch tube. The stream was sent downwards, a little on one side of the axial line, the tube and lime water being placed further out, so

that the gas should fall clear of it when the magnetic power was not on. On rendering the magnet active, the lime water became turbid. This made a beautiful experiment.

Carbonic oxide—More diamagnetic than carbonic acid.

Nitrous oxide—Moderately diamagnetic.

Nitric oxide—Very slightly diamagnetic.

Olefiant gas, coal gas, sulphurous acid gas, muriatic acid gas, hydriodic acid gas, fluosilicon, ammonia, chlorine, iodine, bromine, and cyanogen, were all more or less diamagnetic in air.

Of all the vapours and gases tried, *oxygen* seems to be that which has the least diamagnetic force, and this is the cause of the comparatively low diamagnetic condition of atmospheric air.

(1188) Faraday then surrounded the poles of the magnet with a mica chamber, which could be filled with carbonic acid gas; the former arrangements in respect to the magnetic field, the delivery tube, catch tubes, &c., being preserved, he found *air* and *oxygen* passed to the magnetic axis, being, therefore, *less* diamagnetic than carbonic acid gas. On the other hand:—

Nitrogen, hydrogen, coal gas, olefiant gas, muriatic acid gas, ammonia, and nitrous oxide passed equatorially, and were all, in a greater or less degree, diamagnetic in relation to carbonic acid.

(1189) By covering the poles of the magnet with a French glass shade, similar experiments were made with *hydrogen* and *coal gas* with the following results:—

In *coal gas*—*Air* passed feebly to the axial line; *oxygen* had the appearance of being *strongly magnetic*, presenting a striking phenomenon, and *nitrogen* was clearly *diamagnetic*.

In *Hydrogen*—*Air* passed feebly to the axial line, *nitrogen* was strikingly *diamagnetic*, and *oxygen* as strikingly *magnetic*. *Nitrous oxide, ammonia, carbonic acid, carbonic oxide, and olefiant gas* were *diamagnetic*.

The most striking circumstances in these experiments are the strongly marked diamagnetic character of *nitrogen*, and the feeble diamagnetic condition of *oxygen*, standing as it does, in this respect, far apart from all other gaseous substances.

(1190) Faraday then examined the influence of heat:—

Hot oxygen was powerfully *diamagnetic* in an atmosphere of *cold oxygen*.

Hot carbonic acid was diamagnetic to *cold carbonic acid*. The relation of hot and cold hydrogen could not be ascertained, as Faraday could not succeed in heating the platinum helix which he employed in these experiments by the voltaic battery in an atmosphere of hydrogen, in consequence, as he supposes, of the rapidity with which

that gas is heated and cooled in comparison with other gases. In short, however, all the experiments went to prove that all gases are more diamagnetic when *hot* than when *cold*.

(1191) *Non-Expansion of Gaseous Bodies by Magnetic Force*.—Taking common air as a standard, it appears from the preceding experiments that *nitrogen* and many other gases are strongly *diamagnetic* in relation to it, whilst oxygen has the appearance of a magnetic body. It appears also that the diamagnetic character of flame is due chiefly to the heated state of the gaseous portions.

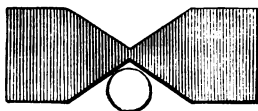
It occurred to Faraday that if the particles of a diamagnetic gas tended to go from strong to weak places of action, in consequence of the direct and immediate effect of the magnetic power on them, such a gas should tend to become enlarged or expanded in the magnetic field. On the other hand, if a gas were magnetic, then the force cast upon the particles by the direct and immediate action of the magnetic power upon them, would urge them *towards* the axis of the magnetic field, and so coinciding with, and being superadded to the pressure of the atmosphere, would tend to cause *contraction* or *diminution of bulk*.

(1192) A change in the bulk of air in the magnetic field had been observed by Plücker; Faraday was, therefore, induced to submit the matter to a minute examination; the result of which was that in none of the gases tried, whether considered as magnetic or diamagnetic bodies, could any alteration in volume be effected by the magnetic force, whether in fields of equal power, or in places where the power is rapidly diminishing; and this result he considers very important in relation to the true nature of magnetic force, either as existing in, or acting upon the particles of bodies. Faraday made similar experiments with liquids, but with very delicate apparatus and powerful electro-magnets, he was unable to observe any change of volume, neither could the least change be observed in the volume of iron or bismuth, however powerful the magnetic force to which they were submitted, and he could obtain no evidence that the magnet exerts any direct power of attraction or repulsion on the particles of gases, or that they move in the magnetic field as they are known to do by any such immediate attraction or repulsion.

(1193) *Differential Magnetic Action of Gases*.—The cause of the diamagnetic change of place is believed by Faraday to be a differential result depending on the *differences* of the two portions or masses of matter occupying the magnetic field; and in the case of gases, the phenomena may be produced and examined in a very useful manner by the employment of soap bubbles. In Faraday's experiments, these bubbles were about $\frac{1}{2}$ an inch in diameter, and by employing

recently-prepared *cold soap water*, and a bent glass tube connected with a bladder and stop-cock, he was able with a little care to blow them of a nearly uniform size and thickness. The gases were examined by placing the bubbles in the angle of a double pole of iron arranged between the poles of the large electro-magnet. When the bubble was of *air*, and a power of 20 pairs of plates employed, it was deflected slightly outwards from the axial line, the deflection being due to the water of the bubble. This deflection served as a correction in experiments with other gases.

Fig. 471.



Nitrogen was driven equatorially with great force, forming a striking experiment when it is considered that this gas constitutes $\frac{1}{4}$ ths of the atmosphere.

Oxygen was pulled inwards towards the axial line with much force, exactly as if it were highly magnetic.

Nitrous oxide and olefiant gas were both driven equatorially.

The other experiments with gases were quite in accordance with those already described, and all tended to prove that the effect is a differential result of the masses of matter present in the magnetic field.

(1194) *Magnetic Characters of Oxygen, Nitrogen, and Space*.—In order to examine the differential action of two gases, tubes the size and shape of fig. 472, of thin flint glass, were filled with the gases and having been sealed up hermetically, they were fastened by means

Fig. 472.



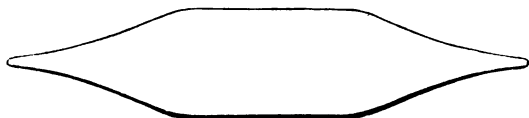
of sealing wax to loops of thread, by which they were suspended perpendicularly from a torsion balance, so that the middle of each should, when in place, be on a level with the magnetic axis. Now, when so suspended, if the gases are both alike in magnetic or diamagnetic power, their position will not be altered on the supervision of the magnetic force; but if one gas is more diamagnetic than another, the *most* diamagnetic will move outwards equatorially, pulling the *least* diamagnetic inwards, till the two are in such new positions that the forces acting on them are equipoised, and they will assume a position of stable equilibrium. Their relative diamagnetic intensities can then be measured by the force required to restore them to their equidistant position from the magnetic axis.

(1195) The tubes being filled respectively with oxygen and nitro-

gen, a most striking effect was observed the moment the magnetic force was thrown into action. The oxygen tube was carried inwards towards the axis, and the nitrogen tube driven outwards on the contrary side. When the tubes had taken up their new position, the oxygen tube was about $\frac{1}{4}$ th of an inch from the iron of the core, and the nitrogen tube $\frac{3}{4}$ ths distant, and *ten* revolutions of the torsion axis altered only in a slight degree these relative distances.

(1196) The effect of rarefaction was then tried; bulbs the size and shape of Fig. 473, were filled with oxygen, and then reduced under

Fig. 473.



the air pump, so that one tube contained gas at the pressure of one atmosphere; a second, gas at half an atmosphere, or 15 inches of mercury; a third, gas at the pressure of 10 inches of mercury; and a fourth, after being filled with oxygen, was reduced to as good a vacuum as an excellent air-pump could effect.

On trying these tubes one against the other, the expanded portion was always driven away, the denser gas going inwards; and when the tube containing gas at one atmosphere pressure was opposed to the vacuum, the former passed axially with such power that it was evidently only the diamagnetic power of the glass tube that prevented it from passing against the iron core, and occupying the centre of the magnetic field.

Oxygen, then, is a very magnetic substance, its magnetic force being in proportion to its density.

With *nitrogen* the differences produced by rarefaction could not be detected, there being no perceptible difference between the tube of gas at one atmosphere pressure, and that reduced as nearly as possible to a vacuum; both tubes remained equidistant from the magnetic axis.

Nitrogen, then, is neither magnetic nor diamagnetic: it is equivalent to a vacuum. Magnetically considered, *it is like space itself*, which may be considered *zero*.

(1197) The lines of magnetic force can traverse *pure space* just as gravitating force does, and as static electric forces do; space, therefore, has a magnetic relation of its own, which will probably, hereafter, be found to be of the utmost importance in natural phenomena. The true zero is represented by such bodies as when added to space produce no magnetic or diamagnetic effect. The term *magnetic*, Faraday

proposes, should be a general one, and include *all* the phenomena and effects produced by the power, and he proposes that bodies magnetic in the sense of iron should be called *paramagnetic* bodies (as placing themselves parallel to the lines of magnetic force), so that the division would stand thus—

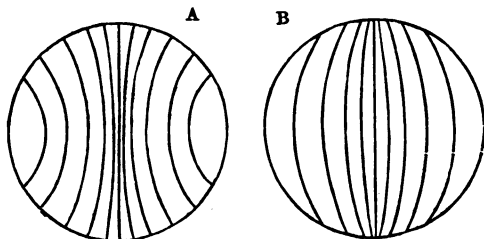
Magnetic	{	Paramagnetic.
		Diamagnetic.

(1198) Amongst all the gases hitherto examined, there is nothing that compares with oxygen; its magnetic power is so great that it makes atmospheric air a magnetic medium of no small power, which must be taken into consideration when experimenting on the diamagnetic condition of other gases. The discovery of the high magnetic condition of oxygen and its variations with variations of temperature and density, suggests an explanation of the cause of the variations of the magnetic force which are now so carefully watched on different parts of the surface of the globe, of the daily and annual variation of the needle, and of the relation between the aurora borealis and the Magnetism of the earth.

(1199) *Magnetic Conducting Power—Atmospheric Magnetism—Magnetic Conduction.*—The remarkable results respecting oxygen and nitrogen just described, led Faraday to the idea that if bodies possess different degrees of conducting power for Magnetism, that difference may account for all the phenomena, and its further consideration may assist in developing the nature of magnetic force. By the term *conducting power*, he means to convey a general expression of the capability which bodies may possess of effecting the transmission of magnetic force, and not to imply anything as to how the process of conduction is carried on; so that if a medium of a certain degree of conducting power occupy the magnetic field, that body will be displaced if another substance possessed of better conducting power be introduced into the field—the result being a *differential effect* of their difference in conducting power.

(1200) In pure space the lines of magnetic force are straight and parallel; if a *paramagnetic* body be introduced, the lines are no longer straight, but there will be a concentration of them on the conducting

Fig. 474.



ing body, so that the space occupied by the conducting body trans-

mits more magnetic force than before (Fig. 471 A). If a *diamagnetic* body be introduced, there will be a divergence of the lines, and the space occupied by the diamagnetic body will transmit less force than before. (Fig. 471 B).

The two bodies affect, *first*, the direction of the lines of force, not only within the space occupied by themselves, but also in the neighbouring space; *secondly*, the *amount* of force in any particular part of the space within or near them, and the influence of this disturbance is easily made manifest experimentally. A small sphere of iron, exactly equidistant from the iron poles, is in a position of unstable equilibrium, and at such time a great concentration of force takes place through it, and at the iron faces opposite to it, and through the intervening axial spaces. If the iron be a spheroid, its greatest diameter points axially, and the circumstances are more favourable for the concentration of force in the axial line passing through the iron than before. The converse is the case with diamagnetic bodies, which find their place of stable equilibrium in the spot where the position of paramagnetic bodies is unstable. Their relative and reverse positions in a field of equal magnetic force, may be retained in the mind by conceiving that if a liquid sphere of a *paramagnetic conductor* were in the place of action, and then the magnetic force developed, it would change in form and be prolonged axially, becoming an *oblong spheroid*, whereas, if such a sphere of diamagnetic matter were placed there, it would be extended in an equatorial direction, and become an *oblate spheroid*.

(1201) The mutual action of two portions of paramagnetic matter in a field of equal magnetic force is that of repulsion, and it is precisely the same with two portions of diamagnetic matter. Faraday found that when the lines of power passing across the magnetic field were strengthened by placing in the field a saturated solution of protosulphate of iron, a small moveable cylinder of phosphorus suspended in the middle of the magnetic field was distinctly repelled by another piece held close to it. Also, when a piece of phosphorus was suspended in water in a field of equal magnetic force, it was repelled equatorially by another piece of phosphorus, but attracted by a tube filled with a saturated solution of protosulphate of iron.

Thus, then, *paramagnetic* and *diamagnetic* bodies attract each other equatorially in a mean medium, but each repels bodies of its own kind.

(1202) *Conduction Polarity*.—*Paramagnetic* polarity consists in the *convergence* of the lines of magnetic force on to two opposed parts of the body, which are to each other in the direction of the magnetic axis. The difference of character of the new poles is at

these parts very great. Faraday thinks it not improbable that polar attraction or repulsion may exist in oxygen, and in all paramagnetic bodies consistent with the attraction and repulsion of magnets having correspondent poles.

Diamagnetic Conduction Polarity is a different matter. It consists in a *divergence* of the lines of power on *to*, or a *convergence from*, the parts which being opposite are in the direction of the magnetic axis. This polarity is to be carefully distinguished from that which depends upon the reversion of the direction of the power; the latter Faraday considers as a property of the particles of magnetic matter, the former as dependent rather upon the action of the mass; the latter is an absolute inversion of the direction of the power, the former only a divergence or deflection of it.

(1203) Though Faraday speaks of iron as illustrating the action of paramagnetic conductors, he draws an important distinction between the polarity of a magnet and the polarity due to mere conduction. A permanent magnet has a polarity in itself which is possessed also by its particles, and this polarity is essentially dependent upon the power which the magnet inherently possesses. The polarity of a conductor is simply a consequence of the condensation or expansion of the lines of force, and is not due to a determinate arrangement of the cause and source of magnetic action. Speaking figuratively, the difference may be compared to that of a voltaic battery, and the conducting wires or substances which connect its extremities. The stream of force passes through both, but it is the battery which originates it, and also determines its direction; the wire is only a better or worse conductor, however, by variation of form or quality, it may diffuse, condense, or vary the stream of power.

(1204) Applying the idea of conduction to magne-crystallic bodies, Faraday thinks that the special results may be understood by supposing that a magne-crystallic body *conducts* better in the *direction* of the magne-crystallic axis than in any other direction, and he concluded, that if a symmetrical crystal of bismuth were carefully examined in different directions, it would be found to be *less* diamagnetic when its magne-crystallic axis is parallel to the axis of magnetic force than when it is perpendicular to it. By means of the differential torsion balance, he was able to make the trial, and found the results as he anticipated. With calcareous spar he was not able, with his present balance, to establish any difference; but concludes that it will prove most diamagnetic when its optic axis, being in a horizontal plane, is placed parallel to the magnetic axis.

(1205) The place and position of iron in a field of equal force, is the result of the extraordinary power which it has of transmitting

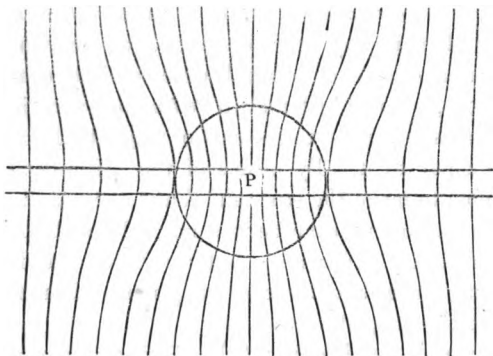
the magnetic force across the space which it occupies, and Faraday accepts the converse phenomena as to the place and position of a diamagnetic body as a proof that it has less power of transmitting the magnetic force than the space it occupies.

(1206) *Atmospheric Magnetism*.—The earth may be assumed to be a mighty compound magnet, the lines of force issuing from the northern and southern parts with different corresponding degrees of inclination, and inclining to, and coalescing with each other over the equatorial parts. The atmosphere consists of 4 volumes of nitrogen and 1 volume of oxygen, or by weight of $3\frac{1}{2}$ parts of the former and 1 part of the latter. These substances are nearly uniformly mixed throughout, so that as regards their manner of investing the earth, they act magnetically as a single medium; nor does there seem to be any tendency in the terrestrial magnetic forces to cause their separation, though they differ very strikingly in their constitution as regards this power.

As regards the magnetic force *nitrogen* is a very indifferent body, being neither diamagnetic nor paramagnetic, whether in a dense state or in a rare state, or whether hot or cold. As regards the magnetic force *oxygen* is highly *paramagnetic*, increasing in force as its temperature is lowered, and diminishing as its temperature is raised, and these properties it carries into the atmosphere, which becomes therefore a highly magnetic medium, varying however in intensity by alterations in its temperature and density.

(1207) Faraday assumes as a *type case* the existence of two globes of air distinct from the surrounding atmosphere by a difference of temperature or a difference of density; that one of these globes is colder or denser than the contiguous parts, and that it is in a portion of space which, without it, would present a field of

Fig. 475.



equal magnetic force. The air of such a globe will facilitate the transmission of the magnetic force through the space which it occupies, determining more lines of force through it than elsewhere. The disposition of these lines, in respect to the line of the dip of the place will be something like what is represented in Fig. 475, and

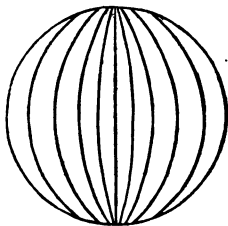
consequently the globe will be polarized as a conductor of the paramagnetic class. Hence the intensity of the magnetic force and its direction will vary not only *within* but *without* the globe, and these will vary in opposite directions, in different places, under the influence of laws which are perfectly regular and well known.

(1208) Now a magnet used as an intensity test will indicate a less intensity at P, because the conducting power of the globe has been increased in consequence of its coldness and density. If on the other hand the globe were warmer or more rarefied than the surrounding space, it would convey less power as being a worse conductor, and the magnet would set with greater force, and give an indication of greater intensity both *within*, and equatorially *without* the globe.

But if changes in the medium can effect the magnet, a magnet ought to make a greater number of vibrations in an atmosphere of nitrogen than in one of oxygen, because these two gases differ naturally in their magnetic relations.

(1209) If another typical globe of air be assumed having a higher temperature than the surrounding air, its condition will be that of a diamagnetic conductor, and it will have power to affect both the intensity and direction of the lines of force in conformity with the action of the former globe, but in the contrary order, although the conditions of the foregoing *typical* globes can never actually occur in nature, still the comparison holds in principle, and we may expect that as the sun leaves us on the *west* some effect correspondent to that of the approach of a body of cold air from the *east* will be produced, which will increase and then diminish, and be followed by another series of effects as the sun rises again and brings warm air with him.

Fig. 476.



(1210) Again, there is more air by weight over a given portion of the surface of the earth at latitudes from 24° to 34° , than there is either at higher latitudes or at the equator, and that should cause a difference from the disposition of the lines of force which would exist if there were equality in that respect. The temperature also of the air is greater at the equatorial parts than in latitudes N. and S. of it; and as an elevation of temperature diminishes the conducting power for Magnetism, so the proportion of force passing through these parts ought to be *less*, and that passing through the colder parts *greater*, than if the temperature of the air were at the same mean degree over the whole surface of the globe.

(1211) *Annual and Daily Variation*.—The effect of the approach and retreat of the sun in his daily course is to produce such variations of changes in the temperature and expansion of the atmosphere, as to influence the lines of force emanating from the earth both in their direction and intensity; the manner in which this influence may be developed, Faraday, by means of figures and descriptions, states, in relation to the annual and daily variation, and the irregular perturbations of the magnetic force, which he thinks are consequences of it. He then applies the result of the magnetic observations at Hobarton* as a test of the probable truth of the hypothesis, and considers that it affords strong confirmation. The upper or N. end of the needle there goes W. till about 21 o'clock, whilst the dip increases; the dip still increasing till noon, the upper end returns rapidly E. as the sun passes by until 2 o'clock the dip then decreasing, after which the needle goes W. again following the sun. On examining the results at Toronto, corresponding effects were found to occur, when the upper or S. end of the needle was considered, and therefore in accordance with the hypothesis.

Faraday also discusses the observations made at Greenwich, Washington, Lake Athabasca, Fort Simpson, and St. Petersburg, and considers them as adding further confirmation. By the aid of these observations he re-states his principles more minutely, endeavouring to indicate what difference changes in the inclination, declination, place of sun, land, sea, &c. will produce.

(1212) Though the sun is the cause of those changes in the atmosphere which affect the lines of force on the earth, he is not assumed as the centre of action as regards those lines; *that*, is considered to exist somewhere in the atmosphere. It appears to be in the upper regions and not on the surface of the earth, because it increases the dip of places N. and S. of the tropics, which have a certain amount of inclination, as at Hobarton and Toronto, both in summer and winter, but it diminishes the dip at places which are within the tropics, and with little inclination, as at St. Helena. By other kinds of observations it appears to be in advance of the sun. All the phenomena indicate that the sun does not act *directly* on the needles at different places, but mediately through its effect on the atmosphere.

(1213) The probable cause of numerous irregular variations, such as those that are shown in the photographic processes of record at Greenwich and Toronto, are then considered, and Faraday thinks that changes in the lines of magnetic force may be produced by the

* "Magnetical and Meteorological Observations. Hobarton, vol. i. 1850." Sabine, Toronto.

varying pressure of the atmosphere, by the occurrence of winds and large currents of air, of rain, and snow; by the passage of those masses of warm and cold air which the meteorologist recognizes in the atmosphere, by the aurora borealis, &c. He thinks it very possible that masses of air at different temperatures may be moved by the magnetic force of the earth, according to the principles of differential action made manifest in the experiments on warm and cold oxygen, in which case, material as well as potential "*magnetic storms*" may exist.

(1214) Faraday, at the conclusion of this paper (26th Series), again alludes to the wonderful magnetic power of *oxygen*. It is in the *air* what *iron* is in the *earth*, and its striking contrast with the nitrogen which dilutes it in the atmosphere, impresses the mind, and by the difference, recalls that which also exists between them in relation to static Electricity and the lightning flash. He expresses his conviction, that there is much to do with oxygen relative to atmospheric Magnetism; and he starts the question—What is the final purpose in nature of its magnetic condition in the atmosphere, liable as it is to annual and diurnal variations, and to entire loss by entering into combination? That it has an important purpose to serve is evident, for nothing in nature is superfluous.

CHAPTER XXII.

MAGNETIC HYPOTHESES.

Notions of the Ancients—Theories of Descartes and Œpinus—Ampère's electrodynamic theory—Faraday's researches—Lines of magnetic force—The moving wire as an examiner of magnetic forces—Magnetic "polarity"—Physical character of the lines of magnetic force—Places of no magnetic action—Faraday's view of the condition of a magnet.

(1215) THE notions entertained by the ancients respecting the immediate source of the power of the magnet, were of the wildest description. Thus Thales and Anaxagoras conceived that the magnet was possessed of an immaterial spirit, in obedience to which iron moved and was attracted; Cornelius Gemma said, that invisible rays pass between the iron and the magnet; others, that there exists a sympathy between them; Epicurus supposed that the atoms of the iron were hooked on to those of the magnet; Plutarch thought that there was an emanation proceeding from the magnet. Cardan said, that iron is attracted because it is *cold*, and Costeo de Lodi regarded iron as the natural food of the magnet. Then came Descartes, whose theory of vortices was for a long time universally adopted. According to his theory, a rush of subtle matter passes rapidly through the earth from the equator towards each pole. This matter being porous, is not arrested in its passage by ordinary matter, but magnetic substances, in consequence of a peculiarity in their molecular structures oppose a resistance and are hence affected. Moreover, the vortex moves with the greatest facility in one particular direction; one of its ends being always turned towards the N. The pores of iron are regarded as valves, which open readily in one direction, but oppose the entrance of any substance in the opposite direction.

(1216) The theory of Descartes was adopted by Euler, who in his Letters (translated 1802) has thus set it forth: "Non-magnetic bodies are freely pervaded by the magnetic matter in all directions; loadstones are pervaded by it in one direction only; one of the poles being adapted to its admission, the other to its escape. But iron and steel, when rendered magnetic, fulfil this last condition; when they are not, it may be affirmed that they do not grant a free

transmission to the magnetic matter in any direction." (Vol. II. p. 242.) "You can easily imagine a series of fluids, one always more subtile than another, and which are perfectly blended together. Nature furnishes instances of this. Water, we know, contains in its pores particles of air which are frequently seen discharging themselves in the form of small bubbles; air, again, it is equally certain, contains in its pores, a fluid incomparably more subtile, viz., *ether*, and which, on many occasions, is separated from it, as in Electricity; and now we see a still further progression, and that ether contains a matter much more subtile than itself—the magnetic matter, which may, perhaps, contain in its turn others still more subtile; at least, this is not impossible. The loadstone, besides a great many pores filled with ether, like all other bodies, contains some still much more narrow, into which the *magnetic matter* alone can find admission. These pores are disposed in such a manner as to have a communication with each other, and constitute tubes or canals through which the magnetic matter passes from the one extremity to the other. Finally, this matter can be transmitted through these tubes only in one direction, without the possibility of returning in the opposite direction." (P. 244.) "As we see nothing that impels the iron towards the loadstone, we say, that the latter attracts it. It cannot be doubted, however, that there is a very subtile, though invisible matter, which produces this effect, by actually impelling the iron towards the loadstone." (Vol. I. p. 214.)

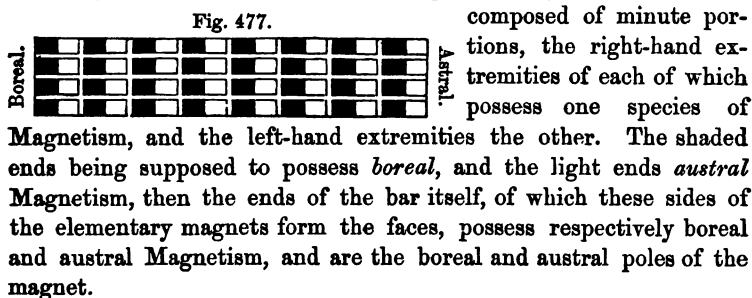
"The arrangement assumed by the steel filings leaves no room to doubt that it is a subtile, invisible matter which runs through the particles of the steel, and disposes them in the direction which we here observe. It is equally clear that this subtile matter pervades the loadstone itself, entering at one of the poles and going out at the other, so as to form by its continual motion round the loadstone a vortex, which re-conducts the subtile matter from one pole to the other, and this motion is without doubt extremely rapid. The nature of the loadstone consists then in a continual vortex which distinguishes it from all other bodies; and the earth itself, in quality of loadstone, must be surrounded with a similar vortex, acting everywhere on magnetic needles, and making continual efforts to dispose them according to its own direction."—(Vol. II. p. 240.)

(1216) Epinus applied the electrical theory of Franklin with great ingenuity to the explanation of the phenomena of Magnetism. The four propositions which his theory includes have been already stated (758). The laws of attraction and repulsion find a satisfactory explanation on this hypothesis, but it fails when applied to the consequences which follow on the division of a magnetic bar;

each piece should have a different and distinct polarity, whereas it is well known that each fragment is a bi-polar magnet, and that this is the case, however many may be the number of pieces into which the bar is divided. Cëpinus endeavoured to overcome this difficulty by supposing that during the act of fracture the balance of magnetic force was disturbed, and that a portion of fluid escaped from the overcharged pole, while another portion entered into that which was undercharged.

(1217) The theory of two magnetic fluids was first propounded by Wilke and Brugmann, and afterwards enforced by Coulomb. According to this hypothesis, a magnet is considered as composed of minute invisible particles or filaments of iron, each of which has individually the properties of a separate magnet. It is assumed that there are two distinct fluids—the *austral* and *boreal*; and under the influence of either in a *free* state, the bar of iron or other metal will point to the N. or S. poles of the earth, according to circumstances. It is within these small particles or metallic elements that the displacement or separation of the two attractive powers takes place; and the particles may be the ultimate atoms of the iron.

A magnetic bar may, therefore, be represented (as in Fig. 477), as

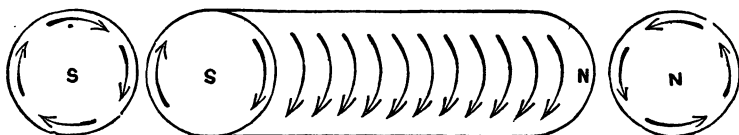


In ordinary iron, these fluids exist in a *combined* state, and are, therefore, perfectly latent; the metal appearing to be destitute of Magnetism. They exist in certain proportions united to each molecule or atom of the metal, and from which they *can never be dis-united*, the only change which they are capable of undergoing being their decomposition into the separate fluids, one of which in a permanent magnet is always collected on one, and the other on the opposite side of each molecule.

This theory occupied the attention of the great mathematician Poisson, who by applying to it the refinements of modern analysis, succeeded in discovering formulæ which represent numerically all the principal phenomena of the science, even in their minutest details, and which furnish a ready and consistent explanation of the physical mode by which they are produced. (*Roget.*)

(1218) *Ampère's Electro-dynamic Theory*.—Reasoning from the phenomena of the mutual action of magnets and electric currents, Ampère was led to deny the existence of any magnetic fluid as distinct from Electricity, and to consider all magnetic phenomena as the visible effects of invisible electric currents perpetually circulating around the particles of which the magnetic bodies are composed. Each particle or magnetic element is, according to this theory, regarded as constituting a voltaic circuit, and a magnet is composed of an assemblage of parallel filaments, each of which is made up of a series of particles, round which electric currents are circulating in the same direction with reference to the axis of the filament, and moving in planes perpendicular to that axis. In a bar of unmagnetized iron the Electricity is supposed to be in a latent or quiescent state; that extremity of the magnetic filament in which when uppermost, the positive current is moving in the same direction as the hands of a watch, has the properties of a S. magnetic pole, and *vice versa*. If the filament be placed horizontally, its N. pole pointing to the N. and its S. pole towards the S., the electric currents circulate on the upper side from W. to E., and downwards on the eastern side; on the under side from E. to W., and upwards on the western side.

Fig. 478.



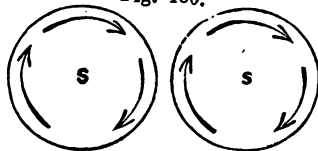
The mutual repulsion of two magnetic poles of the same name, and the attraction of two dissimilar poles, are simple consequences of this hypothesis. It has been shown (944) that there is a repulsive action set up between two wires along which electrical currents are moving in opposite directions, but that when the currents move in the same direction along each wire attraction results.

Fig. 479.

Now it is easy to see (Fig. 479) that when two similar magnetic poles are brought near each other, the hypothetical electric currents are moving in contrary directions at the sides contiguous to each other, and that when two dissimilar poles are approximated (Fig. 480) the currents are flowing in the same direction; hence repulsion



Fig. 480.

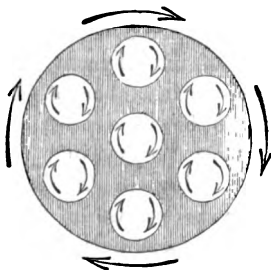


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in the former case, and attraction in the latter. The direction in which the currents are supposed to flow in every possible position of the magnet, and the mutual relations of these currents, are well realized to the mind by drawing a series of arrow heads round a pair of wooden cylinders, and placing them in various positions relatively to each other.

(1219) It follows also as a consequence of this mutual action of

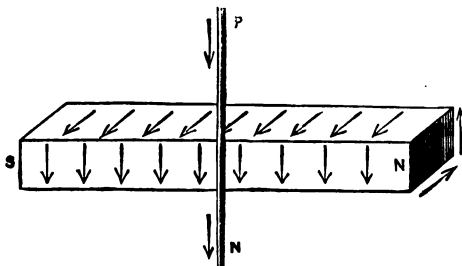
Fig. 481.



currents, that, viewing a magnet as an assemblage of filaments round each of which electrical currents are circulating, the resultant action of the magnet can only be exerted externally; for let Fig. 481 represent the section of a cylindrical magnetic bar, and the small included circles some of its filamentary elements, the currents moving round the contiguous sides of any two of these circles, being opposed in direction,

neutralize each other, while the currents that pass near the circumference are not so compensated by others, and their action is, therefore, fully exerted on external bodies. Again, the tendency of a magnet and a conducting wire to place themselves at right angles to one another (931 *et seq.*) is referred by Ampère's theory to the transverse movements of the electric currents in the magnet which act upon the current in the conductor, and are also acted upon by

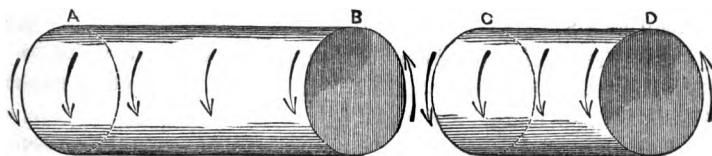
Fig. 482.



that current. Thus, let S N represent a magnet, and P N, a wire conveying a current of Electricity; the arrow heads show the direction in which the currents are moving round the magnet, viz., in planes perpendicular to its axis; the wire P N, tends to

range itself, therefore, transversely to the axis of the bar, in order that the current moving along it should be parallel to that of the current in the nearest part of the magnet. Further, the theory happily explains the induction of an opposite polarity in the adjacent end of a piece of soft iron, by a magnetic pole. Thus, let A B (Fig. 483), be the magnet, and C D, the bar of iron, the former has a tendency to

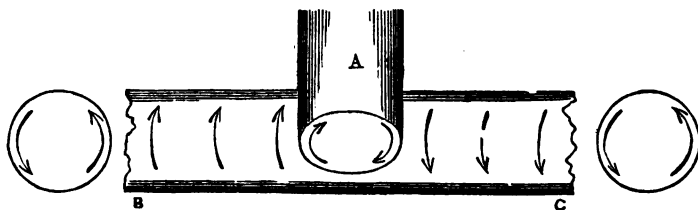
Fig. 483.



excite in the latter a current of Electricity, circulating in the same direction as the currents moving round its own filaments; but it is evident, that if the current at the end of B revolves, as seen by a spectator looking at that end, from right to left, the current induced at the end of the iron bar C, revolving in the same direction in space, will appear to the spectator, looking at that end, to move from left to right; and, as the polarity depends upon the direction of the current with respect to the axis at the extremity, the polarity of B will be the reverse of that of C, and the same as that of D, but the polarities C and A, will be the same. Precisely the same consequences must follow upon the fracture of a magnetic bar; each piece becomes a perfect magnet, the polarities of the fractured ends being opposed to each other.

(1220) If we bring a magnetic pole opposite the centre of a soft iron rod, the two ends of the latter will acquire a temporary polarity of the same kind with that of the inducing pole; a polarity of the opposite nature being induced in the centre of the bar (803). This phenomenon is easily explained by Ampère's theory. Thus

Fig. 484.



suppose the N. pole of the magnet A to be laid on the centre of the bar B C, and at right angles to it, the currents induced in the latter, on the side A C, will be in the direction of the arrow heads, while those induced in the bar, on the side A B, will move the contrary direction; but if we examine the ends of our test cylinders (1218), we shall find, that under these circumstances, the arrow heads are pointing in the same direction at each end; B and C must, therefore, be both N. poles. The parts of B C, however, immediately

under A, will have currents, in opposite directions, induced in them, the point of the bar, therefore, immediately underneath the inducing bar will be a S. pole.

(1221) This beautiful theory of Ampère, which is sustained by the highest mathematical investigation, furnishes a satisfactory explanation of all the mutual actions of magnets and electric currents, and of magnetic and electro-magnetic phenomena in general; as applied to these, "it satisfies every condition that is required of a true theory, uniting the character of simplicity in principle, and comprehensiveness in its application, and possessing this important advantage over the theory of tangential forces, viz., that it presents greater facility of mathematical investigation, and for the comparison of the analytical formulæ thence obtained, with the results of experiment."

—(*Roget.*) The theory, however, as laid down by Ampère, wholly fails to account for *diamagnetic* actions. To render it at all consistent with these phenomena, it has been assumed, that magnetic and electric force might, in diamagnetic matter, induce currents of Electricity in the reverse direction to those in magnetic matter, or else might induce currents where before there were none; whereas, in magnetic cases, it was supposed that they only constrained particle currents to assume a particular direction, which before were in all directions. Others, amongst whom is Weber, have made an addition to the hypothetical views of Ampère, viz., that there is Electricity amongst the particles of matter which is not thrown into the form of a current until the magnetic induction comes upon it, but which then assumes the character of current, having a direction the contrary to that of the currents which Ampère supposed to be always circulating round magnetic matter, and so those other matters are rendered diamagnetic.

A striking experimental distinction between a magnet and a helix (947) has been pointed out by Faraday (*Ex. Res.* 3273), viz., "Whereas, an unchangeable magnet can never raise up a piece of soft iron to a state more than equal to its own, as measured by the moving wire (1225), a helix carrying a current can develop in an iron core magnetic lines of force of a hundred or more times as much power as that possessed by itself when measured by the same means."

(1222) De la Rive (*Notices of the Meetings of the Royal Institution*, Vol I. p. 458), distinguishes magnetic action into four kinds or modes, namely, the *ordinary*, the *diamagnetic*, the *induction of currents*, and the *rotation of a ray*; and he points out that any acceptable hypothesis ought to account for the four modes of action, and, it may be added, ought to agree with, if not account for, the pheno-

mena of electro-chemical action also. He conceives that, as regards these modes of action, this hypothetical result may be obtained, and both Ampère's and Weber's views also retained, in the following manner. All the atoms of matter are supposed to be endowed with electrical currents of a like kind, which move about them for ever, without diminution of their force or velocity, being essentially a part of their nature. The direction of these currents for each atom is through one determinate diameter, which may, therefore, be considered as the axis. When they emerge from the body of the atom they divide in all directions, and running over every part of the surface, converge towards the opposite end of the axis diameter, and, therefore, re-enter the atom to run ever through the same course. The converging and diverging points are, as it were, poles of force.

Where the atoms of matter are close or numerous in a given space, the hypothesis then admits that several atoms may conjoin into a ring, so that their central or axial currents may run one into the other, and not return as before over the surface of each atom; these form the molecules of magnetic matter, and represent Ampère's hypothesis of molecular currents. Where the atoms being fewer in a given space are farther apart, or where, being good conductors, the current runs as freely over the surface as through the axis, then they do not form like groups to the molecules of magnetic matter, but are still considered subject to a species of induction by the action of external magnets and currents, and so give rise to Weber's reverse currents. The induction of momentary currents and the rotation of a ray are considered by De la Rive as in conformity with such a supposition of the electric state of the atoms and particles of matter.

(1223) "This hypothesis," remarks Faraday, "the most perfect that has been offered, requires large assumptions; it is necessary in the first place to conceive of the molecules as being flat or disc-like bodies, however numerous the atoms of each may be; also that the atoms of one molecule do not interfere with or break up the disposition of those of another molecule; also that electro-chemical action may consist with such a constituted molecule; also that the motive force of each atom current is resident in the axis, and on the other hand that the passage of the current over the surface offers *resistance*; for unless there were a difference between the axial and the surface force in one direction or the other, the atoms would have no tendency to congregate in molecules." While, however, criticizing these various hypotheses, and considering their rapid succession rather a proof of weakness in this department of physical knowledge than of strength, Faraday fully admits the value, and even the

necessity of hypothesis where rightly used; meanwhile, he himself proceeds to investigate experimentally, and by a new method, the direction, intensity, and amount of the magnetic forces, and to deduce therefrom new views respecting the condition of the magnet itself, without, however, pretending to convey any clear idea of the physical condition constituting the charged magnetic state, or to explain all the points of difficulty with which this subject is surrounded.

(1224) *Definition of a Line of Magnetic Force.* (*Phil. Trans.*, 1852, p. 1.)—That line which a very small needle describes when it is so moved in either direction correspondent to its length, that the needle is constantly a tangent to the line of motion; or that line along which, if a transverse wire be moved in either direction, there is no tendency to the formation of any current in the wire, whilst, if moved in any other direction, there is such a tendency; or that line which coincides with the direction of the magne-crystallic axis of a crystal of bismuth, which is carried in either direction along it,—the direction of these lines about and between ordinary magnets is easily represented in a general manner by the use of iron filings.

In using this term "line of force," Faraday intends to express simply the direction of the force in a given place, and not any physical idea or notion of the manner in which the force may be there exerted.

(1225) The lines of magnetic force may be recognized either by their action on the magnetic needle, or on a conducting body moving across them, the former showing its results by attractions and repulsions, the latter by the production of a current of Electricity (991 *et seq.*). That this latter method may be advantageously employed, excellent conductors are required; that generally used by Faraday was a short copper wire 0.2 of an inch in thickness. The galvanometer also, instead of including many hundred convolutions of a fine wire, should consist of not more than 48 or 50 inches of stout wire, disposed in two double coils about the astatic needle, because, although the Electricity produced by the intersection of the lines of magnetic force is abundant in quantity, its intensity is so low that the fine wire galvanometer offers great obstruction to its passage.

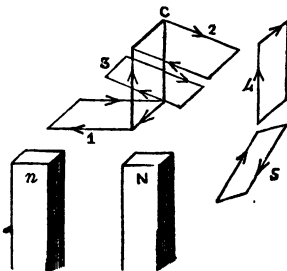
(1226) The moving wire produces its effect when moving *transversely* across the lines of force; and it determines the direction of the polarity by the *direction* of the electric current produced in it during the motion.

A natural standard of this polarity may be obtained by referring

to the lines of force of the earth in the northern hemisphere; thus, *if a person with arms extended move forward in these latitudes, then the direction of the electric current, which would tend to be produced in a wire represented by the arms, would be from the right hand through the arm and body towards the left.* The moving wire may be applied where the needle cannot, to the *interior* of a magnet, e. g.; and though its sensibility does not approach to that of a magnetic needle, yet the facilities with which it is applied, and the diversity of its possible arrangements, render it as valuable as it is correct—a philosophical indication of the presence of magnetic force.

(1227) A piece of metal or conducting matter which moves across lines of magnetic force has, or tends to have, a current of Electricity produced in it. Thus: If N represent a magnetic pole, and over it a circuit be formed of metal of any shape, and which at first is in a position C; then if that circuit be moved in one direction into position 1, or in the contrary direction into positions 2, or 3, or 4, or 5; or if the first position C, be retained, the pole move to or towards the position n, then an electric current will be produced in the circuit having in every case the *same* direction, being that marked by the arrows.

Fig. 485.



Reverse motions give currents in the reverse direction.

No mere *rotation* of a bar magnet on its axis produces any inductive effect on *circuits exterior to it*; in fact, the system of power about the magnet must not be considered as revolving with the magnet any more than the rays of light which emanate from the sun are supposed to revolve with the sun. Therefore, if by a mechanical contrivance a conductor, such as a

Fig. 486.

loop of wire, be caused to rotate together with a bar magnet, no electric current will be produced by such rotation; but if the loop be kept stationary while the magnet revolves, a current is produced; and if the magnet be kept stationary while the loop revolves, a current will also be produced, but in a contrary direction; that is, the current produced by the *direct* revolution of the wire is the same as that produced by the *reverse* revolution of the magnet.

(1228) The magnetic forces are distributed in and round a bar-magnet in the simplest and most regular manner, so that any wire or line proceeding from a point in the magnetic equator of the bar so



as to pass through the magnetic axis to a point on the opposite side of the magnetic equator, must intersect *all* the lines in the plane through which it passes; and a wire proceeding from the end of the magnet, at the magnetic axis, to a point in the magnetic equator, must intersect curves equal to *half those of a great plane*, however small or great the length of the wire may be. But a wire from pole to pole passing close to the equator has no electric current induced in it when revolved round the magnet, because it intersects half of the external lines of force in a great plane *twice in opposite directions*.

A wire ring, somewhat larger than the magnet, held edgewise at one of the poles, and then turned 90° , and carried over the pole to the equator, intersects *once*, all, or nearly all, the lines of the magnet.

(1229) From the results of experiments, Faraday draws the following conclusions: "The *amount* of magnetic force as shown by its effect in evolving electric currents, is determinate for the same lines of force, whatever the distance of the point or plane at which their power is exerted, is from the magnet. Or, it is the same in any two or more sections of the same lines of force, whatever their form or the distance from the seat of the power may be.

"That there is no loss, or destruction, or evanescence, or latent state of the magnetic power by distance.

"That the convergence or divergence of the lines of force causes no difference in their amount.

"That when a wire is moving in a field of equal magnetic force, and with a uniform motion, the current of Electricity produced is proportionate to the *time* and to the *velocity* of the motion.

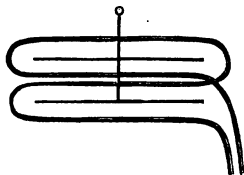
"That the quantity of Electricity thrown into a current is directly as the *amount of curves* intersected."

It also appeared from the experiments, that there exist lines of force *within* the magnet of the same *nature*, and of *equal amount* to those *without*; and every line of force, therefore, at whatever distance it may be taken from the magnet, must be considered as a closed circuit passing in some part of its course through the magnet, and having an equal amount of force in every part of its course.

(1230) In experimenting on the currents produced in wires when they cross lines of magnetic force, it was found expedient to employ a galvanometer, the coil of which was replaced by a single convolution of very stout wire, the fine long wire of the coil galvanometer offering too great obstruction to the passage of currents of such feeble intensity.

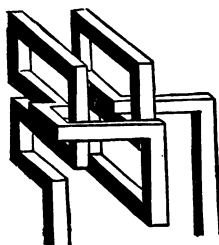
Fig. 487 represents the form of the instrument, the wire 0.2 of an inch in diameter, passing horizontally under the lower needle, then between that and the upper needle over the upper, and then again between that and the lower needle, afterwards attached to a stand, and continued for 19 or 20 feet outside of the glass cover.

Fig. 487.



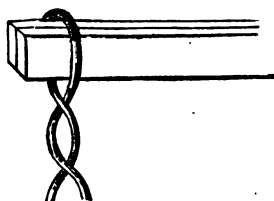
A more perfect apparatus is shown in Fig. 488, in which the conducting coil is cut out of plates of copper, so as to form a square band 0.2 of an inch in thickness, which passes twice round the vibration-plane of each needle, the length of metal round the needles being 24 inches. The metal must be scrupulously clean, and the metallic connexion perfect throughout; and when observations are about to be taken, the temperature should be uniform, galvanometers of this construction being remarkably sensible to thermo-electric currents. The wires forming the connexions should be of thick copper, and not longer than necessary.

Fig. 488.



(1231) These galvanometers proved far more sensible than the fine wire instruments; the mere passage of the ends of the wire soldered together, so as to form a loop *once* between the poles of a horseshoe magnet (Fig. 489), capable of supporting 40 lbs., being sufficient to cause a swing of the needle through 90° .

Fig. 489.



It was found necessary, however, in order to obtain uniform results, that the wire should be moved with the same velocity, for when it was passed rapidly, a deflection equal to 140° was sometimes obtained, whilst a very slow motion gave only 30° or 40° ; but by operating always with the same velocity, and taking the average of several observations, very trustworthy results were obtained.

As an illustration of the obstruction offered by thin wires to these magneto-electric currents, when 28 inches of copper wire, 0.045 of an inch in diameter, were interposed in the circuit, the swing of the needle was reduced from 140° to 40° , and when this wire was replaced by another, 19.6 inches long and 0.0135 of an inch in diameter, the deflection was reduced to 7° or 8° .

In all observations, the swing of the needle was observed and counted as the effect produced, the extent of which may be considered as dependent on the Electricity which passes at the moment through the coil.

(1232) Wires of *different thicknesses* of copper were bent into loops and soldered to the ends of two conducting rods, the other terminations of which dipped into the mercurial cups of the galvanometer. The loops were then passed, with uniform velocity, over one of the poles of a horseshoe magnet, capable of sustaining 21 lbs. The deflection of the needle increased with the thickness of the wire, though not in proportion to the *masses of the wires*, e. g.—

Copper wire, $\frac{1}{8}$ inch thick, deflected the needle,	16°00
Copper wire, $\frac{1}{4}$ " "	44°40
Copper wire, $\frac{1}{2}$ " "	57°37

(1233) The result of many experiments led to the conclusion: "That the current or amount of Electricity evolved in a wire moving amongst the lines of force, is not simply as the space occupied by its breadth, correspondent to the direction of the line of force, which has relation to the *polarity* of the power; nor by that width or diminution of it which includes the number or *amount* of the lines of force, and which, corresponding to the direction of the motion, has relation to the *equatorial* condition of the lines; but is jointly, as the compound ratio of the two, or as the mass of the moving wire. The power acts just as well on the interior portions of the wire as on the exterior or superficial portions, and a central particle, surrounded on all sides by copper, is put in the same relation to the force, as those which being superficial, have air next them on one side.

(1234) When wires of different metals are moved across the lines of force of a magnet, the currents induced in these different bodies are proportional to their electro-conducting power. In repeating these experiments with the thick wire galvanometer, and with loops of wires of the different metals of precisely the same diameter, viz., 0·04 of an inch, the following results were obtained:—

Copper wire deflected the galvanometer	. 63°0
Silver " "	. 61°9
Zinc " "	. 31°5
Tin " "	. 19°1
Iron " "	. 18°0
Platinum " "	. 16°9
Lead " "	. 12°1

(1235) In these experiments the difference in the results was thought to be mainly due to the difference in the *substance* of the loops, the conducting part of each system being very good and the same for each; but on varying the experiments in many ways the conclusion was arrived at: "That the current of Electricity excited in different substances, moving across the lines of magnetic force, appears to be *directly as the conducting power of the substances*, and has no reference to the magnetic character of the body; and the amount of *lines of force* appears to be equal for equal spaces occupied by the different metals, which agrees with the conclusion before arrived at, that, for air, water, bismuth, oxygen, nitrogen, or a vacuum, the lines of force are the same in amount, except that they are more or less concentrated in the substance across which they pass, according as it is more or less competent to conduct or transmit the magnetic force.

(1236) What then is the definition of the term *magnetic polarity*? As Faraday understands it, it means the opposite and *antithetical actions which are manifested at the opposite ends of a portion of a line of force*. But if this be so, is it correctly exhibited or indicated in every case by attractions and repulsions? A weak solution of proto-sulphate of iron, if surrounded by water, will in the magnetic field point *axially*, but if in a stronger solution than itself, it will point *equatorially* (1134); pointing, then, is an effect dependent on media and circumstances. But a wire moving across the magnetic field shows that the lines of force have in all cases the *same general polarity*; therefore, in investigations into the nature of the magnetic force, the indications of the moving wire are most valuable.

In a field of *equal force* a magnetic needle cannot show polarity, as the very fact of pointing implies the disturbance of the equality of arrangement of force; a moving wire, however, shows the full amount of magnetic power without in the least disturbing the disposition of the power.

(1237) At the conclusion of this paper Faraday again expresses his conviction that the idea of *lines of force* possesses advantages over the method of representing magnetic forces by *centres of action*. In a straight wire, for instance, carrying an electric current, it is apparently impossible to represent the magnetic forces by centres of action, whereas the lines of force simply and truly represent them. The moving wire or conductor again, he considers as a very valuable examiner of magnetic forces, as it does not sensibly disturb the forces in the magnetic field, where, however, it indicates the quantity of force independent of tension, and enables us to examine the

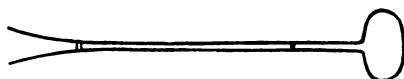
interior of magnets, and thus gain experimental evidence of a nature not otherwise attainable.

(1238) *The Employment of the Induced Magneto-electric Current as a Test and Measure of Magnetic Forces.*—The amount of current induced is precisely proportionate to the amount of lines of magnetic force intersected by the moving wire in which the electric current is generated and appears.

When a compound bar magnet, consisting of two plates, 12 inches

Fig. 490.

a 9 feet long.



b Wire 0.2 inches diameter.

long, 1 inch broad, and 0.5 thick, was introduced once into the loop (Fig. 490) and left there, the current produced at the galvanometer was constantly 16° . The

swing of the needle occupied 13 seconds; it was possible, therefore, to make three or four observations at the same time in this way: the magnet having been introduced into the loop, the electric current is broken by removing *a* or *b* from the mercury cup of the galvanometer, and then the magnet removed, which by this motion does nothing; the mercury contact is then restored and the magnet again introduced into the loop; by this mode of proceeding *two, three*, and even *four* impulses could be given to the needle, and it was found that the deflections were, as near as possible, as 1, 2, 3, and 4; thus using only *one* of the two magnetic bars:—

One introduction gave	8.00
Two	15.75
Three	23.87
Four	31.66

It appears, therefore, that for small arcs the number of degrees of *swing deflection* are nearly proportional to the magnetic force which has been brought into action on the moving wire.

(1239) *Revolving Rectangles and Rings.*—For experimenting with the magnetic forces of the *earth*, the form of moving wire employed was in the form of a rectangle or ring, which was caused to rotate, and the currents produced gathered up by a commutator, and sent on to the galvanometer to be measured. The lines of terrestrial magnetic force are inclined at an angle of 69° to the horizontal plane, but as only comparative results were required, the rotating instrument was always placed in the horizontal plane with the axis of rotation perpendicular to the plane of the magnetic meridian.

(1240) There is this difference between the magnet and the earth

in their action on the moving wire. If a loop be passed over a magnet it encloses *all the lines of force belonging to it*; therefore, *the greater the number of convolutions of that loop the greater the amount of Electricity induced.*

The contrary is the case with regard to the earth's magnetic force; here, *the lines of force intersected are as the areas of the moving rectangles.*

Twelve feet of wire in *one square*, intersects the lines of force passing through an area of 9 square feet (the areas enclosed being as the square of the periphery); but if the same length of wire be arranged in a triple circuit, about *a square of one foot area*, it will only intersect the lines due to that *area*. Large rectangles, are, therefore, advisable in experimenting on the earth's Magnetism.

(1241) Six revolutions of a rectangle of copper wire, 4 feet in length, enclosing, therefore, 1 square foot of area, gave an average swing deflection of $15^{\circ}66$, *nine* revolutions (from left to right) gave $23^{\circ}87$, *nine* reverse revolutions $23^{\circ}27$, *twelve* revolutions gave $31^{\circ}33$,—the means of each for *one* revolution are $2^{\circ}62$, $2^{\circ}61$, and $2^{\circ}61$,—results so much in accordance as to give great confidence in this method of investigating magnetic forces.

Variations in the arrangement of the rectangle, and in the length of the parts of the wires intersecting the lines of magnetic force, have no influence in altering the result, which being dependent alone on the number of lines of force intersected, is the same when the areas of the rectangles are the same.

(1242) When the wires of which the rectangles were made were of different thicknesses, there was a corresponding difference in the *swing*; thus,—

a rectangle of wire 0.05 inch in diameter gave a mean deflection of $2^{\circ}61$ per revolution.

a rectangle of wire 0.10 inch in diameter gave a mean deflection of $7^{\circ}33$ per revolution.

a rectangle of wire 0.20 inch in diameter gave a mean deflection of $8^{\circ}94$ per revolution.

When a delicate Ruhmkorff's galvanometer, the diameter of the wire of which was $\frac{1}{16}$ th of an inch, was employed, great obstruction to the current took place, only a *fiftieth* part of the current from a thick wire (0.1 inch in diameter) rectangle passing through the instrument; but when the rectangle was made up of *four convolutions* of copper wire (0.05 inch in diameter), the mass of wire being the same as before, but its length *four* times as great, *one-fourth* or *one-fifth* part of the current surmounted the obstructions

of the instrument, the current being with the thin wire *less in quantity, but far higher in intensity*, than with the thick.

(1243) A rectangle of wire, 0·2 of an inch in diameter, the square of which was 36 inches in the side, and enclosed, therefore, an area of *nine square feet*, caused in one revolution a swing deflection of upwards of $80^{\circ}44$. Now a rectangle of similar wire having an area of *one square foot* gave $8^{\circ}94$ per revolution which is very nearly $\frac{1}{10}$ th of $81^{\circ}44 - 21^{\circ}44 = 9^{\circ}04$ —the two numbers are so nearly alike that the experiment may be considered as proving the truth of the statement, “that the *magneto-electric current evolved is as the amount of lines of force intersected.*”

Faraday thinks it not unlikely that by improved arrangements, the moving wire may hereafter be applied with advantage to the investigation of the *earth's magnetic force in different latitudes and places*. The axis of rotation must be *perpendicular* to the lines of force, i. e. to the *dip*.

(1244) From a correct and close investigation of the disposition and characters of the magnetic force, the magnets should be of *hard steel and invariable*; when this is the case, Faraday found that the power of a magnetic bar, as indicated by the moving wire, is very little affected by bringing near to it, in favourable or unfavourable positions, other and far more powerful bars; and from his results he draws the following conclusions:—

1°. Lines of force of different magnets in favourable positions to each other *coalesce*.

2°. There is no increase of the total force of the lines by this coalescence.

3°. The analogy of a magnet with two or more voltaic batteries associated end to end in one circuit, is perfect. Probably some effect corresponding to *intensity* in the case of batteries, will be found to exist among magnets.

4°. The increase of power upon a magnetic needle, or piece of soft iron, placed between two opposite poles, is caused by the concentration upon it of the lines which were before diffused, and not by the *addition* of the power represented by the lines of force of one pole to that of the lines of force of the other. There is no more power represented by all the lines of force than before; and a line of force is not more powerful because it coalesces with a line of force of another magnet. In this respect the analogy with the voltaic pile is also perfect.

5°. Coalescence is not the addition of one line of force to another *in power*, but their union in one common circuit.

(1245) Faraday magnetized to saturation a very hard steel bar, 12

inches long, 1 inch broad, and 0.05 inch thick—its power as measured by the moving wire was $6^{\circ}9$. It was now broken into two pieces nearly in the middle; one-half had a power of $5^{\circ}94$, the other of $5^{\circ}89$. The two pieces placed side by side with poles together as a compound magnet, had a power of $11^{\circ}06$, not much below the sum of the powers of each half ascertained separately, and the loss on each half as compared with the original bar was not greater than was to be expected considering the saturated state of the original magnet.

This again is in perfect harmony with the voltaic battery, for it is well known that if a battery of 20 plates be separated into two of 10, or four batteries of 5 pairs, *each of the smaller batteries can supply as much dynamic Electricity* as the original battery, provided there be no obstruction to the passage of the current.

(1246) *Physical Character of the Lines of Magnetic Force.*—Having shown that the lines indicated in a general manner by the disposition of iron filings around or between magnets may be taken as exact representants of the magnetic power, both as to disposition and amount, Faraday enters into a speculation respecting the physical character of these lines, and the manner in which they may be supposed to be continued through space.

(1247) A pure case of action at a distance, and of the propagation of a line of force in a straight line is presented by *gravitation*. Here there is no dependence on a second or reacting body; a metal cylinder, for instance, gravitates to the earth with a weight exactly the same, whether left like a pendulum, freely to hang towards it, or whether it is drawn aside by other attractions; into the exercise of this power, *time* does not enter, and the line of gravitation is merely an ideal line, representing the direction in which the power is directed.

Turning to the phenomena of *radiation*, we find that the force is propagated by rays, which may be deflected and bent into curved lines, showing their physical existence; and though there is no dependence on a second or reacting body, yet the lines of force have a relation to time, light requiring eight minutes in passing from the sun to the earth.

The electric force may be regarded as intermediate between gravitation and radiation; the presence of two or more acting particles is required, but these particles must be in an *antithetical* condition in respect to each other; the power is *dual*, it acts in curved lines, and is affected by media having different specific inductive capacities.

(183.)

(1248) The grand question to be considered is—Have the lines of magnetic force a physical existence? In these lines nothing resembling the polarization of light and heat has been detected; they have no relation to *time*; their amount, unlike gravitation, is limited; but they may be changed in direction at pleasure, and they are essentially dual in their nature, the two opposite magnetic forces being mutually related; and as in static electrical induction one Electricity cannot exist without a relation to, equality with, or dependence on, the other, so in Magnetism an absolute charge of N. and S. polarity is also an impossibility. In a bar magnet the outer forces at the poles are related to each other by curved lines through space, and, although, by approaching a second magnet the disposition of those second lines may be changed, yet their sum remains unaltered. That the lines of force are closed curves, passing in one part of their course through the magnet, and in the other part through the space around it, is proved by the moving wire, and the fact is considered by Faraday as implying that such lines have a physical existence.

(1249) There is a perfect analogy between a magnet, an insulated voltaic battery, and an electric conductor polarized by induction, as far as regards the disposition of the *external* lines of force, but in neither the battery nor the conductor are the lines of force continued *internally*, as is the case with the magnet; consequently, on separating the conductor or battery in the middle, no charge appears there, nor any origin of new lines of inductive force, but the two divided portions remain in opposite states, or absolutely charged; in the magnet, on the other hand, there is on division a development of new external lines of force, and no absolute charge of northness or southness, because the lines of force are continuous through the body of the magnet.

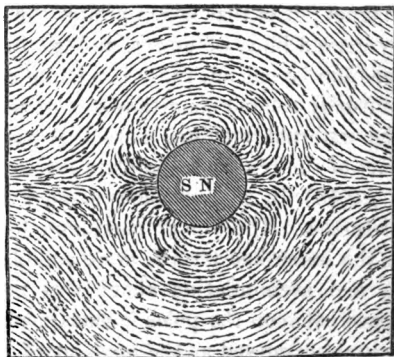
(1250) The analogy between the electric and magnetic forces is further sustained, by comparing together several of their well-known physical phenomena. It has been elsewhere stated (465), that Faraday views a line of electro-dynamic force as “an axis of power having contrary forces exactly equal in amount in contrary directions.” It is precisely the same with the line of magnetic force: thus an electric current (or an electric axis of power) has been shown, both by Ampère and Davy, to have a tendency to elongate itself; but a magnetic axis of power has a tendency to shorten itself; again, like electric currents attract each other (944), but like magnetic lines of force, exercise mutual repulsion. Now, these tendencies seem at first not analogies but contrasts, but they coincide; when it

is considered that the two axes of power are at right angles to each other, and viewed in this way, the probable *oneness* of condition of the electric and magnetic forms of power appears in abundant instances. Thus, unlike magnetic lines, when *end on*, as when similar poles are face to face, *repel*; unlike electric currents, when in the same relation, *repel* also; like electric forces, when *end on*, *coalesce*; like magnetic forces do the same; like electric currents, *end to end*, do not add to their sums; the quantity of Electricity circulating in a battery is not increased by adding to the number of the plates; and like magnetic lines of force, do not increase each other; lastly, like electric currents, side by side (a voltaic battery with large plates compared with one with small plates), add their quantities together, and like magnetic forces do the same.

(1251) When a wire is placed in the neighbourhood of a magnet and left at rest, it does not produce the least disturbance of the disposition of the magnetic forces; but when it is moved across the lines of force a current of Electricity is developed; this cannot be supposed to be a mere effect of motion; there must be a previous state of tension as regards the wire, which when motion is superadded, produces the dynamic state; but this gives a physical character to the lines of magnetic force, and shows a physical atmosphere of power around the magnet. Assuming, then, the physical existence of these lines, does the idea accord with the general phenomena of Magnetism? The general disposition of the lines is beautifully shown by iron filings round a bar magnet; but their form may be influenced by the form of the magnet, and by the condition and relation of the surrounding medium. As long as the magnet is alone, the lines must extend round it to infinite distances, but they may be condensed and compressed into a small local space, as shown in Fig. 491. The

Fig. 491.

relation of the lines to the surrounding space can be varied again by occupying a portion of the space with different substances. Thus, when a piece of iron is brought into the magnetic field, there is a concentration of lines of force on to it, and more power is transmitted through the space thus occupied than if it were not there. This is shown



in Fig. 492; but there is neither an addition to, nor a diminution of

Fig. 492.

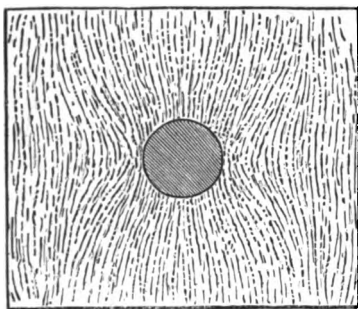
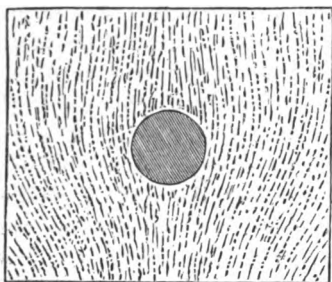


Fig. 493.



the total amount of power; there is only a new distribution of it, some passing where it did not pass before, being removed from places where it was previously transmitted. The effects of other paramagnetic bodies are proportionate to their conducting power. Diamagnetic bodies, on the other hand, expand the extent of action, as illustrated in Fig. 493; so a magnetic needle would appear to increase in intensity; from this it would appear that the indications of a needle are not always the same, the force it shows diminishing as the magnetic medium with which it is surrounded, increases in conducting power.

(1252) The magnet with its surrounding sphyndyloid of power is analogous in its condition to a

voltaic battery immersed in water, or to a gymnotus or torpedo, when these fish, at their own will, fill the surrounding fluid with lines of electric force. The direction of these lines may be traced in the water round the battery by a magnetic needle, or by the galvanometer; there is, probably, just such a medium, magnetically speaking, round a magnet in free space. This medium, when deprived of all material substance, may be the *æther*, but it is essential to the magnet; it is that which relates the external polarities to each other by curved lines of power, and as in the battery, if the conducting medium be cut off, there is no line of force, so without this external mutually related condition of the poles, a magnet could not exist: the external medium is as essential as the magnet itself, being a part of the true and complete magnetic system.

(1253) In a horseshoe magnet the lines of force are greatly distorted. The line of maximum force, from pole to pole, grows up as the horseshoe form is more completely given, the power gathering in and accumulating about this line, because the bad conducting space between the poles is shortened. A bent voltaic battery, or a gymnotus curved at the moment of its action, present like results.

(1254) The action of the keeper in reducing the power of the magnet

in the space around is evident: a good conductor is substituted for a bad, and, hence, more power is transmitted through it and less through space. Again, when a magnet is charged to saturation with the keeper on, it falls in power when the keeper is removed, because the keeper while on, in consequence of its excellent conducting power, enables the magnet to take up and sustain a higher condition of charge, which faculty it loses when the keeper is removed. The same explanation applies to the well-known fact, that a magnet will receive a much higher charge when a piece of iron is in contact with its poles than when it is surrounded with the lower paramagnetic air. It also shows why the armature of the loadstone is useful. A magnet when charged to supersaturation loses its power when left alone; but if the feeble magneto-conducting air be replaced by a body of good conducting power, as when the magnet is surrounded by iron, it retains its power.

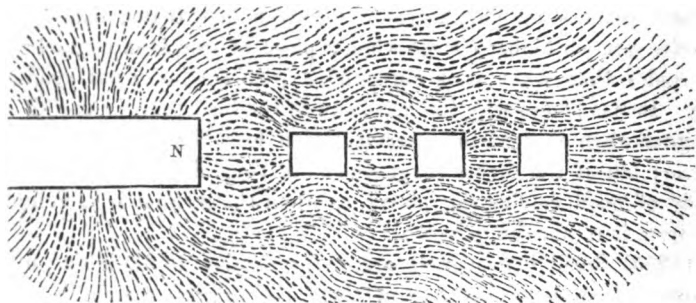
(1255) Small bar-magnets are, in proportion to their size, much stronger than large, because in them the excited system is better sustained by the imperfectly magneto-conducting surrounding medium; and when a magnet is too thick in proportion to its length, there is a reduction of power, because as the thickness increases, more *internal* exciting force has to be sustained, while the surrounding space being scarcely altered is but little improved in conducting power; on the other hand, by increasing the length of the magnet without at the same time giving it a corresponding increase in thickness, there is a diminution of power, because, now while the exciting force within remains the same, the external lines which act as a resisting medium are increased in length. A bar of steel, 1 inch long, and $\frac{1}{8}$ ths of an inch in diameter, will not, when magnetized to supersaturation, retain twenty-five times the power of a bar of similar steel *one* inch long, and $\frac{1}{8}$ th of an inch in diameter, although it contains twenty-five times as much steel; but a third bar *two* inches long, and $\frac{1}{8}$ ths of an inch in diameter will retain much more power, because the *external* medium by which the power is supported is increased. Every part of the surface of a magnet is, so to say, pouring forth external lines of magnetic force, as is shown by iron filings (Fig. 278), and the larger the magnet to a certain extent, and the larger the amount of external conducting medium in contact with it, the more freely is this transmission made.

(1256) The relation between the length of a magnet, and its thickness is thus understood; the two must bear such a proportion to each other, that the physical lines of magnetic power excited by the bar shall be exactly sustained by the external medium from pole to pole. If the bar be too short, the lines of magnetic power are more

numerous than those which the space about it can convey ; but the advantageous increase in length is, at the same time, limited by the increasing resistance within, especially at the equator of the bar.

(1257) The lines of force proceeding from a magnetic bar may be deflected and distorted by varying the *medium* surrounding the magnet ; an instructive case is presented in Fig. 494, where several

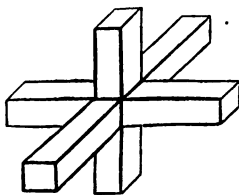
Fig. 494.



cubes of soft iron are placed in a line at short distances from each other, before the N. extremity of a powerful magnetic bar. The undulations of the lines are beautifully shown by iron filings ; nevertheless, the total force is shown by the moving wire to be unaffected in amount, and a section across the same lines of force, in any part of their deflected course, yields the same amount of effect ; so, also, in all those beautiful variations, which are observed in the forms taken by iron filings when magnets are placed in different positions relatively to each other, the power is definite in amount, being only removed from one place to another ; all of which is in perfect harmony with the idea of a physical line of magnetic force.

(1258) *Places of no Magnetic Action.*—The following instructive experiments are described by Faraday (*Phil. Mag., Feb. 1856*). Six soft iron bars were each surrounded with a coil of 32 convolutions of copper wire 0·05 of an inch in diameter ; the coils were wound principally round the middles of the bars, so that they could be shifted at pleasure towards either end ; they were then arranged as in Fig. 495, so that, when excited, their like poles were together in

Fig. 495.



such a manner as to include a cubical space or chamber, to which access could be obtained either by removing a portion of the solid angles of the ends, or by drawing one of the electro-magnets a little way from the others. A small magnetic needle hung in the middle of this space, gave no indications of any magnetic power, and a crystal of bismuth

was entirely indifferent there. A piece of soft iron hung on a jointed copper wire within the chamber showed no signs of magnetic power. Iron filings, sprinkled on a card and introduced across the chamber, were not affected at the middle part, but only near the partly open angles. A ring helix of many convolutions, having its terminations passing out at opposite corners, was connected with a very sensitive galvanometer and rotated; it showed no trace of inductive action. Many other attempts were made, but the results were altogether negative.

Thus, then, the chamber, though surrounded by a high intensity of magnetic power, was perfectly destitute of magnetic properties, and quite free from magnetic influence. It is the perfect analogue of the space presented within a deep metallic vessel or globe, when charged with Electricity; and as, in this case, there is no Electricity within, because that necessary connexion and dependence of the electric *duals* which is essential to their nature cannot be; so in the case of the magnets there is no appearance of magnetic force in the cubical chamber, because the duals are not both there at once, and one cannot be present without the other.

(1259) Again, let a hole be drilled in the end of an iron rod, about an inch in depth, and the same in diameter; and let the rod, which may be 9 or 10 inches long, and $1\frac{1}{4}$ inch in diameter, be placed in a helix of copper wire, associated with a powerful battery; a small piece of iron, say 0.3 of an inch in length and thickness, if brought near the outer edge of the excited magnetic pole, will be very powerfully attracted, but at the bottom of the hole it will be quite indifferent, neither will any attraction against the side of the hole be manifested until it approaches the mouth. If iron filings be introduced into the hole on a pasteboard tray, only those near the outer edge will bristle out, those inside will be quite unaffected, and on inverting the rod they will all fall out; but as they pass, the outer edge will be caught away, and fringe the external angle. But if an iron wire, long enough to extend from the bottom, outside and beyond the end of the rod be introduced, it will be powerfully attracted, even though it does not touch the iron anywhere but at the bottom of the hole. A piece of gun-barrel may be used in these experiments.

(1260) Similar phenomena may be observed by placing 4 bar magnets with their similar poles together, so as to form a flat square chamber, as shown in Fig. 496, or with their edges upwards, so as to form a vertical chamber, as in Fig. 497. Iron filings may be sprinkled on a pasteboard tray, and examined in the chamber of Fig. 496, and a small magnetic needle may be introduced into the

Fig. 496.

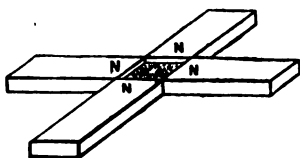
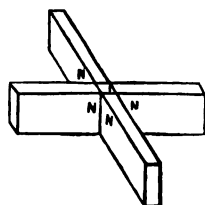


Fig. 497.



vertical chamber of Fig. 497. The direction of the lines of force in the medium plane is beautifully shown by the filings, and the magnetic needle shows that about the middle of the vertical chamber scarcely a trace of power remains.

The necessity of the complete and equivalent dual relation of the magnetic force, and the gradual diminution and final loss of power when this is diminished or interfered with, is the great point to be observed in these experiments.

(1261) We give in conclusion a statement of what Faraday supposes to be the condition of a magnet; a view which, however, he puts forth with his usual reservation, and which does not pretend to explain the state of the source of magnetic power, or of the coercitivity by which that state is either resisted in its attainment, or sustained in its permanent condition. "Contemplating," he says (*Phil. Mag.*, Feb. 1855), "a bar magnet by itself, I see in it a source of dual power. I believe its dualities are especially related to each other, and cannot exist but by that relation. I think that though related through the magnet by sustaining power, they are not so related by discharging or inducing power, or power equal in amount to the coercitive or sustaining power. The relation externally appears to me to be through the space around the magnet; in which space a sphondyloid of power is present, consisting of closed curves of magnetic force. That the space is not magnetically dark appears to me by this, that when bodies occupy that space, having like relation by known phenomena to the power as the space has, as copper, mercury, &c., they produce magneto-electric currents when moved. When bodies (media) occupy the space around the magnet, they modify its capability of transmitting and relating the dual force of the magnet, and as they increase or diminish that capability are paramagnetic or diamagnetic in their nature, giving rise to the phenomena which come under the term of magnetic conduction. The same magnet can hold different charges as the medium connecting its poles varies; and so one fully charged with a good medium (such as iron) between its poles, falls in power when the iron

is replaced by air, or by space, or by bismuth. Corresponding effects occur with longer or shorter magnets, or with magnets made thick by adding many sideways together. The medium about a magnet may be mixed in its nature, and then more dual power is disposed of through the better conductor than the worse, but the whole amount of power remains unchanged. The powers and utility of the media and of space itself fail if the dual force or polar action be interrupted. The magnet could not exist without a surrounding medium or space, and would be extinguished if deprived of it, and *is* extinguished if the space be occupied adversely by the dual power of a dominant magnet of sufficient force. The polarity of each line of force is in the same direction throughout the whole of its closed course. Pointing in one direction or another, is a differential action, due to the convergence or divergence of the lines of force upon the substance acted on, according as it is a better or worse conductor of the magnetic force."

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ERRATA.

- Page 31,—7 lines from top, for "or" read "as."
 „ 53,—22 lines from top, for "change" read "charge."
 „ 81,—7 lines from top, for "small stars" read "a small star."
 „ 84,—5 and 6 lines from top, for "change" read "charge."
 „ 193,—4 lines from top, delete full stop after "induction" and let the sentence run on.
 „ 206,—18 lines from top, for "Chalmers" read "Chambers."
 „ 208,—8 lines from top, for "laying" read "lying."
 „ 219,—2 lines from bottom, for "invested" read "inverted."
 „ 239,—22 lines from bottom, for "eclectric" read "electric."
 „ 240,—11 lines from bottom, after "W" insert "than."
 „ 243,—14 lines from top, transpose the words "the" and "his."
 „ 251,—15 lines from bottom, for "caps" read "cups."
 „ 253,—15 lines from top, for "with" read "pith."
 „ 264,—17 lines from bottom, for "enlose" read "enclose."
 „ 269,—17 lines from bottom, for "to" read "with."
 „ 294,—14 lines from bottom, insert "of" before "gold leaf."
 „ 302,—12 lines from bottom, for "action" read "section."
 „ 302,—12 lines from top, for "this" read "the."
 „ 313,—11 lines from top, for "with" read "to."
 „ 400,—19 lines from top, for "sulphuret" read "sulphur."
 „ 420,—last line, for "Electro-phopiologiques" read "Electro-physiologiques."
 „ 534,—18 lines from top, for "9-36" read "1-36."
 „ 552,—20 lines from top, after "been" insert "that."
 „ 574,—5 lines from top, after "and" insert "the best."
 „ 744,—8 lines from bottom, for "conductor" read "condenser."
 „ 770,—2 lines from top, for "filled" read "fitted."
 „ 774,—8 lines from bottom, for "zinc" read "sine."

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