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Lecture LV. On magnetism.

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LECTURE LV.

ON MAGNETISM.

THE theory of magnetism bears a very strong resemblance to that of electricity, and it must therefore be placed near it in a system of natural philosophy. We have seen the electric fluid not only exerting attractions and repulsions, and causing a peculiar distribution of neighbouring portions of a fluid similar to itself, but also excited in one body, and transferred to another, in such a manner as to be perceptible to the senses, or at least to cause sensible effects, in its passage. The attraction and repulsion, and the peculiar distribution of the neighbouring fluid, are found in the phenomena of magnetism; but we do not perceive that there is ever any actual excitation, or any perceptible transfer of the magnetic fluid from one body to another distinct body; and it has also this striking peculiarity, that metallic iron is very nearly, if not absolutely, the only substance capable of exhibiting any indications of its presence or activity.

For explaining the phenomena of magnetism, we suppose the particles of a peculiar fluid to repel each other, and to attract the particles of metallic iron with equal forces, diminishing as the square of the distance increases; and the particles of such iron must also be imagined to repel each other, in a similar manner. Iron and steel, when soft, are conductors of the magnetic fluid, and become less and less pervious to it as their hardness increases. The ground work of this theory is due to Mr. Aepinus, but the forces have been more particularly investigated by Coulomb and others. There are the same objections to these hypotheses as to those which constitute the theory of electricity, if considered as original and fundamental properties of matter: and it is additionally difficult to imagine, why iron, and iron only, whether apparently magnetic or not, should repel similar particles of iron with a peculiar force, which happens to be precisely a balance to the attraction of the magnetic fluid for iron. This is obviously improbable; but the hypotheses are still of great utility in assisting us to generalise, and to retain in memory, a number of particular facts which would otherwise be insulated. The doctrine of the circulation of streams of the magnetic fluid has been justly and universally abandoned, and some other theories, much more ingenious and more probable, for instance that of Mr. Prévost, appear to be too complicated, and too little supported by facts, to require much of our attention.

The distinction between conductors and nonconductors is, with respect to the electric fluid, irregular and intricate: but in magnetism, the softness or hardness of the iron or steel constitutes the only difference. Heat, as softening iron, must consequently render it a conductor; even the heat of boiling water affects it in a certain degree, although it can scarcely be supposed to alter its temper; but the effect of a moderate heat is not so considerable in magnetism as in electricity. A strong degree of heat appears, from the experiments of Gilbert, and of Mr. Cavallo, to destroy completely all magnetic action.

It is perfectly certain that magnetic effects are produced by quantities of iron incapable of being detected either by their weight or by any chemical tests. Mr. Cavallo found that a few particles of steel, adhering to a hone, on which the point of a needle was slightly rubbed, imparted to it magnetic properties; and Mr. Coulomb has observed that there are scarcely any bodies in nature which do not exhibit some marks of being subjected to the influence of magnetism, although its force is always proportional to the quantity of iron which they contain, as far as that quantity can be ascertained; a single grain being sufficient to make 20 pounds of another metal sensibly magnetic. A combination with a large proportion of oxygen deprives iron of the whole or the greater part of its magnetic properties; finery cinder is still considerably magnetic, but the more perfect oxids and the salts of iron only in a slight degree; it is also said that antimony renders iron incapable of being attracted by the magnet. Nickel, when freed from arsenic and from cobalt, is decidedly magnetic, and the more so as it contains less iron. Some of the older chemists supposed nickel to be a compound metal containing iron, and we may still venture to assume this opinion as a magnetical hypothesis. There is indeed no way of demonstrating that it is impossible for two substances to be so united as to be incapable of separation by the art of the chemist; had nickel been as dense as platina, or as light as cork, we could not have supposed that it contained any considerable quantity of iron, but in fact the specific gravity of these metals is very nearly the same, and nickel is never found in nature but in the neighbourhood of iron ; we may therefore suspect, with some reason, that the hypothesis of the existence of iron in nickel may be even chemically true. The aurora borealis is certainly in some measure a magnetical phenomenon, and if iron were the only substance capaple of exhibiting magnetic effects, it would follow that some ferruginous particles must exist in the upper regions of the atmosphere. The light usually attending this magnetical meteor may possibly be derived from electricity, which may be the immediate cause of a change of the distribution of the magnetic fluid, contained in the ferruginous vapours, that are imagined to float in the air.

We are still less capable of distinguishing with certainty in magnetism, than in electricity, a positive from a negative state, or a real redundancy of the fluid from a deficiency. The north pole of a magnet may be considered as the part in which the magnetic fluid is either redundant or deficient, provided that the south pole be understood in a contrary sense: thus, if the north pole of a magnet be supposed to be positively charged, the south pole must be imagined to be negative; and in hard iron or steel these poles may be considered as unchangeable.

A north pole, therefore, always repels a north pole, and attracts a south pole. And in a neutral piece of soft iron, near to the north pole of a magnet, the fluid becomes so distributed by induction, as to form a temporary south pole next to the magnet, and the whole piece is of course attracted, from the greater proximity of the attracting pole. If the bar is sufficiently soft, and not too long, the remoter end becomes a north pole, and the whole bar a perfect temporary magnet. But when the bar is of hard steel, the state of induction is imperfect, from the resistance opposed to the motion of the fluid; hence the attraction is less powerful, and an opposite pole is formed, at a certain distance, within the bar; and beyond this another pole, similar to the first; the alternation being sometimes repeated more than once. The distribution of the fluid within the magnet is also affected by the neighbourhood of a piece of soft iron, the north pole becoming more powerful by the vicinity of the new south pole, and the south pole being consequently strengthened in a certain degree; so that the attractive power of the whole magnet is increased by the proximity of the iron. A weak magnet is capable of receiving a temporary induction of a contrary magnetism from the action of a more powerful one, its north pole becoming a south pole on the approach of a stronger north pole; but the original south pole still retains its situation at the opposite end, and restores the magnet nearly to its original condition, after the removal of the disturbing cause.

The polarity of magnets, or their disposition to assume a certain direction, is of still greater importance than their attractive power. If a small magnet, or simply a soft wire, be poised on a centre, it will arrange itself in such a direction, as will produce an equilibrium of the attractions and repulsions of the poles of a larger magnet; being a tangent to a certain oval figure, passing through those poles, of which the properties have been calculated by various mathematicians. This polarity may easily be imitated by electricity; a suspended wire being brought near to the ends of a positive and negative conductor, which are placed parallel to each other, as in Nairne's electrical machine, its position is perfectly similar to that of a needle attracted by a magnet, of which those conductors represent the poles. (Plate XLI. Fig. 569.)

The same effect is observable in iron filings placed near a magnet, and they adhere to each other in curved lines, by virtue of their induced magnetism, the north pole of each particle being attached to the south pole of the particle next it. This arrangement may be seen by placing the filings either on clean mercury, or on any surface that can be agitated; and it may be imitated by strewing powder on a plate of glass, supported by two balls, which are contrarily electrified. (Plate XLI. Fig. 570.)

The polarity of a needle may often be observed when it exhibits no sensible attraction or repulsion as a whole; and this may easily be understood by considering that when one end of a needle is repelled from a given point, and the other is attracted towards it, the two forces, if equal, will tend to turn it round its centre, but will wholly destroy each other's effects with respect to any progressive motion of the whole needle. Thus, when the end of a magnet is placed under a surface on which iron filings are spread, and the surface is shaken, so as to leave the particles for a moment in the air, they are not drawn sensibly towards the magnet, but their ends, which are nearest to the point over the magnet, are turned a little downwards, so that they strike the paper further and further from the magnet, and then fall outwards, as if they were repelled by it. (Plate XLI. Fig. 571.)

The magnets, which we have hitherto considered, are such as have a simple and well determined form; but the great compound magnet, which directs the mariner's compass, and which appears to consist principally of the metallic and slightly oxidated iron, contained in the internal parts of the earth, is probably of a far more intricate structure, and we can only judge of its nature from the various phenomena derived from its influence.

The accumulation and the deficiency of the magnetic fluid, which determine the place of the poles of this magnet, are probably in fact considerably diffused, but they may generally be imagined, without much error in the result, to centre in two points, one of them nearer to the north pole of the earth, the other to the south pole. In consequence of their attractions and repulsions, a needle, whether previously magnetic or not, assumes always, if freely poised, the direction necessary for its equilibrium; which, in various parts of the globe, is variously inclined to the meridian and to the horizon. Hence arises the use of the compass in navigation and in surveying: a needle, which is poised with a liberty of horizontal motion, assuming the direction of the magnetic meridian, which for a certain time remains almost invariable for the same place; and a similar property is also observable in the dipping needle, which is moveable only in a vertical plane; for when this plane is placed in the magnetic meridian, the needle acquires an inclination to the horizon, which varies according to the situation of the place with respect to the magnetic poles. (Plate XLI. Fig. 572, 573.)

The natural polarity of the needle may be in some measure illustrated by inclosing an artificial magnet in a globe; the direction of a small needle, suspended over any part of its surface, being determined by the position of the poles of the magnet, in the same manner as the direction of the compass is determined by the magnetical poles of the earth, although with much more regularity. In either case the whole needle is scarcely more or less attracted towards the globe than if the influence of magnetism were removed; except when the small needle is placed very near to one of the poles of the artificial magnet, or, on the other hand, when the dipping needle is employed in the neighbourhood of some strata of ferruginous substances, which, in particular parts of the earth, interfere materially with the more general effects, and alter the direction of the magnetic meridian.

A bar of soft iron, placed in the situation of the dipping needle, acquires from the earth, by induction, a temporary state of magnetism, which may be reversed at pleasure by reversing its direction; but bars of iron, which have remained long in or near this direction, assume a permanent polarity; for iron, even when it has been at first quite soft, becomes in time a little harder. A natural magnet is no more than a heavy iron ore, which, in the course of ages, has acquired a strong polarity from the great primitive magnet. It must have lain in some degree detached, and must possess but little conducting power, in order to have received and to retain its magnetism.

We cannot, from any assumed situation of two or more magnetic poles, calculate the true position of the needle for all places; and even in the same place, its direction is observed to change in the course of years, according to a law which has never yet been generally determined, although the variation which has been observed, at any one place, since the discovery of the compass, may perhaps be comprehended in some very intricate expressions; but the less dependence can be placed on any calculations of this kind, as there is reason to think that the change depends rather on chemical than on physical causes. Dr. Halley indeed conjectured that the earth contained a nucleus, or separate sphere, revolving freely within it, or rather floating in a fluid contained in the intermediate space, and causing the variation of the magnetic meridian; and others have attributed the effect to the motions of the celestial bodies: but in either case the changes produced would have been much more regular and universal than those which have been actually observed. Temporary changes of the terrestrial magnetism have certainly been sometimes occasioned by other causes; such causes are, therefore, most likely to be concerned in the more permanent effects. Thus, the eruption of Mount Hecla was found to derange the position of the needle considerably; the aurora borealis has been observed to cause its north pole to move

6 or 7 degrees to the westward of its usual position; and a still more remarkable change occurs continually in the diurnal variation. In these climates the north pole of the needle moves slowly westwards from about 8 in the morning till 2, and in the evening returns again; a change which has with great probability been attributed to the temporary elevation of the temperature of the earth, eastwards of the place of observation, where the sun's action takes place at an earlier hour in the morning, and to the diminution of the magnetic attraction in consequence of the heat thus communicated. In winter this variation amounts to about 7 minutes, in summer to 13 or 14.

Important as the use of the compass is at present to navigation, it would be still more valuable if its declination from the true meridian were constant for the same place, or even if it varied according to any discoverable law; since it would afford a ready mode of determining the longitude of a place by a comparison of an astronomical observation of its latitude with another of the magnitude of the declination. And in some cases it may even now be applied to this purpose, where we have a collection of late and numerous observations. Such observations have from time to time been arranged in charts, furnished with lines indicating the magnitude of the declination or variation at the places through which they pass, beginning from the line of no variation, and proceeding on the opposite sides of this line to show the magnitude of the variation east or west. It is obvious that the intersection of a given parallel of latitude, with the line showing the magnitude of the variation, will indicate the precise situation of the place at which the observations have been made.

The line of no variation passed in 1657 through London, and in 1666 through Paris: its northern extremity appears to have moved continually eastwards, and its southern parts westwards; and it now passes through the middle of Asia. The opposite portion seems to have moved more uniformly westwards; it now runs from North America to the middle of the South Atlantic. On the European side of these lines, the declination is westerly; on the South American side, it is easterly. The variation in London has been for several years a little more than 24°. In the West Indies it changes but slowly; for instance it was 5° near the island of Barbadoes, from 1700 to 1756. (Plate XLI. Fig. 574 . . 576. Plate XLII. XLIII.)

The dip of the north pole of the needle in the neighbourhood of London is 72°. Hence the lower end of a bar standing upright, as a poker, or a lamp iron, becomes always a north pole, and the temporary south pole of a piece of soft iron being uppermost, it is somewhat more strongly attracted by the north pole of a magnet placed over it, than by its south pole; the distribution of the fluid in the magnet itself being also a little more favourable to the attraction, while its north pole is downwards. It is obvious that the magnetism of the northern magnetic pole of the earth must resemble that of the south pole of a magnet, since it attracts the north pole; so that if we considered the nature of the distribution of the fluid, rather than its situation in the earth, we should call it a south pole. Although it is impossible to find any places for two, or even for a greater number of magnetic poles, which will correctly explain the direction of the needle in every part of the earth's surface, yet the dip may be determined with tolerable accuracy, from the supposition of a small magnet placed at the centre of the earth, and directed towards a point in Baffin's Bay, about 75° north latitude, and 70° longitude west of London; and the variation of the dip is so inconsiderable, that a very slow change of the position of this supposed magnet would probably be sufficient to produce it; but the operation of such a magnet, according to the general laws of the forces concerned, could not possibly account for the very irregular disposition of the curves indicating the degree of variation or declination; a general idea of these might perhaps be obtained from the supposition of two magnetic poles situated in a line considerably distant from the centre of the earth; but this hypothesis is by no means sufficiently accurate to allow us to place any dependence on it. (Plate XLI. Fig. 577, 578.)

The art of making magnets consists in a proper application of the attractions and repulsions of the magnetic fluid, by means of the different conducting powers of different kinds of iron and steel, to the production and preservation of such a distribution of the fluid in a magnet, as is the best fitted to the exhibition of its peculiar properties.

We may begin with any bar of iron that has long stood in a vertical position; but it is more common to employ an artificial magnet of greater strength. When one pole of such a magnet touches the end of a bar of hard iron or steel; that end assumes in some degree the opposite character, and the opposite end the same character: but in drawing the pole along the bar, the first end becomes neutral, and afterwards has the opposite polarity; while the second end has its force at first a little increased, then becomes neutral, and afterwards is opposite to what it first was. When the operation is repeated, the effect is at first in some measure destroyed, and it is difficult to understand why the repetition adds materially to the inequality of the distribution of the fluid; but the fact is certain, and the strength of the new magnet is for some time increased at each stroke, until it has acquired all that it is capable of receiving. Several magnets, made in this manner, may be placed side by side, and each of them being nearly equal in strength to the first, the whole collection will produce together a much stronger effect; and in this manner we may obtain from a weak magnet others continually stronger, until we arrive at the greatest degree of polarity of which the metal is capable. It is, however, more usual to employ the process called the double touch: placing two magnets, with their opposite poles near to each other, or the opposite poles of a single magnet, bent into the form of a horseshoe, in contact with the middle of the bar: the opposite actions of these two poles then conspire in their effort to displace the magnetic fluid, and the magnets having been drawn backwards and forwards repeatedly, an equal number of times to and from each end of the bar, with a considerable pressure, they are at last withdrawn in the middle, in order to keep the poles at equal distances.

Iron filings, or the scoriae from a smith's forge, when finely levigated, and formed into a paste with linseed oil, are also capable of being made collectively magnetic. A bar of steel, placed red hot between two magnets, and suddenly quenched by cold water, becomes in some degree magnetic, but not so powerfully as it may be rendered by other means. For preserving magnets, it is usual to place their poles in contact with the opposite poles of other magnets, or with pieces of soft iron, which, in consequence of their own induced magnetism, tend to favour the accumulation of the magnetic power in a greater quantity than the metal can retain after they are removed. Hence the ancients imagined that the magnet fed on iron.

A single magnet may be made of two bars of steel, with their ends pressed into close contact; and it might be expected that when these bars are separated, or when a common magnet has been divided in the middle, the portions should possess the properties of the respective poles only. But in fact the ends which have been in contact are found to acquire the properties of the poles opposite to those of their respective pieces, and a certain point in each piece is neutral, which is at first nearer to the newly formed pole than to the other end, but is removed by degrees to a more central situation. In this case we must suppose, contrarily to the general principles of the theory, that the magnetic fluid has actually escaped by degrees from one of the pieces, and has been received from the atmosphere by the other.

There is no reason to imagine any immediate connexion between magnetism and electricity, except that electricity affects the conducting powers of iron or steel for magnetism, in the same manner as heat or agitation. In some cases a blow, an increase of temperature, or a shock of electricity, may expedite a little the acquisition of polarity; but more commonly any one of these causes impairs the magnetic power. Professor Robison found, that when a good magnet was struck for three quarters of an hour, and allowed in the mean time to ring, its efficacy was destroyed; although the same operation had little effect when the ringing was impeded; so that the continued exertion of the cohesive and repulsive powers appears to favour the transmission of the magnetic as well as of the electric fluid. The internal agitation, produced in bending a magnetic wire round a cylinder, also destroys its polarity, and the operation of a file has the same effect. Mr. Cavallo has found that brass becomes in general much more capable of being attracted when it has been hammered, even between two flints; and that this property is again diminished by fire: in this case it may be conjectured that hammering increases the conducting power of the iron contained in the brass, and thus renders it more susceptible of magnetic action. Mr. Cavallo also observed that a magnetic needle was more powerfully attracted by iron filings during their solution in acids, especially in the sulfuric acid, than either before or after the operation: others have not always succeeded in the experiment; but there is nothing improbable in the circumstance, and there may have been some actual difference in the results, dependent on causes too minute for observation. In subjects so little understood as the theory of magnetism, we are obliged to admit some paradoxical propositions, which are only surprising on account of the imperfect state of our knowledge. Yet, little as we can understand the intimate nature of magnetical actions, they exhibit to us a number of extremely amusing as well as interesting phenomena; and the principles of crystallization, and even of vital growth and reproduction, are no where so closely imitated, as in the arrangement of the small particles of iron in the neighbourhood of a magnet, and in the production of a multitude of complete magnets, from the influence of a parent of the same kind.