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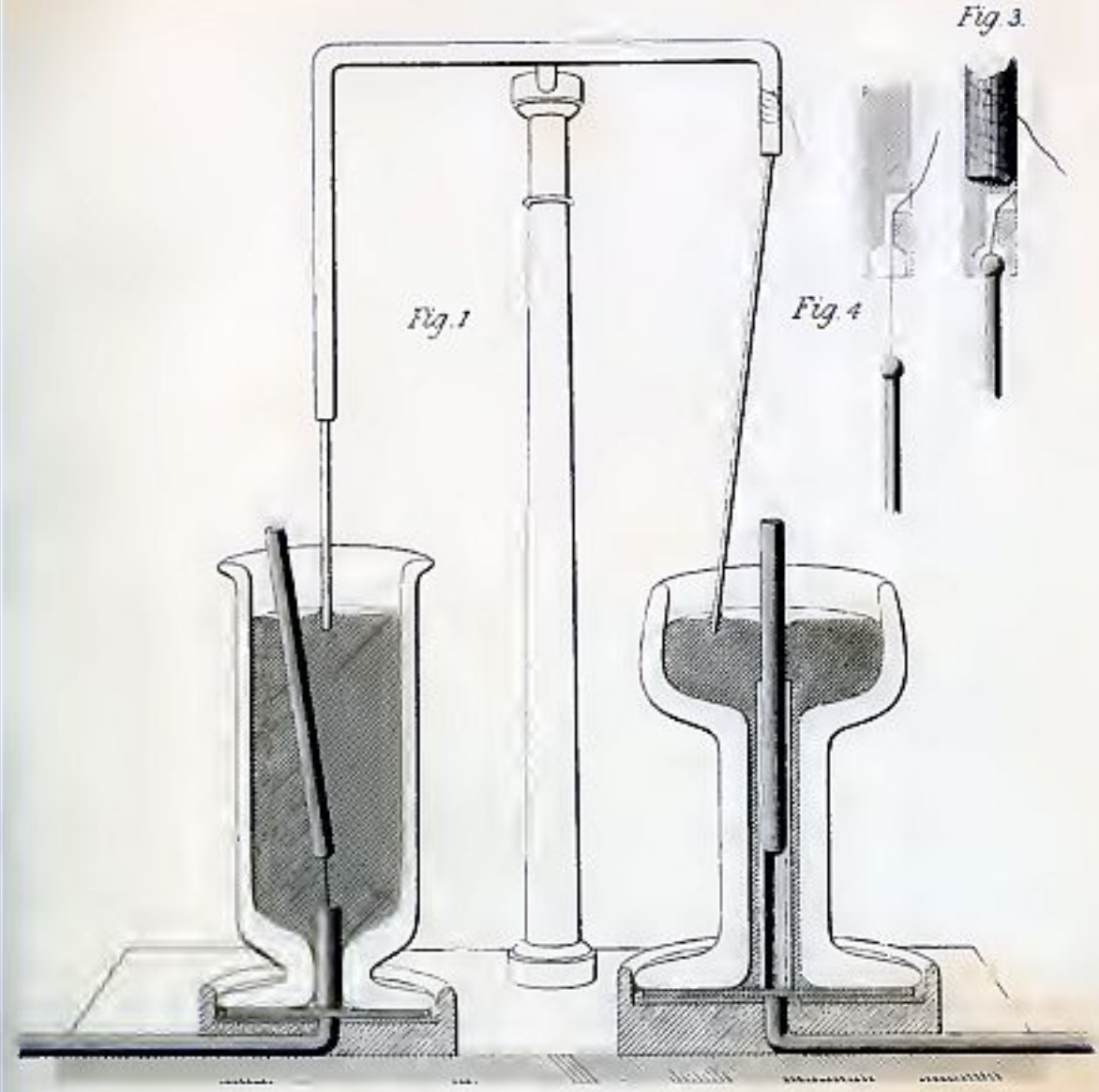
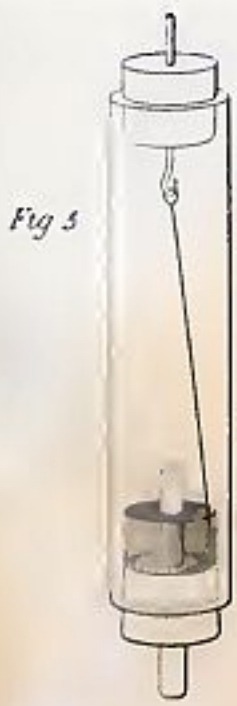
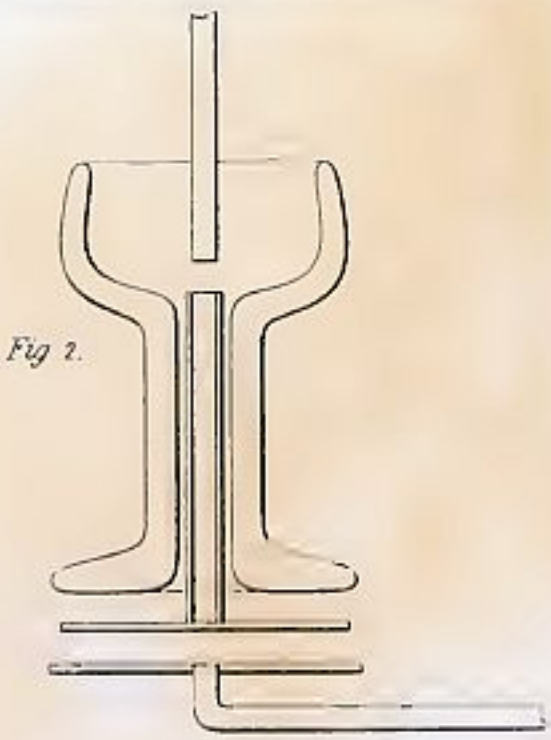
Royal Institution of Great Britain
First electrical motor







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the product from sulphuric ether, it is less volatile, and more energetic in its action upon oxygenated bodies than ether. Owing to its easy decomposition, its point of volatilization, and ignorance of its peculiar affinities, it has not yet been separated from its concomitants, and exhibited in a distinct form.

In the products from nitric ether, this compound proves to be a triple combination of carbon, hydrogen, and azote, hitherto unknown. Its effects upon metallic oxides appear to be quite analogous to those of the compound produced from sulphuric ether, but it is easily separable from the other products. It forms a fulminating combination with platinum.

Art. IX.—*On some new Electro-Magnetical Motions, and on the Theory of Magnetism.* *By* M. Faraday, *Chemical Assistant in the Royal Institution.*

In making an experiment the beginning of last week, to ascertain the position of the magnetic needle to the connecting wire of a voltaic apparatus, I was led into a series which appear to me to give some new views of electro-magnetic action, and of magnetism altogether; and to render more distinct and clear those already taken. After the great men who have already experimented on the subject, I should have felt doubtful that any thing I could do could be new or possess an interest, but that the experiments seem to me to reconcile considerably the opposite opinions that are entertained on it. I am induced in consequence to publish this account of them, in the hope they will assist in making this important branch of knowledge more perfect.

The apparatus used was that invented by Dr. Hare of Philadelphia, and called by him a calorimotor; it is in fact a single pair of large plates, each having its power heightened by the induction of others. Consequently all the positions and motions of the needles, poles, *&c.*, are opposite to those produced by an apparatus of several plates; for, if a current be supposed to exist in the connecting wire of a battery from

the zinc to the copper, it will be in each connected pair of plates from the copper to the zinc; and the wire I have used is that connection between the two plates of one pair. In the diagrams I may have occasion to subjoin the ends of the connecting wire, marked Z and C, are connected with the zinc and copper-plates respectively; the sections are all horizontal and seen from above, and the arrow-heads have been used sometimes to mark the pole of a needle or magnet which points to the north, and sometimes to mark the direction of motion; no difficulty can occur in ascertaining to which of those uses any particular head is applied.

On placing the wire perpendicularly, and bringing a needle towards it to ascertain the attractive and repulsive positions with regard to the wire; instead of finding these to be four, one attractive and one repulsive, for each pole, I found them to be eight, two attractive and two repulsive for each pole: thus allowing the needle to take its natural position across the wire, which is exactly opposite to that pointed out by Oersted for the reason before-mentioned, and then drawing the support away from the wire slowly, so as to bring the north pole, for instance, nearer to it, there is attraction, as is to be expected; but on continuing to make the end of the needle come nearer to the wire, repulsion takes place, though the wire still be on the same side of the needle. If the wire be on the other side of the same pole of the needle, it will repel it when opposite to most parts between the centre of motion and the end; but there is a small portion at the end where it attracts it. Fig. 1, plate iii, shews the positions of attraction for the north and south poles, fig. 2, the positions of repulsion.

If the wire be made to approach perpendicularly towards one pole of the needle, the pole will pass off on one side, in that direction which the attraction and repulsion at the extreme point of the pole would give; but, if the wire be continually made to approach the centre of motion, by either the one or other side of the needle, the tendency to move in the former direction diminishes; it then becomes null, and the needle is quite indifferent to the wire; and ultimately the motion is

reversed, and the needle powerfully endeavours to pass the opposite way.

It is evident from this 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 this 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.

By attending to fig. 3, which represents sections of the wire in its different positions to the needle, all this will be plain; the active poles are represented by two dots, and the arrow-heads shew the tendency of the wire in its positions to go round these poles.

Several important conclusions flow from these facts; such as that there is no attraction between the wire and either pole of a magnet; that the wire ought to revolve round a magnetic pole, and a magnetic pole round the wire; that both attraction and repulsion of connecting wires, and probably magnets, are compound actions; that true magnetic poles are centres of action induced by the whole bar, *&c. &c.* Such of these as I have been able to confirm by experiment, shall be stated, with their proofs.

The revolution of the wire and the pole round each other being the first important thing required to prove the nature of the force mutually exerted by them, various means were tried to succeed in producing it. The difficulty consisted in making a suspension of part of the wire sufficiently delicate for the motion, and yet affording sufficient mass of matter for contact. This was overcome in the following manner:—A piece of brass wire had a small button of silver soldered on to its end, a little cup was hollowed in the silver, and the metal being amalgamated, it would then retain a drop of mercury in it, though

placed upside down for an upper centre of motion; for a lower centre, a similar cup was made of copper, into which a little mercury was put; this was placed in a jar of water under the former centre. A piece of copper wire was then bent into the form of a crank, its ends amalgamated, and the distances being arranged, they were placed in the cups. To prevent too much friction from the weight of the wire on the lower cup, it had been passed through a cork duly adjusted in size, and that being pushed down on the wire till immersed in the water, the friction became very little, and the wire very mobile yet with good contacts. The plates being then connected with the two cups, the apparatus was completed. In this state, a magnetic pole being brought to the centre of motion of the crank, the wire immediately made an effort to revolve until it struck the magnet, and that being rapidly brought round to the other side, the wire again made a revolution, giving evidence that it would have gone round continually but for the extension of the magnet on the outside. To do away with this impediment, the wire and lower metal cup were removed, and a deep basin of mercury placed beneath; at the bottom of this was a piece of wax, and a small round bar magnet was stuck upright in it, so that one pole was about half or three-fourths of an inch above the surface of the mercury, and directly under the silver cup. A straight piece of copper wire, long enough to reach from the cup, and dip about half an inch into the mercury, had its ends amalgamated, and a small round piece of cork fixed on to one of them to make it more buoyant; this being dipped in the mercury close beside the magnet, and the other end placed under the little cup, the wire remained upright, for the adhesion of the cork to the magnet was sufficient for that purpose, and yet at its lower end had freedom of motion round the pole. The connection being now made from the plates to the upper cup, and to the mercury below, the wire immediately began to revolve round the pole of the magnet, and continued to do so as long as the connexion was continued.

When it was wished to give a large diameter to the circle described by the wire, the cork was moved from the magnet,

and a little loop of platinum passed round the magnet and wire, to prevent them from separating too far. Revolution again took place on making the connexion, but more slowly as the distance increased.

The direction in which the wire moved was according to the way in which the connexions were made, and to the magnetic pole brought into action. When the upper part of the wire was connected with the zinc, and the lower with the copper plate, the motion round the north and south poles of a magnet were as in fig. 4 and 5, looking from above; when the connexions were reversed, the motions were in the opposite direction.

On bringing the magnetic pole from the centre of motion to the side of the wire, there was neither attraction nor repulsion; but the wire endeavoured to pass off in a circle, still having the pole for its centre, and that either to the one side or the other, according to the above law.

When the pole was on the outside the wire, the wire moved in a direction directly contrary to that taken when the pole was in the inside; but it did not move far, the endeavour was still to go round the pole as a centre, and it only moved till that power and the power which retained it in a circle about its own axis were equipoised.

The next object was to make the magnet revolve round the wire. This was done by so loading one pole of the small magnet with platinum that the magnet would float upright in a basin of mercury, with the other pole above its surface; then connecting the mercury with one plate, and bringing a wire from the other perpendicularly into it in another part near the floating magnet: the upper pole immediately began to revolve round the wire, whilst the lower pole being removed away caused no interference or counteracting effect.

The motions were again according to the pole and the connexions. When the upper part of the wire was in contact with the zinc plate, and the lower with the copper, the direction of the curve described by the north and south poles were as in fig. 6 and 7. When the connexions were reversed, the motions were in the opposite directions.

Having succeeded thus far, I endeavoured to make a wire and a magnet revolve on their own axis by preventing the rotation in a circle round them, but have not been able to get the slightest indications that such can be the case; nor does it, on consideration, appear probable. The motions evidently belong to the current, or whatever else it be, that is passing through the wire, and not to the wire itself, except as the vehicle of the current. When that current is made a curve by the form of the wire, it is easy to conceive how, in revolving, it should take the wire with it; but when the wire is straight, the current may revolve without any motion being communicated to the wire through which it passes.

M. Ampere has shewn that two similar connecting wires, by which is meant, having currents in the same direction through them, attract each other; and that two wires having currents in opposite directions through them, repel each other; the attraction and repulsion taking place in right lines between them. From the attraction of the north pole of a needle on one side the wire and of the south on the other, and the repulsion of the poles on the opposite sides, Dr. Wollaston called this magnetism vertiginous, and conceived that the phænomena might be explained upon the supposition of an electro-magnetic current passing round the axis of the conjunctive wire, its direction depending upon that of the electric current, and exhibiting north and south powers on the opposite sides. It is, indeed, an ascertained fact, that the connecting wire has different powers at its opposite sides; or rather each power continues all round the wire, the direction being the same; and hence it is evident that the attractions and repulsions of M. Ampere's wires are not simple, but complicated results.

A simple case which may be taken of magnetic motion, is the circle described by the wire or the pole round each other. If a wire be made into a helix, as M. Ampere describes, the arrangement is such that all the vertiginous magnetism, as Dr. Wollaston has named it, of the one kind, or one side of the wire, is concentrated in the axis of the helix, whilst the contrary kind is very much diffused, *i. e.*, the power exerted by a great length

of wire to make a pole pass one way round it, all tends to carry that pole to a particular spot, whilst the opposite power is diffused and much weakened in its action on any one pole. Hence the power on one side of the wire is very much concentrated, and its particular effects brought out strongly, whilst that on the other is rendered insensible. A means is thus obtained of separating, as it were, the one power from the other: but when this is done, and we examine the end of the helix, it is found very much to resemble a magnetic pole; the power is concentrated at the extremity of the helix; it attracts or repels one pole in all directions; and I find that it causes the revolution of the connecting wire round it, just as a magnetic pole does. Hence it may, for the present, be considered identical with a magnetic pole; and I think that the experimental evidence of the ensuing pages will much strengthen that opinion.

Assuming, then, that the pole of a magnetic needle presents us with the properties of one side of the wire, the phenomena it presents with the wire itself, offers us a means of analysis which, probably, if well pursued, will give us a much more intimate knowledge of the state of the powers active in magnets. When it is placed near the wire, always assuming the latter to be connected with the battery, it is made to revolve round it, passing towards that side by which it is attracted, and from that side by which it is repelled, *i. e.*, the pole is at once attracted and repelled by equal powers, and therefore neither recedes or approaches; but the powers being from opposite sides of the wire, the pole in its double effort to recede from one side and approach the other revolves in the circle, that circle being evidently decided by the particular pole and state of the wire, and deducible from the law before mentioned.

The phenomena presented by the approximation of one pole to two or more wires, or two poles to one or more wires, offer many illustrations of this double action, and will lead to more correct views of the magnet. These experiments are easily made by loading a needle with platinum at one pole, that the other may float above mercury, or by almost floating a small magnetic needle by cork in a basin of water, at the bottom of

which is some mercury with which to connect the wires. In describing them I shall refrain from entering into all their variations, or pursuing them to such conclusions as are not directly important.

Two similar wires, Ampere has shewn, attract each other; and Sir H. Davy has shewn that the filings adhering to them attract from one to another on the same side. They are in that position in which the north and south influence of the different wires attract each other. They seem also to neutralize each other in the parts that face, for the magnetic pole is quite inactive between them, but if put close together, it moves round the outside of both, circulating round them as round one wire, and their influences being in the same direction, the greatest effect is found to be at the farther outside surfaces of the wires. If several similar wires be put together, side by side like a ribbon, the result is the same, and the needle revolves round them all; the internal wires appear to lose part of their force, which is carried on towards the extreme wire in opposite directions, so that the floating pole is accelerated in its motion as it passes by the edges that they form. If, in place of a ribbon of parallel wires, a slip of metal be used, the effect is the same, and the edges act as if they contained in a concentrated state the power that belonged to the inner portion of the slip. In this way we procure the means of removing, as it were, in that direction, the two sides of the wire from each other.

If two wires in opposite states be arranged parallel to each other, and the pole be brought near them, it will circulate round either of them in obedience to the law laid down; but as the wires have opposite currents, it moves in opposite directions round the two, so that when equidistant from them, the pole is propelled in a right line perpendicular to the line which joins them, either receding or approaching; and if it approaches, passing between and then receding: hence it exhibits the curious appearance of being first attracted by the two wires, and afterwards repelled. (Fig. 8.) If the con-

nexion with both wires be inverted, or if the pole be changed, the line it describes is in the opposite direction. If these two opposite currents be made by bending a piece of silked wire parallel to itself, fig. 9, it, when connected with the apparatus, becomes a curious magnet; with the north pole, for instance, it attracts powerfully on one side at the line between the two currents, but repels strongly to the right or left; whilst on the other side the line repels the north pole, but attracts it strongly to the right or left. With the south pole the attractions and repulsions are reversed.

When both poles of the needle were allowed to come into action on the wire or wires, the effects were in accordance with those described. When a magnetic needle was floated on water, and the perpendicular wire brought towards it, the needle turned round more or less, until it took a direction perpendicular to, and across the wire, the poles being in such positions that either of them alone would revolve round the wire in a circle proceeding by the side to which it had gone, according to the law before stated. The needle then approaches to the wire, its centre (not either pole) going in a direct line towards it. If the wire be then lifted up and put down on the other side the needle, the needle passes on in the same line receding from the wire, so that the wire seems here to be both attractive and repulsive of the needle. This effect will be readily understood from fig. 10, where the poles and direction of the wire is not marked, because they are the same as before. If either be reversed, the others reverse themselves. The experiment is analogous to the one described above; there the pole passed between two dissimilar wires, here the wire between two dissimilar poles.

If two dissimilar wires be used, and the magnet have both poles active, it is repelled, turned round, or is attracted in various ways, until it settles across between the two wires; all its motions being easily reducible to those impressed on the poles by the wires, both wires and both poles being active in giving that position. Then if it happens not to be

midway between the two, or they are not of equal power, it goes slowly towards one of them, and acts with it just as with the single wire of the last paragraph.

Fig. 11 and 12 exhibit more distinctly the direction of the forces which influence the poles in passing between two dissimilar wires: fig. 11, when the pole draws up between the wires; fig. 12, the pole thrown out from between them. The poles and state of the wire are not marked, because the diagrams illustrate the attraction and repulsion of both poles: for any particular pole, the connexion of the wires must be accordingly.

If one of the poles be brought purposely near either wire in the position in which it appears to attract most strongly, still if freedom of motion be given by a little tapping, the needle will slip along till it stands midway across the wire.

A beautiful little apparatus has been made by M. de la Rive, to whom I am indebted for one of them, consisting of a small voltaic combination floating by a cork; the ends of the little zinc and copper slips come through the cork, and are connected above by a piece of silked wire which has been wrapped four or five times round a cylinder, and the wires tied together with a silk thread so as to form a close helix about one inch in diameter. When placed on acidulated water it is very obedient to the magnet, and serves admirably to transform, as it were, the experiments with straight wires that have been mentioned, to the similar ones made with helices. Thus, if a magnet be brought near it and level with its axis, the apparatus will recede or turn round until that side of the curve next to the nearest pole is the side attracted by it. It will then approach the pole, pass it, recede from it until it gains the middle of the magnet, where it will rest like an equator round it, its motions and position being still the same as those before pointed out. (Fig. 13.) If brought near either pole it will still return to the centre; and if purposely placed in the opposite direction at the centre of the magnet, it will pass off by either pole to which it happens to be nearest, being apparently first attracted by the pole and afterwards repelled, as is actually the case; will, if any circumstance disturbs its perpendicularity to the magnet,

turn half way round; and will then pass on to the magnet again, into the position first described. If, instead of passing the magnet through the curve, it be held over it; it stands in a plane perpendicular to the magnet, but in an opposite direction to the former one. So that a magnet, both within and without this curve, causes it to direct.

When the poles of the magnet are brought over this floating curve, there are some movements and positions which at first appears anomalous, but are by a little attention easily reducible to the circular movement of the wire about the pole. I do not think it necessary to state them particularly.

The attractive and repulsive positions of this curve may be seen by fig. 13, the curve in the two dotted positions is attracted by the poles near them. If the positions be reversed, repulsion takes place.

From the central situation of the magnet in these experiments, it may be concluded that a strong and powerful curve or helix would suspend a powerful needle in its centre. By making a needle almost float on water and putting the helix over a glass tube, this result has in part been obtained.

In all these magnetic movements between wires and poles, those which resemble attraction and repulsion, that is to say, those which took place in right lines, required at least either two poles and a wire, or two wires and a pole; for such as appear to exist between the wire and either pole of the battery, are deceptive and may be resolved into the circular motion. It has been allowed, I believe, by all who have experimented on these phenomena, that the similar powers repel and the dissimilar powers attract each other; and that, whether they exist in the poles of magnets or in the opposite sides of conducting wires. This being admitted, the simplest cases of magnetic action will be those exerted by the poles of helices, for, as they offer the magnetic states of the opposite sides of the wire independent, or nearly so, one of the other, we are enabled by them to bring into action two of those powers only, to the exclusion of the rest; and, from experiment it appears that when the powers are similar, repulsion takes

place, and when dissimilar, attraction; so that two cases of repulsion and one of attraction are produced by the combination of these magnetic powers *.

The next cases of magnetic motion, in the order of simplicity, are those where three powers are concerned or those produced by a pole and a wire. These are the circular motions described in the early part of this paper. They resolve themselves into two, a north pole and the wire round each other, and a south pole, and the wire round each other. The law which governs these motions has been stated.

Then follow the actions between two wires, these when similarly electrified attract as M. Ampere has shewn; for then the opposite sides are towards each other, and the four powers all combine to draw the currents together forming a double attraction; but, when the wires are dissimilar they repel, because, then on both sides the wire the same powers are opposed, and cause a double repulsion.

The motions that result from the action of two dissimilar poles and a wire next follow: the wire endeavours to describe opposite circles round the poles; consequently, it is carried in a line passing through the central part of the needle in which they are situated. If the wire is on the side on which the circles close together, it is attracted; if on the opposite side, from whence the circles open, it is repelled, fig. 10.

The motions of a pole with two wires are almost the same as the last; when the wires are dissimilar, the pole endeavours to form two opposite circles about the wires; when it is on that side the wires on which the circles meet, it is attracted; when on the side on which they open, it is repelled, figs. 8, 11, 12.

Finally, the motion between two poles and two dissimilar wires, is an instance where several powers combine to produce an effect.

M. Ampere, whilst reasoning on the discovery of M. Oersted, was led to the adoption of a theory, by which he endeavoured to account for the properties of magnets, by the existence of

* This is perhaps not strictly true, because, though the opposite powers are weakened, they still remain in action.

concentric currents of electricity in them, arranged round the axis of the magnet. In support of this theory, he first formed the spiral or helix wire, in which currents could be made to pass nearly perpendicular to, and round the axis of a cylinder. The ends of such helices were found, when connected with the voltaic apparatus to be in opposite magnetic states, and to present the appearance of poles. Whilst pursuing the mutual action of poles and wires, and tracing out the circular movements, it seemed to me that much information respecting the competency of this theory might be gained from an attempt to trace the action of the helix, and compare it with that of the magnet more rigorously than had yet been done; and to form artificial electro-magnets, and analyze natural ones. In doing this, I think I have so far succeeded as to trace the action of an electro-magnetic pole, either in attracting or repelling, to the circulating motion before described.

If three inches of connecting wire be taken, and a magnetic pole be allowed to circulate round the middle of it, describing a circle of a little less than one inch in diameter, it will be moved with equal force in all parts of the circle, fig. 14; bend then the wire into a circle, leaving that part round which the pole revolves perpendicularly, undisturbed, as seen by the dotted lines, and make it a condition that the pole be restrained from moving out of the circle by a radius. It will immediately be evident that the wire now acts very differently on the pole in the different parts of the circle it describes. Every part of it will be active at the same time on the pole, to make it move through the centre of the wire ring, whilst as it passes away from that position the powers diverge from it, and it is either removed from their action or submitted to opposing ones, until on its arriving at the opposite part of the circle it is urged by a very small portion indeed of those which moved it before. As it continues to go round, its motion is accelerated, the forces rapidly gather together on it, until it again reaches the centre of the wire ring where they are at their highest, and afterwards diminish as before. Thus the pole is perpetually urged in a circle, but with powers constantly changing. If the wire ring

be conceived to be occupied by a plane, then the centre of that plane is the spot where the powers are most active on the pole, and move it with most force. Now this spot is actually the pole of this magnetic apparatus. It seems to have powers over the circulating pole, making it approach or attracting it on the one side, and making it recede or repelling it on the other, with powers varying as the distance; but its powers are only apparent, for the force is in the ring, and this spot is merely the place where they are most accumulated: and though it seems to have opposite powers, namely, those of attracting and repelling; yet this is merely a consequence of its situation in the circle, the motion being uniform in its direction, and really and truly impressed on the pole by its motor, the wire.

At page 81, it was shewn that two or more similar wires put together in a line, acted as one; the power being, as it were, accumulated towards the extreme wires, by a species of induction taking place among them all: and at the same time was noticed the similar case of a plate of metal connecting the ends of the apparatus, its powers being apparently strongest at the edges. If, then, a series of concentric rings be placed one inside the other, they having the electric current sent through them in the same direction; or if, which is the same thing, a flat spiral of silked wire passing from the centre to the circumference be formed, and its ends be in connexion with the battery, fig. 15, then the circle of revolution would still be as in fig. 14, passing through the centre of the rings or spiral, but the power would be very much increased. Such a spiral, when made, beautifully illustrates this fact; it takes up an enormous quantity of iron filings, which approach to the form of cones, so strong is the action at the centre; and its action on the needle by the different sides, is eminently powerful.

If in place of putting ring within ring, they be placed side by side, so as to form a cylinder, or if a helix be made, then the same kind of neutralization takes place in the intermediate wires, and accumulated effect in the extreme ones, as before. The line which the pole would now travel, supposing the inner end of the radius to move over the inner

and outer surface of the cylinder, would be through the axis of the cylinder round the edge to one side, back up that side, and round to the axis, down which it would go, as before. In this case the force would probably be greatest at the two extremes of the axis of the cylinder, and least at the middle distance on the outside.

Now consider the internal space of the cylinder filled up by rings or spirals, all having the currents in the same direction: the direction and kind of force would be the same, but very much strengthened: it would exist in the strongest degree down the axis of the mass, because of the circular form, and it would have the two sides of the point in the centre of the simple ring, which *seemed* to possess attractive and repulsive powers on the pole, removed to the ends of the cylinder; giving rise to two points, apparently distinct in their action, one being attractive, and the other repulsive, of the poles of a magnet. Now conceive that the pole is not confined to a motion about the sides of the ring, or the flat spiral, or cylinder, it is evident that if placed in the axis of any of them at a proper distance for action, it, being impelled by two or more powers in equal circles, would move in a right line in the intersection of those circles, and approach directly to, or recede from, the points before spoken of, giving the appearance of a direct attraction and repulsion: and if placed out of that axis, it would move towards or from the same spot in a curve line, its direction and force being determined by the curve lines representing the active forces from the portions of wire forming the ends of the cylinder, spiral, or ring, and the strength of those forces.

Thus the phenomena of a helix, or a solid cylinder of spiral silked wire, are reduced to the simple revolution of the magnetic pole round the connecting wire of the battery, and its resemblance to a magnet is so great, that the strongest presumption arises in the mind they both owe their powers, as M. Ampere has stated, to the same cause. Filings of iron sprinkled on paper held over this cylinder, arranged in curved lines passing from one end to the other, shewing the path the pole would follow, and so they do over a magnet; the ends attract and re-

pel as do those of a magnet; and in almost every point do they agree. The following experiments will illustrate and confirm the truth of these remarks on the action of the ring, helix, or cylinder; and will shew in what their actions agree with, and differ (for there are differences) from, the action of a magnet.

A small magnet being nearly floated in water by cork, a ring of silked copper wire, fig. 16, having its ends connected with the battery, was brought near its poles in different positions; sometimes the pole was repelled from, sometimes attracted into, the ring, according to the position of the pole, and the connexions with the battery. If the wire happened to be opposite to the pole, the pole passed sideways, and outwards when it was repelled, and sideways and inwards when it was attracted; and on entering within the ring and passing through, it moved sideways in the opposite direction, endeavouring to go round the wire. The actions also presented by M. de la Rive's ring are actions of this kind, and indeed are those which best illustrate the relations between the ring and the pole; some of them have been mentioned, and if referred to, will be found to accord with the statement given.

With a flat spiral the magnetic power was very much increased; and when the rings were not continued to the centre, the power of the inner edge over the outer was well shewn either by the pole of a needle, or iron filings. With the latter, the appearance was extremely beautiful and instructive; when laid flat upon a heap of them, they arranged themselves in lines, passing through the ring parallel to its axis, and then folding up on either side as radii round to the edge, where they met; so that they represented, exactly, the lines which a pole would have described round the sides of the rings: and those filings which were in the axis of the rings, stood up in perpendicular filaments, half an inch long and so as to form an actual axis to the ring, tending neither one way nor the other, but according in their form and arrangement with what has been described; whilst the intermediate portion also formed long threads, bending this way and that from the centre, more or less, according as they were further from, or nearer to, it.

With a helix the phenomena were interesting, because according to the view given of the attractions and repulsions, that is of the motions toward and from the ends, some conclusions should follow, that if found to be true in fact, and to hold also with magnets, would go far to prove the identity of the two. Thus the end which seems to attract a certain pole on the outside, ought to repel it as it were on the inside, and that which seems to repel it on the outside, ought to appear to attract it on the inside; *i. e.*, that as the motions on the inside and outside are in different directions for the same pole, it would move in the one case to and in the other case from the same end of the helix. Some phenomena of this kind have been described in explaining figs. 8, 11, 12, and 13; others are as follows.

A helix of silked copper wire was made round a glass tube, the tube being about an inch in diameter; the helix was about three inches long. A magnetic needle nearly as long was floated with cork, so as to move about in water with the slightest impulse; the helix being connected with the apparatus and put into the water in which the needle lay, its ends appeared to attract and repel the poles of the needle according to the laws before-mentioned. But, if that end which attracted one of the poles of the needle was brought near that pole, it entered the glass tube, but did not stop just within side in the neighbourhood of this pole (as we may call it for the moment) of the helix, but passed up the tube, drawing the whole needle in, and went to the opposite pole of the helix, or the one which on the outside would have repelled it. On trying the other pole of the magnet with its corresponding end or pole of the helix the same effect took place; the needle-pole entered the tube and passed to the other end, taking the whole needle into the same position it was in before.

Thus each end of the helix seemed to attract and repel both poles of the needle: but this is only a natural consequence from the circulating motion before experimentally demonstrated, and each pole would have gone through the helix and round on the outside, but for the counteraction of the opposite pole.

It has been stated that the poles circulate in opposite directions round the wires, and they would consequently circulate in opposite directions through and round the helix; when, therefore, one end of the helix was near that pole, which would, according to the law stated, enter it and endeavour to go through, it would enter, and it would continue its course until the other pole, at first at a distance, would be brought within action of the helix; and, when they were both equally within the helix and consequently equally acted on, their tendency to go in different directions would counterbalance each other, and the needle would remain motionless. If it were possible to separate the two poles from each other, they would dart out of each end of the helix, being apparently repelled by those parts that before seemed to attract them, as is evident from the first and many other experiments.

By reversing the needle and placing it purposely in the helix in that position, the poles of the needle and the corresponding poles of the helix as they attract on the outside, are brought together on the inside, but both pairs now seem to repel; and, whichever end of the helix the needle happens to be nearest to, it will be thrown out at. This motion may be seen to exhibit in its passing state, attraction between similar poles, since the inner and active pole is drawn towards that end on the inside, by which it is thrown off on the outside *.

These experiments may be made with the single curve of M. de la Rive, in which case it is the wire that moves and not the magnet, but as the motions are reciprocal, they may be readily anticipated.

A plate of copper was bent nearly into a cylinder, and its edges made to dip into two portions of mercury; when placed in a current it acted exactly as a helix.

A solid cylinder of silked wire was made exactly in fashion like a helix, but that one length of the wire served as the axis, and the folds were repeated over and over again. This

* The magnetizing power of the helix is so strong that if the experiment be made slowly the needle will have its magnetism changed, and the result will be fallacious.

as well as the former helix, had poles the same in every respect as to kind as the north and south poles of a magnet; they took up filings, they made the connecting wire revolve, they attracted and repelled in four parallel positions as is described of common magnets in the first pages of this paper, and filings sprinkled on paper over them, formed curves from one to the other as with magnets; these lines indicating the direction in which a north or south pole would move about them.

Now with respect to the accordance which is found between the appearances of a helix or cylinder when in the voltaic circuit, and a cylindrical common magnet, or even a regular square bar magnet; it is so great, as at first to leave little doubt, that whatever it is that causes the properties of the one, also causes the properties of the other, for the one may be substituted for the other in, I believe, every magnetical experiment: and, in the bar magnet, all the effects on a single pole or filings, *&c.*, agree with the notion of a circulation, which if the magnet were not solid would pass through its centre, and back on the outside.

The following, however, are differences between the appearances of a magnet and those of a helix or cylinder: one pole of a magnet attracts the opposite pole of a magnetic needle in all directions and positions; but when the helix is held along-side the needle nearly parallel to it, and with opposite poles together, so that attraction should take place, and then the helix be moved on so that the pole of the needle gradually comes nearer to the middle of the helix, repulsion generally takes place before the pole gets to the middle of the helix, and in a situation where with the magnet it would be attracted. This is probably occasioned by the want of continuity in the sides of the curves or elements of the helix, in consequence of which the unity of action which takes place in the rings into which a magnet may be considered to be divided is interfered with and disturbed.

Another difference is that the poles, or those spots to which the needle points when perpendicular to the end or sides of a magnet

or helix, and where the motive power may be considered perhaps as most concentrated, is in the helix at the extremity of its axis, and not any distance in from the end; whilst in the most regular magnets it is almost always situate in the axis at some distance in from the end: a needle pointing perpendicularly towards the end of a magnet is in a line with its axis, but perpendicularly to the side it points to a spot some distance from the end, whilst in the helix, or cylinder, it still points to the end. This variation is, probably, to be attributed to the distribution of the exciting cause of magnetism in the magnet and helix. In the latter, it is necessarily uniform every where, inasmuch as the current of electricity is uniform. In the magnet it is probably more active in the middle than elsewhere: for as the north pole of a magnet brought near a south one increases its activity, and that the more as it is nearer, it is fair to infer that the similar parts which are actually united in the inner part of the bar, have the same power. Thus a piece of soft iron put to one end of a horse-shoe magnet, immediately moves the pole towards that end; but if it be then made to touch the other end also, the pole moves in the opposite direction, and is weakened; and it moves the farther, and is made weaker as the contact is more perfect. The presumption is, that if it were complete, the two poles of the magnet would be diffused over the whole of its mass, the instrument then exhibiting no attractive or repulsive powers. Hence it is not improbable that, caused by some induction, a greater accumulation of power taking place in the middle of the magnet than at the end, may cause the poles to be inwards, rather than at the extremities.

A third difference is, that the similar poles of magnets, though they repel at most distances, yet when brought very near together, attract each other. This power is not strong, but I do not believe it is occasioned by the superior strength of one pole over the other, since the most equal magnets exert it, and since the poles as to their magnetism remain the same, and are able to take up as much, if not more, iron filings when together, as when separated; whereas opposite poles, when in contact, do

not take up so much. With similar helix poles, this attraction does not take place.

The attempts to make magnets resembling the helix and the flat spirals, have been very unsuccessful. A plate of steel was formed into a cylinder and then magnetized, one end was north all round, the other south; but the outside and the inside had the same properties, and no pole of a needle would have gone up the axis and down the sides, as with the helix, but would have stopped at the dissimilar pole of the needle. Hence it is certain, that the rings of which the cylinder may be supposed to be formed, are not in the same state as those of which the helix was composed. All attempts to magnetize a flat circular plate of steel, so as to have one pole in the centre of one side, and the other pole in the centre of the opposite side, for the purpose of imitating the flat spiral, fig. 15, failed; nothing but an irregular distribution of the magnetism could be obtained.

M. Ampere is, I believe, undecided with regard to the size of the currents of electricity that are assumed to exist in magnets, perpendicular to their axis. In one part of his memoirs they are said, I think, to be concentric; but this cannot be the case with those of the cylinder magnet, except two be supposed in opposite directions, the one on the inside, the other on the outside surface. In another part, I believe, the opinion is advanced that they may be exceedingly small; and it is, perhaps, possible to explain the case of the most irregular magnet by theoretically bending such small currents in the direction required.

In the previous attempt to explain some of the electro-magnetic motions, and to shew the relation between electro and other magnets, I have not intended to adopt any theory of the cause of magnetism, nor to oppose any. It appears very probable that in the regular bar magnet, the steel, or iron, is in the same state as the copper wire of the helix magnet; and, perhaps, as M. Ampere supports in his theory, by the same means, namely, currents of electricity; but still other proofs are wanting of the presence of a power like electricity than the magnetic effects only. With regard to the opposite sides of the connecting

wire, and the powers emanating from them, I have merely spoken of them as two, to distinguish the one set of effects from the other. The high authority of Dr. Wollaston is attached to the opinion that a single electro-magnetic current passing round the axis of the wire in a direction determined by the position of the voltaic poles, is sufficient to explain all the phenomena.

M. Ampere, who has been engaged so actively in this branch of natural philosophy, drew from his theory, the conclusion that a circular wire forming part of the connexion between the poles of the battery, should be directed by the earth's magnetism, and stand in a plane perpendicular to the magnetic meridian and the dipping needle. This result was said to be actually obtained, but its accuracy has been questioned, both on theoretical and experimental grounds. As the magnet directs the wire when in form of a curve, and the curve a needle, I endeavoured to repeat the experiment, and succeeded in the following manner:—A voltaic combination of two plates was formed, which were connected by a copper wire, bent into a circular form; the plates were put into a small glass jar with dilute acid, and the jar floated on the surface of water: being then left to itself in a quiet atmosphere, the instrument so arranged itself that the curve was in a plane perpendicular to the magnetic meridian; when moved from this position, either one way or the other, it returned again; and on examining the side of the curve towards the north, it was found to be that, which, according to the law already stated, would be attracted by a south pole. A voltaic circle made in a silver capsule, and mounted with a curve, also produced the same effect; as did likewise, very readily, M. de la Rive's small ring apparatus*. When placed on acidulated water, the gas liberated from the plates prevented its taking up a steady position; but when put into a little floating cell, made out of the neck of a Florence flask, the whole readily took the position mentioned above, and even vibrated slowly about it.

As the straight connecting wire is directed by a magnet, there

* See Miscellanea.

is every reason to believe that it will act in the same way with the earth, and take a direction perpendicular to the magnetic meridian. It also should act with the magnetic pole of the earth, as with the pole of a magnet, and endeavour to circulate round it. Theoretically, therefore, a horizontal wire perpendicular to the magnetic meridian, if connected first in one way with a voltaic battery, and then in the opposite way, should have its weight altered; for in the one case it would tend to pass in a circle downwards, and in the other upwards. This alteration should take place differently in different parts of the world. The effect is actually produced by the pole of a magnet, but I have not succeeded in obtaining it, employing only the polarity of the earth.

Sept. 11, 1821.

ART. X. *Letter from* Dr. Hastings *to the* Editor, *respecting the Division of the Eighth pair of Nerves.*

SIR,

As the accuracy of my experiments on the par vagum, contained in a former Number of your *Journal*, has been established by those since conducted at the Royal Institution, I should not add one sentence to what has been already written on the subject, had not Mr. Broughton in his reply made personal allusions, which compel me to state,

That my observations were made in consequence of the accusation of inaccuracy, brought against me by that gentleman; and that I have again, with great care, compared them with his *first* paper, and can perceive no instance in which they are not fully applicable to it. In what part of Mr. Broughton's first paper does he say, that the contents of the stomachs of the rabbits operated on, were compared with those of the stomachs of healthy rabbits, similarly fed, and killed at the same time? where does he say that the eighth pair of nerves in the dog were found after death divided, or that he took care to place the animal in such a situation, that he must have observed it, if it had vomited any part of the milk? where does he say that he found the ends of the nerves uniformly apart from each other? what