XXXIII.—*Electro-Magnetic Experiments and Observations.* By THOMAS STEWART TRAILL, M. D. F. R. S. EDIN. & WILLIAM SCORESBY, *jun.*, Esq. F. R. S. LOND. & EDIN.

(Read May 6. 1822.)

THE interesting discoveries of OERSTED, and the subsequent researches of AMPERE, ARAGO, DAVY, and VON BUCH, which promise to throw a clearer light on the mysterious nature of Galvanism and Magnetism, induced us to undertake, and pursue conjunctly, a series of Electro-magnetic experiments. In prosecuting our inquiries in this new branch of scientific investigation, we have observed various interesting facts, some of which appeared to us new, while others did not seem to have been detailed so fully as their importance merited.

Some of our earliest experiments on this subject were performed in November 1821, with a cup of platina and slip of rolled zinc, in the manner proposed by M. M. VON BUCH *. In order to ascertain the effect produced on the needle, by both sides of the lower portion of the zinc, the whole apparatus was placed on a piece of plate-glass. With this small apparatus the electro-magnetic effect was slight, and its intensity irregular, when the proportion of the acid amounted only to $\frac{1}{30}$th or even $\frac{1}{20}$th of the liquid employed; but the needle was

 very

* *Annals of Philosophy*, vol. ii. p. 282.

very sensibly affected, whenever the strength of the acid liquor in the cup was sufficient to cause such an effervescence with the zinc as to render the liquid turbid.

The most striking phenomena of this galvanic arrangement are, the different effects produced on the magnetic needle by the relative positions of the platina and zinc, in regard to the magnetic meridian, and the opposite influence of the outer and inner sides of the slip of zinc, as will be seen in the tabular results below.

1. Cup North.

1. Compass at	O.	See Pl. XXX. Fig. 1. deflected to the	E *.
2. -	I	- - -	W.
3. -	*i*	- - -	W.
4. -	*o*	- - -	E.

2. Cup South.

1. Compass at	O,	deflected to	W.
2. -	I,	-	E.
3. -	*i*,	-	E.
4. -	*o*,	-	W.

3. Cup West.

1. Compass at	O,	not sensibly deflected.
2. -	I,	inversion of Poles.
3. -	*i*,	inversion of Poles.
4. -	*o*,	not sensibly deflected.

4. Cup East.

1. Compass at	O,	inversion of Poles.
2. -	I,	not sensibly deflected.
3. -	*i*,	not sensibly deflected.
4. -	*o*,	inversion of Poles.

In

* In this paper, where it is not otherwise specially indicated, the deflection, to either hand, means the deflection of the *North Pole* of the needle.

PLATE XXX

Eng^d. for the Royal Soc. Tran. Vol. IX. page 466.

Fig. 1.

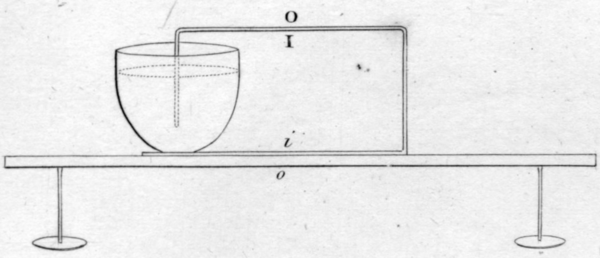


Fig. 2.

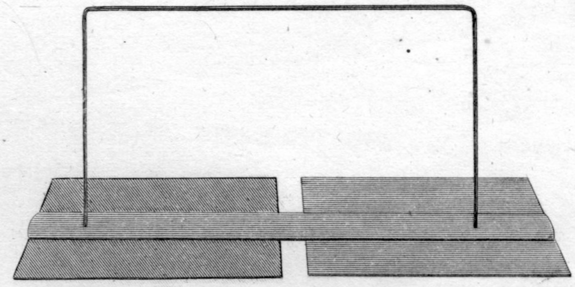


Fig. 3.

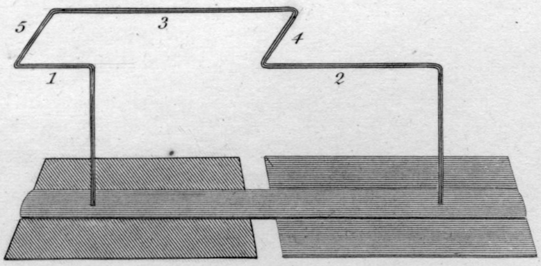


Fig. 4.

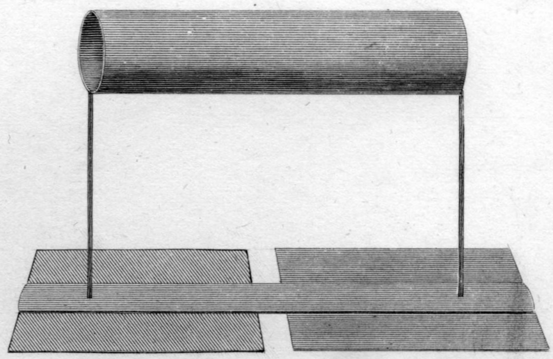


Fig. 5.

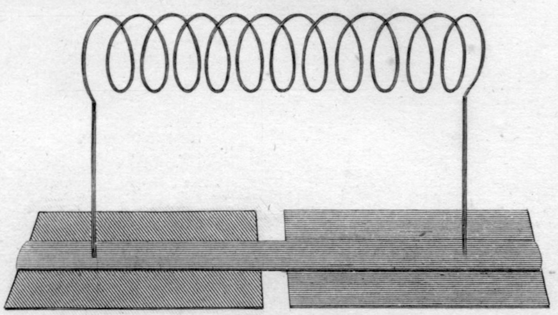
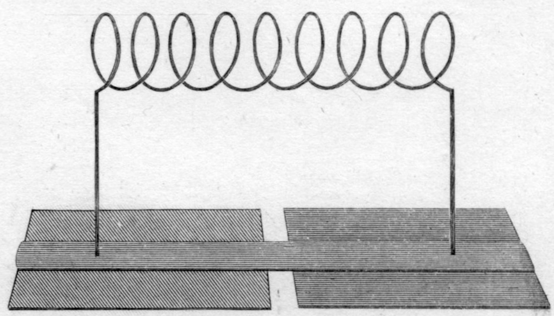


Fig. 6.



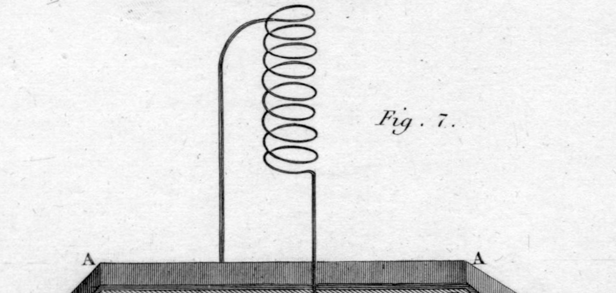


Fig. 7.

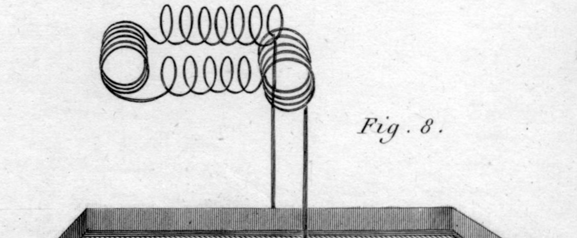


Fig. 8.

T. S. Traill del^t.

W. H. Lizars sculp^t.

In using this apparatus, we found it necessary to change the acid frequently, otherwise the results were not so complete as stated in the 3d and 4th series, and the action on the needle appeared to be subject to capricious and sudden movements, probably produced by the unequal action of the zinc and acid. We therefore constructed another apparatus, which combines simplicity with cheapness.

It consists of two single plates of zinc and copper, 4 inches square, retained about $\frac{3}{4}$th inch apart by a slip of mahogany rivetted to them, as in Fig. 2. This, while it preserves the due position of the plates, affords a convenient support to the connecting wires or helices, which can be instantaneously changed without displacing the plates; for the ends of the wires are merely inserted into holes which perforate the wood. When experiments were to be made, the plates, thus connected, were placed in a shallow earthen-ware dish, containing the acid liquor *.

Our first experiments with this apparatus were made on 15th November, and have been many times since repeated with the same results.

Experiments with the simple connecting-wire, Fig. 2.

1. Zinc North.

1. Needle placed below the wire, deflected to the W.
2. - above - - E.

2. Zinc

* The liquid which we found most convenient, is 1 part of nitric acid with 30 parts of water, and $\frac{1}{2}$ a part of sulphuric acid. The zinc plates were made according to Messrs Silvesters' and Robson's patent, now in the hands of Messrs Philips, George and Co., about $\frac{1}{23}$ inch in thickness; the connecting wires and helices were of copper, or of brass wire, from $\frac{1}{30}$ to $\frac{1}{15}$ inch in thickness; the helices most used had a diameter of about 2 inches; and the needle employed was either a small pocket compass, with an agate cap, or a naked needle, supported on a fine point fixed at right angles on a glass rod.

2. Zinc South.
   1. Needle placed below the wire, deflected to the E.
   2. - above - - W.
3. Zinc West.
   No sensible effect either above or below the wire.
4. Zinc East.
   No sensible effect either above or below the wire.

In these experiments, there appears to be a maximum of deflection when the connecting wire is in the magnetic meridian; but when it is at right angles to that meridian, the effect is imperceptible. This, however, is evidently owing to the small portion of the connecting medium, which, in this position, can act on the needle; for when a broad piece of metal was substituted for the connecting wire, the needle was powerfully acted on, as was evident by its short oscillations; and the same thing was observed with Von Buch's apparatus above described.

In order to ascertain how far the influence of the connecting wire depended on the supposed direction of a galvanic current or currents, passing from one metal to the other, a connecting wire was bent several times at right angles, as is shewn in perspective in Fig. 3., and the following effects were observed on applying a needle to different parts of the wire, in different positions of the plates.

1. Zinc North.

When the needle was presented to those portions of the wire in the magnetic meridian 1, 2, 3, the deflection was as follows:

1. Above the wire, deflection - to W.
2. Below - - to E.

but in other parts of the wire there was no deflection.

2. Zinc

2. Zinc South.

When the needle was presented to the portions of the wire in the magnetic meridian 1, 2, 3.

1. Above the wire, deflection - to E.
2. Below - - to W.

but in other parts of the wire no sensible deflection.

3. Zinc West.

In this position there are two parts of the wire in the magnetic meridian 4, 5, which present reversed results.

1. Above that portion, number 4, deflection to E.
2. Below - - 4, - to W.

but 3. Above - - 5, - to W.

4. Below - - 5, - to E.

4. Zinc East.

In this position the influence of the portions 4 and 5 were exactly as in the last position of the zinc. At first sight the results of former experiments ought to have led us to expect a difference; but a little reflection will shew, that if these effects are produced by a current passing from the zinc to the copper, by the connecting wire, when the zinc is west, the current must pass northward through 5, and southward through 4; and in the opposite directions through both, when the zinc plate is placed to the east of the copper. This circumstance counteracts the effect of turning the plates, and the appearances agree with the result of our previous experiments, no less than with those that follow.

The phenomena of electro-magnetism appear to favour the idea of currents capable of affecting the needle differently, passing in opposite directions, and on opposite sides of the connecting wire, from the two metals forming the galvanic arrangement; and the results which we obtained with the bent wire, prove that the influence of the relative position of the zinc

zinc and copper plates, depends rather on the direction which is thus communicated to the electro-motive currents, than on the point of the compass from which they begin to flow.

Helices were substituted for the connecting wires already described. These were usually formed by bending copper-wire 10 or 12 times round a wooden cylinder. We did not find any difference in effect, whatever might be the metal of which they were made, or whether they were $\frac{1}{2}$, 1, 2, 3, or 4 inches in diameter; but we found those of two inches most convenient in our experiments. They were either *right* or *left* helices; and for one experiment we employed a helix, one-half of which was a right, and the other a left helix *.

In the following experiments, the needle was generally introduced iu the centre of the helix; but it did not alter the results, when moved about in it, provided the needle had free space to turn round.

Experiments with a Right Helix. Fig. 5.

1. Zinc North.
   Needle introduced in the axes had its poles inverted.
2. Zinc South.
   No deflection of the needle.
3. Zinc West.
   Needle deflected to the E.
4. Zinc East.
   Needle deflected to the W.

Experiments

* Those unaccustomed to such operations, find some difficulty in distinguishing between a right and a left helix; but if it be placed on one end, the spires of a *right* helix rise in the direction of the sun's diurnal course; those of a left helix in the opposite direction.

Experiments with a Left Helix. Fig. 6.

1. Zinc North.
   Needle not deflected.
2. Zinc South.
   Needle had its poles inverted.
3. Zinc West.
   Needle deflected to W.
4. Zinc East.
   Needle deflected to E.

Experiments with a Double Helix.

This helix is 6 inches in length, and 2 in diameter; it consists of 16 spires, 8 of which are in a right, and 8 in a left direction.

The needle, when placed in either end, was deflected, as in the order of the simple helices, to which it belonged. When placed in the centre of this helix, the needle only obeyed terrestrial magnetism; but the slightest deviation to either extremity produced a deflection.

Instead of the helices, we employed a thin tube of brass, Fig. 4.; but with the small apparatus no certain effects were produced. In subsequent experiments, however, with a larger galvanic arrangement, we remarked singular irregular motions of the needle in its axis, which were not easily reducible to any general law.

To increase the power of our electro-motive apparatus, without rendering it complicated, seemed desirable, as we thought that we perceived a law, respecting the action of helices, which we hoped to develope more clearly by an increase of power.

We procured a copper tray, 14 inches long by 10 inches wide, and 1 deep, AA, Fig. 7. BB is a plate of zinc, 13 inches

inches long by 9 wide, which has a short pipe of the same metal soldered to its centre, for supporting one end of the connecting wires, while the other is inserted in a similar pipe soldered to the copper-tray, as represented at C. When this apparatus was used, nothing more was necessary than to separate the zinc and copper by a few slips of window-glass, or by thick paper, and then pour the acid into the tray. The effect of changing the relative positions of the metallic plates, as in the former experiments, could be instantly produced, by moving one end of the connecting wire to either side of the copper-tray. On this account, it is the most convenient form of the apparatus, and is sufficiently powerful to give sparks, and to magnetise small sewing needles, if previously softened by heat.

With this apparatus all our former experiments were repeated, and the following are the general results which were obtained.

The effect of the simple and conducting bent wires differed only in energy from what was before observed. The deflections, when the acid was fresh, was $= 90°$ to either hand; and in those positions where there was no deflection, there was evidently very strong electro-magnetic action.

When helices were employed, we found that the needle introduced invariably arranged itself parallel to the axis of the helix, whatever might be its direction. This law was strikingly illustrated by the combination represented in Fig. 8. Here a very long left helix was employed, portions of which were bent toward the four cardinal points; and on successively introducing the needle into each, it assumed the direction of the axis of that portion of the helix; but in such a manner, that the *north* pole of the needle is always directed, so as to meet the

the supposed current, passing from the zinc toward the copper by the helices.

With right helices, the needle as invariably arranges itself in the direction of the axis of the helix; but, in this case, the *south* pole of the needle is always directed, so as to meet the current, which we have supposed to proceed from the zinc to the copper by the connecting wires.

This general statement will supersede the necessity of detailing the numerous experiments which we made to determine these laws. It is evident that the deflections of the needle, when the helices were arranged either in an east or a west direction, could never be less than 90°; and in certain directions must have amounted to complete inversion of the poles.

The foregoing experiments were made with horizontal helices; and we conceived that it was important to ascertain the effect which an inclined, or a vertical position of the helices might produce on the needle.

With a vertical helix, as in Fig. 7., a needle, poised on a centre, dipped so much as to have its free motion destroyed: we therefore introduced a magnetic needle, suspended by a fine thread, or a fibre of raw silk. This uniformly assumed the direction of the axis of the helix, whether truly vertical, or inclined to the horizon.

In a Right Vertical Helix.

1. When the end of the helix connected with the zinc is uppermost, the N. pole is *depressed*.
2. When the end of the helix connected with the zinc is lowermost, the N. pole is *elevated*.

That is, the *south pole*, as in a horizontal right helix, is turned, to meet the supposed current proceeding from the zinc.

In a Left Vertical Helix.

1. When the end of the helix connected with the zinc is uppermost, the N. pole of the needle is *elevated.*
2. When the end of the helix connected with the zinc is lowermost, the N. pole of the needle is *depressed.*

That is, the *north pole*, as in a left horizontal helix, is turned, to meet the current proceeding from the zinc.

Similar experiments were made on helices inclined at angles of 70° and 20°. The needles assumed the direction of tne axis of those helices; and the other phenomena were similar to what are above stated.

We may then reduce the influence of the interior of the helices on electro-magnetic arrangements, into two general laws.

1*st*, When a magnetic needle is introduced into such a helix, it has a tendency to assume a direction parallel to the axis of the helix.

2*d*, When the helix is a *right helix*, the *South* pole of the needle is deflected toward that part of it in connection with the zinc; and when it is a *left helix*, the *North* pole of the needle is deflected toward that part of it in immediate contact with the zinc.

In prosecuting our experiments, we had occasion to observe, that the upright wires supporting the helices, were not without their influence on the needle. When the needle approached the vertical portion of the connecting wires, there were marks of strong electro-magnetic action; but the deflections of the needle differed at each side of the wire. There is some difficulty in ascertaining the precise effects of each side of the wire, and we therefore substituted, first, a rectangular tube of copper, of the same form as the connecting wire in Fig. 2., the sides of which were about $\frac{5}{8}$ths of an inch in breadth; and afterwards a solid piece of lead, cast of the same size and shape as the

the tube. With both of these, as a connecting piece, the deflections of the needle were found to be precisely similar.

These deflections will be easiest represented by references to horizontal sections of the limbs of the connecting piece, as below.

I. Zinc North.

1.	Needle applied to	*s* S,	deflected 90° E.
2.	- -	*n* S,	- 90° W.
3.	- -	*w* S,	inversion of poles.
4.	- -	*e* S,	no deflection, but vigorous action.
5.	- -	*s* N,	deflection 90° W.
6.	- -	*n* N,	- 90° E.
7.	- -	*w* N,	no deflection, but vigorous action.
8.	- -	*e* N,	inversion of poles.

II. Zinc South.

1.	Needle applied to	*s* S,	deflected 90° W.
2.	- -	*n* S,	- 90° E.
3.	- -	*w* S,	no deflection, but vigorous action.
4.	- -	*e* S,	inversion of poles.
5.	- -	*s* N,	deflected 90° E.
6.	- -	*n* N,	- 90° W.
7.	- -	*w* N,	inversion of poles.
8.	- -	*e* N,	no deflection, but vigorous action.

Similar

Similar experiments were repeatedly made with the zinc west and east; but in both those cases, the effects of the vertical portions of the limbs were perfectly similar to those here given under II., or *Zinc South;* so that the same table will represent the action of the four sides of the vertical limbs in three positions of the zinc. When the compass is carried round one of these vertical limbs of the connecting piece, the needle makes one revolution on its centre.

We next examined the effect of the horizontal part of the rectangular connecting piece on the magnetic needle.

I. Zinc North.

1.	Needle above the horizontal part deflected	90° E.
2.	- below - -	90° W.

II. Zinc South.

1.	Needle above the horizontal part deflected	90° W.
2.	- below - -	90° E.

III. Zinc West.

1. Needle above shewed no deflection, but vigorous action.
2. - below had its poles inverted.

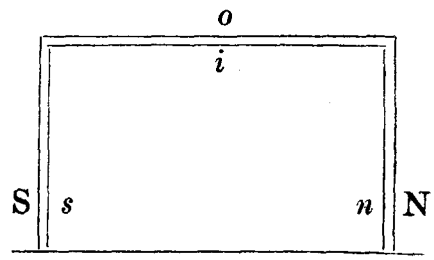
IV. Zinc East.

1. Needle above had its poles inverted.
2. - below shewed no deflection, but vigorous action.

When the needle was applied to the two perpendicular surfaces of the horizontal part, there was a difference of deflection, as it approached either the upper, or the lower surface, partaking of the effect of that surface to which the compass was approximated. The action of the upper and under surfaces of the rectangular conducting piece, when the zinc was north or south, did not differ from that of the simple connecting wire in Fig. 2.; but the breadth of these surfaces developed

veloped an effect on the needle when the zinc was west, or east, which could not be detected by using a small connecting wire.

On comparing the results obtained by using different kinds of connecting pieces, it appears, that if the needle be applied along their exterior surface, as in the direction S, *o*, N, the deflection will be the same, while the relative position of the zinc and copper are unchanged, or while the electro-motive current flows in one direction; and if the needle be carried along the interior surfaces of the connecting piece, as in the direction *s*, *i*, *n*, the deflection will be uniformly in the opposite direction.



The thin brass cylinder Fig. 4. was then applied to the tray and plate apparatus, Fig. 7.

I. Zinc North.

1. Needle in its axis, deflected E.
2. - at its upper surface E.
3. - at its lower surface W.

II. Zinc South.

1. Needle in its axis, not at all deflected.
2. - above, deflected W.
3. - below - E.

III. Zinc West.

1. Needle in its axis not deflected, but vigorously acted on.
2. - above, not visibly acted on.
3. - below, had its poles inverted.

Zinc

IV. Zinc East.

1. Needle in its axis, deflected 90° E.
2. - above, deflected E.
3. - below, not deflected, but strongly acted on.

The sides of this cylindric tube shewed no action, except when the needle was moved toward the upper, or under part of the tube, when it partook more or less of the action peculiar to that surface.

The electro-magnetic effects of the outside of the cylindrical tube, appear to differ in no respect from those of rectangular connecting pieces, or common connecting wires. When a needle is introduced in its axis, and is deflected at all, that deflection partakes, more or less, of the direction it assumes, when applied to the upper surface of either; but the degree of deflection appears to be subject to sudden variations and irregularities, of which the cause was not always apparent. If we may be allowed the expression, it seemed as if the electro-magnetic current moved through the tube with difficulty.

Finding the outside of the tube giving such decided electro-magnetic indications, we examined the action of the outside of the helices.

Experiments with Right Helix.

I. Zinc North.

1. Needle applied above, deflected 90° E.
2. - below, - 90° W.

II. Zinc South.

1. Needle applied above, deflected 90° W.
2. - below, - 90° E.

III. Zinc

III. Zinc West.

1. Needle applied above, deflected 90° W.
2. - below, inversion of poles.

IV. Zinc East.

1. Needle applied above, deflected 90° E.
2. - below, deflected to E.; but varying a little in degree, as moved along the helix.

Experiments with Left Helix.

I. Zinc North.

1. Needle applied above, deflected 90° E.
2. - below, - 90° W.

II. Zinc South.

1. Needle applied above, deflected 90° W.
2. - below, - 90° E.

III. Zinc West.

1. Needle applied above, deflected 90° E.
2. - below, inversion of poles.

IV. Zinc East.

1. Needle applied above, deflected 90° W.
2. - below, deflected to W.; but varying a little in degree, when moved toward either end of the helix.

These experiments shew, that the reversed action of right and left helices is chiefly confined to their interior; for when the zinc is south or north, the outsides of left and right helices act similarly on the needle; when, however, the zine is west or east, the deflections of the needle are reversed in each sort of helix. The analogy also between the outsides of helices, and

and the surfaces of the horizontal part of the rectangular pieces is very close; the upper surfaces of helices, when the zinc is west or east, affording the only differences of action between helices and other connecting pieces, while a complete inversion of poles takes place at the lower sides of *all*, when the zinc is to the westward of the copper.

We beg leave to lay before the Society these details of our experiments, rather as contributions toward the materials of a theory of electro-magnetic action, than with the idea of deducing from them any speculations on the nature of this mysterious agent; yet we cannot avoid remarking, that, while the substances connecting the poles of a galvanic arrangement become real magnets, the opposite effects of their upper and under surfaces appear to favour the doctrine of two electro-magnetic currents, moving in opposite directions; and that the *Boreal Magnetism* of the interior of *Right* Helices, and the *Austral Magnetism* observed in *Left* Helices, combined with the superior energy of helices over simple wires, seem to give probability to the supposition, that the two currents have a natural tendency to pursue a course in the direction of those spirals.

XXXIV.