XIV. *On the temporary magnetic effect induced in iron bodies by rotation. In a Letter to* J. F. W. Herschel, *Esq. Sec. R. S. by* Peter Barlow, *F. R. S. Communicated April 14th,* 1825.

Read May 5, 1825.

Dear Sir,

It is more than two years since, in a conversation I had with you on subjects connected with magnetism, you enquired what effect I thought might result from giving to an iron ball a rapid rotation? The subject however dropped, and it did not occur to me again, till in some speculative views in which I was lately engaged, as to the cause of the rotation of the earth's magnetic poles, the apparent irregularity of the terrestrial directive powers, &c. I was led to consider that, probably, rotation might have a certain influence. We know that iron is rendered magnetic by various processes, as drilling, hammering, &c. and it was possible also by rotation; your query now occurred to my mind; and knowing at the same time that Mr. Christie had found a permanent change in the magnetic state of an iron plate by a mere change of position on its axis, it seemed highly probable this change, due only to a simple inversion, would be increased by a rapid rotation. In this respect, however, I was deceived; for I found afterwards, that all the effect that was produced was merely temporary; and if any permanent change did take place, it was too small in my cast iron shell to be observed with the small compass I employed in these experiments.

Being however thus urged to the inquiry, as well by my own speculative views as by your query, and encouraged by Mr. CHRISTIE's results, I resolved to put the idea to the test of experiment, and to attempt it at once upon a scale that should decide the question in the first instance.

As soon as I had determined upon the experiment, I found an excellent opportunity of making the first trial, through the kindness of Generals CUPPAGE and MILLAR, of the Royal Artillery, who gave me permission to have a 13 inch mortar shell fixed to the mandrel of one of the powerful turning lathes worked by the steam engine in the Royal Arsenal. This having been done, and the compass properly placed near the shell, I turned the shell slowly round, in order to ascertain whether in this case, as in Mr. CHRISTIE's, there were any effects depending on a change of position; but if there were any, it was so small in the cast iron shell as not to have been rendered sensible with the small compass I employed. The wheel being now put in geer, the shell commenced its revolutions at the rate of 640 per minute, and the needle was deflected out several degrees, at which it remained perfectly stationary while the ball was in motion: but it returned immediately to its original bearing as soon as the motion ceased.

I now inverted the motion of the shell, and the needle was deflected about the same quantity the contrary way, observing a similar steady direction as in the former case; but as before, it returned to its original bearing the moment the motion was discontinued.

These experiments were repeated several times before some scientific officers of the artillery and engineers, always with the same results.

I afterwards found, that the needle being placed in different situations, its motion was reversed, although the direction of motion in the shell was the same; the amount of the whole deflection also differed very considerably according to the situation of the compass, its direction in some cases having been wholly reversed, while in others no perceptible motion was produced, although the rotation of the shell remained the same both in direction and in speed.

I was therefore desirous of undertaking a regular set of experiments, in order to reduce the several apparently anomalous results to some certain law of action; and as the shell in question was rather too heavy for us to feel a perfect security, as to personal safety, when it was in rapid rotation, and moreover, as its effects were larger than seemed necessary for the purpose, I now selected a Shrapnel shell of 8 inches in diameter, which weighed only 30 lbs. and chose another lathe, whose axis was nearly north and south, that in the former instance having been east and west. I had also a table made with a circular hole in it, which I could place at any height above, below, or about the centre of the ball; I could also set my compass on any azimuth on the same, and observe the effects of the direct and reversed motion; but after several days observations, I found the results so complicated, and the needle so much influenced by the iron work of the lathe and other machinery, that it would be useless to proceed, unless I could contrive to produce the rotation out of the way of any disturbing cause of the kind above mentioned.

This also, through the kindness of Colonel Sir ALEXANDER DICKSON, and the officers above named, I was enabled to

accomplish; and having got the machine erected on my own premises, I was soon enabled to clear up the difficulties which had hitherto so much embarrassed my proceedings, although even here, in the first instance, I found some results very difficult to explain.

The machine I now employed is shown in the annexed drawing. Plate XXIV.

A B C D is a strong wooden frame, resembling that of a common electrical machine, the shell S being hung in the same manner as the cylinder; the axis is made in two parts of gun metal, and very strong; *s s* are two strong screw bolts and nuts, which were used for fixing the frame firmly to the top of the table, the bolt passing through from below. E G F is a substantial table with its feet sunk into the ground, and the floor of the room cut away where they passed through, in order to prevent any effect of shaking on the stand carrying the compass.

The stand consisted of an upright pedestal filled with sand, to render it steady, and to this was fixed the table ML, with a semicircular hole cut in it, so that it might be placed near the shell. This table might be elevated or depressed at pleasure, and it was divided into the points, quarter points, &c. of the compass.

By means of different holes bored in the top of the table, the machine might be placed N and S, E and W, &c. at pleasure, and the motion of the shell be inverted by turning the handle to the right or left. The large wheel is six times the diameter of the small one; and as it might easily be turned twice in a second, the number of revolutions of the shell were gradually about 720 per minute. The little apparatus

seen above the shell, is a small stand and sliding wire, carrying a common lamp glass, in which a very small dipping needle was suspended by silk; and when the lamp glass was out of the ring, the latter served for setting the horizontal needle on, so as to bring it over any required point of the shell. It should be observed that the pedestal was moveable, and might therefore be placed on either side of the machine. The stand and upright figure 2, is one of two large magnets ultimately employed for neutralizing the needle.

The machine being thus prepared, I screwed it down; first with its axis in the magnetic meridian, and then placed the compass successively at the several points on the table all round, and registered the deviation produced at each, with the motion of the shell direct and reversed. I then removed it, and placed the axis east and west, and again registered in the same manner; but the results were very irregular with respect to quantity. Although I obtained some uniformity *regarding direction only*, viz. in both cases I found four points of change at about 30° from each extremity of the axis, or four points of non action. For example, when the axis was in the meridian from N 30° E to N 30° W, the motion of the needle arising from the rotation was made to the right. From N 30° W to S 30° W to the left. From S 30° W to S 30° E to the right. From S 30° E to N 30° E to the left; the direction of motion in the shell being the same; with the direction of motion reversed, the deviation was reversed also. While at these four points themselves, the needle had no motion. I tried also a variety of other positions, but I could obtain no such results as to lead to a concise expression of

the effect, and for this reason I shall not trouble you with the detail of them.

It at length occurred to me, that the reason of my failure arose from the compound influence under which the needle was placed, viz. that of the iron ball and of the earth; I therefore now neutralized it from the effect of both, by means of magnets properly disposed, adjusting it always before the rotation to a direction tangential to the ball, so that whatever effect was produced at each point, might at least become decided as to its direction. I now immediately arrived at that kind of general law I had been in search of; for I found when things were thus arranged, that whatever might be the direction of the axis of rotation, if the motion of the ball were made towards the needle, the north end of the latter was attracted; and if from the needle, the north end was repelled by the iron, the points immediately in the axis (when of course the motion of the shell was parallel to the needle) being neutral, or those at which the change of direction took place; in other words, if the motion of the shell continue the same, and the compass be successively placed all round the ball, in that semi-circle (from one axis to the other) in which the motion is towards the needle, the north end approaches the ball, and in the other semicircle it recedes, or the south end approaches; the points of non action being in the two extremities of the axis, and those of maximum effect in two opposite points at right angles to the axis; in which two latter the needle, when properly neutratralized, points directly to the centre of the ball.

This will be perhaps better understood by reference to fig. 3, where S is the shell, *a b* its axis, and *n s*, *n s*, &c. the

needle in its various positions prior to the motion, and $n' s'$, $n' s'$, &c. its direction as resulting from the motion; the rotation of the shell being from c towards d.. of course with the rotation reversed, the effect will be reversed also.

Now this effect you will, I think, find to be perfectly consistent with the view you have taken of the subject, in your letter of Jan. 13th, where you say in reference to your former query, and to the views I then entertained, "I should rather have expected a diminution of the magnetic polarity, commensurate to the rapidity of rotation and a change in the direction of the magnetic axis of the globe, from parallelism to that of the earth, to a position somewhere intermediate between that and the axis of rotation, but approaching nearer the latter as the velocity increased, &c."

The fact is, that the needle in my experiments being under no influence prior to the rotation from either the iron or the earth, the direction which it takes up in consequence of the motion, enables us to discover the precise direction of the new forces thus impressed upon the shell, and it will be seen immediately to indicate a polarization of the latter in the direction $c d$; that is, in a direction perpendicular to the axis of motion, and to the plane passing through that axis and the actual poles of the ball.

You will of course understand that I do not mean that such a polarization actually takes place; I mean merely that the cohesive power of the iron is such, as to resist in a certain degree the inductive powers of the earth, whereby the magnetic forces are changed, as you have suggested, from their original direction, parallel to the magnetic axis of the ball into a position oblique to it, which oblique forces

being resolved into two, the one parallel to the original axis, and the other perpendicular to it, and the former being nearly neutralized by the magnets used for the purpose in the first instance, the perpendicular forces will act upon the needle in the same manner as if the ball were really polarized in the direction above alluded to.

Having got this view of the subject, I soon found that many of my former results, which appeared to have scarcely any conformity among themselves, were perfectly consistent with this hypothesis: of these the experiments given above, before the needle was neutralized, may be mentioned. In these I found the point of change to be at about 30° on each side of the axis, so that the arcs in which similar effects were produced were divided into the unequal portions of 60°, 120°, 60°, and 120°, which appeared to be anomalous; but according to the view now taken of the subject, this is perfectly consistent; it is precisely what ought to happen according to the law tan. dip. = 2 tan. mag. lat. and which actually takes place on the earth. That is in passing from the magnetic equator 30° towards the pole, the dipping needle has actually described a quadrant, as referred to its position at the equator; and it would describe a quadrant, in an opposite direction in going 30° towards the other pole; so that in passing through 60° the needle is actually inverted; but if we start from mag. lat. 30° through the pole, we must pass through an arc of 120° before the direction of the needle is inverted, and the same in the other half of the meridian; and in like manner by referring the motion of my needle as induced by the rotation of the shell to its original magnetic direction, it is obvious that I ought to have found, as I actually

did before I was aware of the cause, a point of change at 30° distance on each side of the meridian passing through the axis; which meridian, as respects the induced power, is actually the equator of the new magnetic sphere.

To render this more obvious, let us refer to fig. 4, in which AB represents the axis of rotation of the shell, the black lines the needle in its natural direction, and the dotted lines the direction the needle has a tendency to assume according to the law above named, in consequence of the magnetism impressed by the rotation in the line *n s*. Beginning at the point A, if we say the motion is from left to right, that is from *n* to *n'*, it will be from right to left at 60°, 75°, 90°, &c. till we arrive again at 30°; at this point as at the former the new power is exerted in the actual direction of the needle, and if it were greater than its natural directive power, it would wholly invert it; in this case it would pass to either hand; but as the new power cannot invert it, it has no tendency to deflect it, and it therefore remains stationary. Thus one of the results which was at first the most perplexing, serves to confirm the law we have established.

On similar principles, if we conceive a circle passing vertically from 90° to 90°, and if the needle be perfectly neutralized at different positions in this circle, and rendered parallel to the axis at each, then in every case the needle will have a tendency to take up a position directly at right angles to the axis of the shell, and it will point in opposite directions at certain parts of this circle: thus, if to fix the idea we conceive the axis to be in the meridian, and the motion of the shell from west to east, then at the east point of the horizon the needle will point to the west, and it will do the

same at all points between the horizon and an altitude of 60°; beyond this, the north end will point to the east till we have passed the zenith 30° on the west side; and then again from this point to the west horizon the north end will again point to the west; and similar changes will take place below the ball. This, which is a necessary consequence of our hypothesis, is completely verified by experiment.

It will of course be understood, that the supposition of the axis being in the meridian is merely to fix the idea; for a similar motion takes place whatever direction the axis of the shell may have.

It is presumed, that what has now been stated is sufficient, without referring to any further experiments, to establish the principal fact adverted to in this letter, viz. that when any iron body is put in rapid rotation on any line not coinciding with its magnetic axis, a temporary derangement takes place in its magnetic powers, which in its effects is equivalent to a new axis of polarization perpendicular to the plane passing through its axis of polarization and rotation.

I have stated in the beginning of this letter the motives which led me to undertake these experiments; but notwithstanding I have certainly found a stronger effect produced by the rotation than I anticipated, yet it does not appear to be of a kind to throw any new light upon the difficult subject of terrestrial magnetism. I think there are strong reasons for assuming, that the magnetism of the earth is of that kind which we call induced magnetism; but at present we have no knowledge of the inductive principle, and are therefore unable to judge, how far the earth's rotation may be influential in producing those discrepancies from the gene-

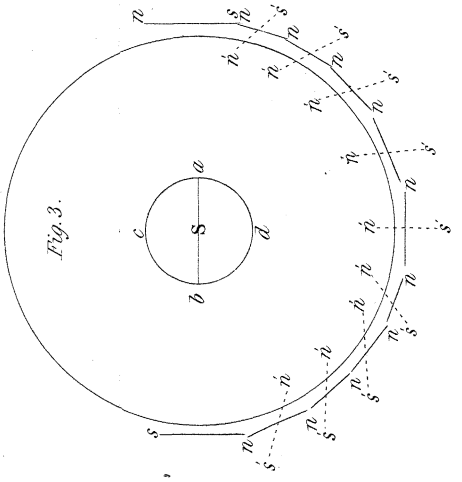
Fig. 3.
a
b
c
d
S

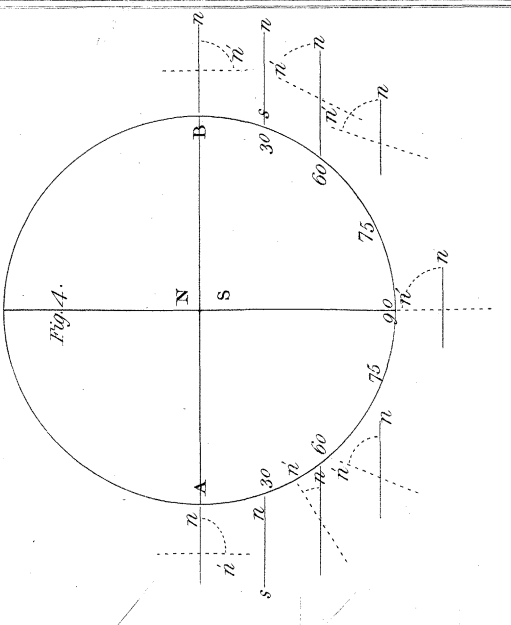
Fig. 4.
B
A
N
S
30
60
75
90

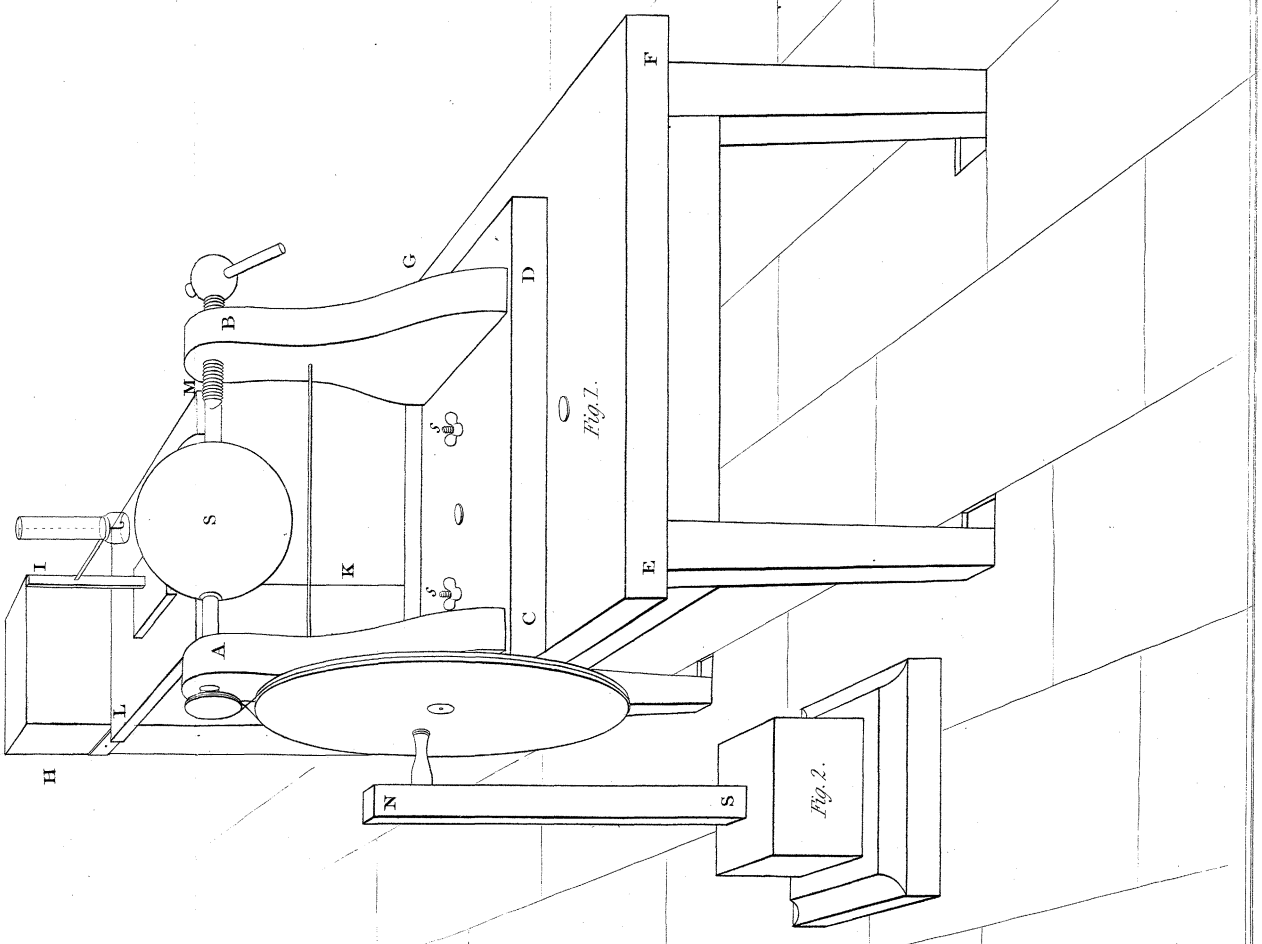
Fig. 1.
Fig. 2.
A
B
C
D
E
F
G
H
K
L
M
N
S

ral laws which are known to exist. The formula, which we owe to Mr. BIOT and to Mr. KRAFT, expressing the law of the dips in different latitudes, viz. tan. dip. = 2 tang. mag. lat. certainly agrees with observation in many cases, but the variation computed on the same principles, and which necessarily ought also to coincide with observation, is widely in error. It seems therefore very obvious that some disturbing cause exists, but whether any part of it can be attributed to the rotation of the earth is, notwithstanding the preceding results, very doubtful; at the same time I may perhaps be allowed to observe, that one of the essential conditions for the production of such an effect has place in the earth, viz. that it does not revolve about its polarized axis; and if the inductive principle through which it receives its magnetism be exterior to itself, then it would follow almost of necessity that some such an effect should take place. I beg however to be understood as advancing nothing in this letter, beyond the mere experimental fact above stated, which, even if it should find no useful application, may perhaps be thought sufficiently curious to be recorded in the Transactions of the Royal Society.

PETER BARLOW.