# PART III.

## *On Electro Magnetism.*

## SECTION I.

### SKETCH OF THE PRESENT STATE OF ELECTRO MAGNETISM.

230. IT was for many years suspected that there existed a strong analogy, if not a complete identity, between the electric and magnetic fluids, and various attempts were made to establish such relation on satisfactory principles. It was known, for instance, that lightning destroyed and reversed the polarity of magnetized needles, and that it produced a magnetic power in pieces of steel which had not before any such action. Now lightning and electricity have been long known to be identical; consequently, electricity ought to produce similar effects to lightning on magnetic and simple steel bars; but the attempts which were made to discover a satisfactory proof of this action by means of the electric apparatus were not attended with success; at least all that was effected in this way amounted only to communicating the

magnetic property to steel bars, but without the experimenter being able to predict in what directions the poles would lie, and therefore was little more than might be produced by a blow, by twisting, and various other means. It was indeed stated that the magnetism was more fully developed when the shock was passed through the needle transversely, than when it passed lengthwise; but still no definite conclusions could be drawn from the experiments.

231. Philosophers having thus failed of tracing the analogy between the electric and magnetic fluids, by means of the electrical apparatus, had next recourse to the Galvanic battery, which was known to possess electrical properties. Of these experiments those of Ritter are the only ones of any importance. He stated that he had succeeded, by placing a Louis d'or in contact with the extremities of a galvanic circuit, in giving to it a positive and negative electric pole, which remained after it had been in contact with other metals; he also magnetised a gold needle by means of the galvanic battery, and seems to have had some obscure ideas of electric terrestrial poles at right angles to the magnetic poles. These experiments, however, were never much regarded, and the relation between the two fluids seemed still to remain doubtful.

232. Soon after the time that Ritter made his

experiments, Professor Œrsted, of Copenhagen, published a work in which some hints are thrown out respecting the analogy between the electric, galvanic, and magnetic fluids; which were supposed to differ from each other only in their degree of tension. The galvanic fluid is there conceived to be more latent than the electric, and the magnetic still more so than the galvanic. The science, however, made no farther progress from this time (1807) till the year 1820, when the same learned Dane succeeded in establishing the reciprocal action of the galvanic and magnetic fluids upon each other by the most satisfactory experiments. These have been since repeated, and much extended by Ampere, Biot, Arago, in France; by Sir H. Davy, Professor Cummings, and Mr. Faraday, in England, and have thus led to the establishment of a new branch of philosophy designated electro-magnetism, of which it is proposed to give a concise view in the following pages.

233. *Œrsted's experiments.*—As these leading experiments are very concisely and clearly stated by the author, we shall give them in his own words.

The galvanic machine being charged, and its poles connected by a wire of any metal (which may be called the *conductor* or *uniting wire)*, the following effects will be noticed:

"Let the straight part of this wire be placed horizontally above the magnetic needle properly suspended, and parallel to it. If necessary, the uniting wire is bent so as to assume a proper position for the experiment. Things being in this state the needle will be moved, and the end of it next the negative side of the battery will go westward.

"If the distance of the uniting wire does not exceed three quarters of an inch from the needle, the declination of the needle makes an angle of about 45°. If the distance is increased, the angle diminishes proportionally. The declination likewise varies with the power of the battery.

"The uniting wire may change its place, either towards the east or west, provided it continue parallel to the needle, without any other change of the effect than in respect to its quantity. Hence the effect cannot be ascribed to attraction; for the same pole of the magnetic needle which approaches the uniting wire, while placed on its east side, ought to recede from it when on the west side, if these declinations depended on attraction and repulsions. The uniting conductor may consist of several wires or metallic ribbons connected together. The nature of the metal does not alter the effect, but merely the quantity. Wires of platinum, gold, silver, brass, iron, ribbons of lead and tin, a mass of mercury, were employed with equal success. The conductor does not lose its effect though interrupted by water, unless the interruption amounts to several inches in length.

"The effect of the uniting wire passes to the needle through glass, metals, wood, water, resin, stone ware, stones, for it is not taken away by interposing plates of glass, metal, or wood. Even glass, metal, and wood, interposed at once, do not destroy, and indeed scarcely diminish the effect. The disc of the electrophorus, plates of porphyry, a stone-ware vessel, even filled with water, were interposed with the same result. We found the effects unchanged when the needle was included in a brass box filled with water. It is needless to observe that the transmission of effects through all these matters has never before been observed in electricity and galvanism. If the uniting wire be placed in a horizontal plane under the magnetic needle, all the effects are the same as when it is above the needle, only they are in opposite directions; for the pole of the magnetic needle next the negative end of the battery declines to the east.

"That these facts may be more easily retained, we may use this formula,—the pole above which the negative electricity enters is turned to the *west*; under which, to the *east*.

"If the uniting wire be so turned in a horizontal plane as to form a gradually increasing angle with the magnetic meridian, the declination of the needle *increases*, if the motion of the wire be towards the place of the disturbed needle; but it diminishes if the wire moves further from that place.

"When the uniting wire is situated in the same horizontal plane in which the needle moves, and parallel to it, no declination is produced either to the east or west; but an *inclination* takes place, so that the pole next which the negative electricity enters the wire is *depressed* when the wire is situated on the west side, and elevated when situated on the east side.

"If the uniting wire be placed perpendicularly to the plane of the magnetic meridian, whether above or below it, the needle remains at rest, unless it be very near the pole; in that case the pole is *elevated* when the entrance is from the *west* side of the wire, and depressed when from the east side.

"When the uniting wire is placed perpendicularly opposite to the pole of the magnetic needle, and the upper extremity of the wire receives the negative electricity, the pole is moved towards the east; but when the wire is opposite to a point between the pole and the middle of the needle, the pole is moved towards the west. When the upper end of the wire receives positive electricity, the phenomena are reversed.

"If the uniting wire be bent so as to form two legs parallel to each other, it repels or attracts the magnetic poles according to the different conditions of the case. Suppose the wire placed opposite to either pole of the needle, so that the plane of the parallel legs is perpendicular to the magnetic meridian, and let the eastern leg be united with the negative end, the western leg with the positive end of the battery, and in that case the nearest pole will be repelled either to the east or west, according to the position of the plane of the leg. The eastmost leg being united with the positive, and westward with the negative side of the battery, the nearest pole will be attracted. When the plane of the legs is placed perpendicular to the place between the pole and the middle of the needle, the same effects recur, but reversed.

"A brass needle, suspended like a magnetic needle, is not moved by the effect of the uniting wire. Needles of glass and of gum lac, remain likewise quiescent."

233. These facts having laid the foundation of the present interesting science of electro magnetism, I have thought it best to give the statement in the author's own words; but in what follows, it will be necessary to be more concise.

The experiments of Mr. Œrsted were no sooner promulgated, than they were repeated and considerably extended by M. M. Ampere, Arago, and Biot; by Sir H. Davy, Mr. Faraday, and Professor Cummings, as well as by several celebrated German philosophers; and many curious and interesting facts and phenomenas were thus elicited.

234. M. Ampere, for instance, discovered that not only there is a reciprocal action between the galvanic wire and the magnetic needle, but that two such wires act upon each other, by attraction, when they both proceed from the same extremity of the battery, and by repulsion when they proceed from opposite extremities; that is, two conducting wires, free to move, being placed parallel to each other, and the corresponding extremities proceeding to the like poles of two different galvanic machines, the wires will be attracted to each other; but if the corresponding extremities of the wire proceed from contrary poles of the batteries, then the wires will indicate a mutual repulsion between them.

235. Again, it was shown by M. Arago that the connecting wire of a galvanic battery had an obvious action upon iron filings, and that it would hold them suspended like an artificial magnet, but that they fell the moment the contact with the battery was broken. The same thing was discovered by Sir H. Davy, who also showed that the filings on the opposite sides of two parallel wires attracted each other, and that those on the same sides repelled.

236. The latter experiments naturally led to an attempt to magnetize steel wires by the galvanic

battery, in which the first successful attempt was made by Sir H. Davy, although it was effected at nearly the same time by M. Arago. In the first instance the needle was simply laid transverse of the single wire, and the operation required a certain time; but M. Arago afterwards made use of a spiral wire, and was thus enabled to produce the maximum effect almost instantaneously. Sir H. Davy also succeeded in magnetizing steel needles with the electrical battery at very considerable distances, and thus demonstrated that the magnetic power was not peculiar to the galvanic apparatus.

237. The next question was, since there is so obvious a connection between the freely suspended galvanic wire and a magnet, has the former a directive quality from the influence of the terrestrial magnetism?

This led M. Ampere to the construction of a simple apparatus, which will be described in a subsequent section, and by which he proved that if a part of the galvanic wire, bent into the form of a rectangle nearly shut, and free to move, be left to the action of the terrestrial magnetism, it will adjust its plane to one perpendicular to the magnetic meridian, and that by giving to a similarly formed wire a freedom of motion on a horizontal axis, it will conform itself to that plane which in our first part has been called the plane of no attraction; that is, the plane of the wire will in all cases have a tendency to place itself at right angles with the plane of the magnetic meridian, and to the line of direction of the dipping needle.

These experiments are more fully illustrated in our last section.

238. At this stage of the enquiry Mr. Faraday, of the Royal Institution, commenced his enquiries. He proved that the action which had hitherto been noticed between the magnetic and the galvanic wire, was neither attraction nor repulsion, but was of such a nature as to give to the magnetic needle a tendency to revolve about the wire, and he at length succeeded in producing this rotation; viz. he was enabled by a very simple apparatus, which we have described in our third section, to cause either pole of a magnet to revolve about a fixed galvanic wire, and conversely, by fixing the magnet, he caused the wire to revolve about the former, and by the same apparatus also, the wire and magnet being both free, may be made to revolve about each other; and he subsequently was enabled to produce a rotation of the wire by the mere influence of the terrestrial magnetism upon it. These beautiful experiments threw an entire new light upon the science of electro magnetism.

239. M. Ampere having been informed of Mr. Faraday's experiments, succeeded in causing the magnet to revolve on its own axis, by introducing

it as a part of the galvanic circuit; an experiment attempted by Mr. Faraday, but which he had not been able to perform; and Sir H. Davy by his experiments on the mercurial vortices, proved also the rotation of the wire on its axis, which is effected in another manner in our 10th experiment. See section iii.

240. Such was the state of this science when I undertook the experiments reported in the following section, and by which, if I have not deceived myself, the whole of the apparently anomalous actions hitherto observed, may not only be explained, as to the general effects, but the disturbance on the needle computed for any determinate position of the compass and wire, in a manner very similar, but more simple, than that which has been illustrated in reference to the iron ball and magnetic needle.

It may be proper to observe that several experiments, besides those alluded to above, had already been made by other philosophers, and which led to many curious facts, but as they do not appear to have had any influence in advancing the theory of the science they have not been referred to in the preceding sketch; but some of them are given in our third section.

## SECTION II.

### ON THE MATHEMATICAL LAWS OF ELECTRO MAGNETISM.*

241. ALL the experiments that have been made on the subject of electro magnetism, since the first discovery of that power by Mr. Œrsted, seem to indicate a strong affinity, although not a complete identity, between the simply magnetic and the electro magnetic fluids; or, if the identity be admitted, still a certain difference must be conceived to have place in the modes of action.

In the preceding parts of this work I have attempted to reduce the laws of induced magnetism to mathematical principles, and to render the results susceptible of numerical computation, the mass of iron, and its position with respect to the compass, being given; and as soon as I heard of Mr. Œrsted's discovery, I was desirous to establish, on similar principles, the law of electro magnetism; but it was some time before I was able to construct an apparatus convenient for the purpose. Having, however, at length effected this necessary prelimi-

* The substance of this section was placed in the hands of Sir H. Davy by Major Colby, last March, and was read before the Royal Society, May 23. I am sorry I have been obliged to publish it before the council has decided respecting its appearance in the Transactions.

nary to my satisfaction, I proceeded to make the course of experiments, and to undertake the investigations which form the subject of the present section.

242. My first object was to repeat very carefully all the experiments of Mr. Œrsted, M. M. Ampere, and Arago; of Sir H. Davy and Mr. Faraday, with some others suggested by the results thus obtained; and having attentively considered all the peculiarities of action thus developed, I was led to consider that all the apparently anomalous effects produced on a magnetized needle by the action of a galvanic wire, might be explained by the admission of one simple principle; viz. *that every particle of the galvanic fluid in the conducting wire acts on every particle of the magnetic fluid in a magnetized needle, with a force varying inversely as the square of the distance; but that the action of the particles of the fluid in the wire is neither to attract nor to repel either poles of a magnetic particle, but a tangential force which has a tendency to place the poles of either fluids at right angles to those of the other; whereby a magnetic particle, supposing it under the influence of the wire only, would always place itself at right angles to the line let fall from it perpendicular to the wire, and to the direction of the wire itself at that point.*

I pretend not to illustrate the mechanical principles by which such an action can be produced; I propose only to show, that if such a force be admitted, all the results obtained from the reciprocal action of a galvanic wire and a magnetized needle may not only be explained, but computed, and that the results agree numerically with experiments.

243. The galvanic machine which I have employed, is constructed after the principle of Dr. Hare's colorimoter, differing from his only in the mechanical contrivance for lowering and raising it out of the fluid; it consists of 20 zinc and 20 copper plates, each ten inches square; but it possesses a power far beyond what is requisite for repeating all the experiments alluded to in the commencement of this paper.

244. That part of the apparatus which peculiarly appertains to the experiments I am about to detail, is represented in (fig. 1. pl. 4). A B is an upright stand, placed near the poles of the battery; *a b*, *c d*, are two staples of stout copper wire, driven into the upright, the two ends at *b* and *c* passing quite through, as shown at C and *Z*; and on which two wires are fastened by spiral turns, and with which the communication is made with the poles of the battery; *e f*, *g h*, are two copper wires of the same dimension as the staples, each four feet long, having their ends flattened and drilled so as just to enable them to slide freely upon the wires *a b*, *c d*, and the vertical wire *f h*, also 4 feet

in length, which passes through a hole in the top of the table F G H I, and so tight as to render it perfectly fixed. On the plane of the table, which is two feet in square, the circle N E S W is described about the centre *o*, and divided into the points of the compass and smaller divisions; N S, is an index or box ruler, through which the wire *f h* passes, so that the former may be turned freely about the latter, and set to any proposed azimuth. On this ruler is placed the small compass *c'*, by means of which the deviation at any time may be taken; *c''* is another compass placed on the top of the support L *c''*, and is intended to remain fixed in its place, in order to serve as a standard for estimating and comparing the power of the battery at different times.

For the principal experiments this apparatus is placed so that the plane of the rectangle of wires is perpendicular to the magnetic meridian; because in this position the horizontal wires being east and west, they have no effect in deflection the needle from its direction, (at least there is only one exception to this, which will be noticed hereafter,) and consequently all the effect produced upon the needle during the rotation of the index in the circle N E S W, is due to the vertical wire only, except so far as the horizontal wires may increase or diminish the directive power of the needle.

This, however, in the cases to which we shall refer is very inconsiderable.

245. But in order that we may know precisely what part of the change of deviation between one situation of the compass and another is actually due to that change of position, recourse must be had to the standard compass, which, always remaining fixed in its position, may be used as a constant indicator of the strength of the battery. But as the application of this measure to computation is involved in principles not at present explained, it will be proper first to inform the reader of the means which I employ in the first instance to preserve an uniformity of action during every separate course of experiments. These were as follow:—

246. The vessel which contains the dilute acid, into which the plates are immersed, holds nearly twenty gallons; and I begin the experiments with little more than twelve gallons; moreover the plates are not, in the first instance, let down to their lowest point. The intensity shown by the standard compass after the connection has been made, some minutes is noted; and by breaking off and making the contact anew, this same intensity occurs again, the power being always strongest when the contact is first made; then when the standard compass returns to its former

bearing, the observation with the other compass is taken; the contact broken, and renewed, and so on as long as the battery retains sufficient power. When this fails, the plates are lowered a little more, the power thus increased, and the observations resumed, till at length the plates being wholly down, and the power too weak, recourse is had to a supply of more dilute acid; by which means a tolerably steady action is kept up longer than is necessary for any series of experiments of this kind. It will be observed here, that in this case the only use made of the standard compass is to indicate the *same intensity of action*, and consequently involves no theoretical principle that will be objected to by the most scrupulous theorist or observer, but it will be seen in a subsequent article that this indicator is susceptible of a more extensive application.

247. Having thus made the reader acquainted with the means employed and the precautions adopted, to ensure accuracy, I shall proceed now to explain the principles of computation, and to compare the numerical results thus obtained, with those derived from experiments.

According to the hypothesis (art. 242) if we conceive the wire in the first instance to be vertical, and the compass placed to the north or south of it, and opposite its middle point, the centre of action will lie in the horizontal plane, and at right angles to the natural horizontal direction of the needle. The latter, therefore, (which for simplicity sake we shall at present consider as indefinitely short with regard to the distance), will at either of those points, be acted upon by two rectangular forces; viz. the galvanic force in an east and west direction, and which we may denote by $f$, and the natural magnetic or directive force $m$; consequently, according to the principle of forces, the resultant will be expressed by $\sqrt{(f^2 + m^2)}$ and the angle which it makes with the natural direction of the needle, being called $\Delta$, we shall have

$$\tan \Delta = \frac{f}{m} \quad \ldots\ldots\ldots\ldots \quad (1)$$

*Hence the magnetic force being constant, the tangent of the needle's deviation at the north or south will be a correct measure of the galvanic power.*

248. We have thus a principle by means of which we may verify a part at least of our theory by experiments.

For example; since by the supposition every particle of the galvanic vertical wire acts inversely as the square of its distance from a given point, we ought to find a determined relation between the tangent of deviation, and the length of the wire; or the length of the wire remaining constant, between the tangent of deviation and the distance, provided always that the intensity of the battery remain constant.

The apparatus already explained furnishes us with the opportunity of making both these comparisons. For by means of the sliding horizontal rods, the vertical conducting part of the wire may be shortened in an instant; and in the second case, it is only necessary to slide up the compass to different distances, which may likewise be done so quickly, that it will not be necessary even to have recourse to the standard compass.

It is fortunate also that the calculation here alluded to is of the simplest kind. For denoting the length of the wire by $2\ l$, and the distance of the compass by $d$; assuming also $x$ as any variable length, the corresponding elementary action at this distance will be $\frac{\dot{x}}{d^2 + x^2}$, and the sum of these actions will be

$$\int \frac{\dot{x}}{d^2 + x^2} = \frac{1}{d} \text{ arc. tan } \frac{x}{d}$$

which vanishes when $x$ vanishes; and which therefore when $x = l$, and the two lengths are included, becomes

$$\frac{2}{d} \text{ arc. tan } \frac{l}{d}$$

consequently if we denote the deviation, as we have done above by $\Delta$, we ought to find this force vary inversely as tan $\Delta$, or

$$\cot \Delta \left\{ \frac{1}{d} \text{ arc. tan } \frac{l}{d} \right\} = \text{a constant quantity.}$$

The following are a few out of numerous experiments of this kind which I have made, and which have been all found equally satisfactory.

249. *Experiments to determine the magnetic deviation caused by a galvanic vertical wire at different distances. Length of vertical wire* 36 *inches.*

| Deviation by standard compass. | Distance of the other compass from the wire. | Mean* observed deviation. $\Delta$ | Value of $\frac{2}{d}$ arc. tan $\frac{l}{d}$ $= A$ | Constant product. $A \cot \Delta$ |
|---|---|---|---|---|
| 25° 0′ | 12 inches | 5° 37′ | 18·772 | 190880 |
| Ditto | 8 ditto | 11 15 | 34·100 | 171432 |
| Ditto | 6 ditto | 16 30 | 47·712 | 161062 |
| Ditto | 4 ditto | 26 30 | 77·500 | 154440 |
| | | | Mean | 164728 |

250. When it is considered that these observations were made on a compass needle only one inch in length, and that the divisions extended only to quarter points, it is impossible to expect a closer approximation. The needle and card, however, being delicately suspended, and the latter very distinctly divided, I could depend upon my observations to the nearest *degree;* for by means of a strong magnifying power I could always bisect and trisect the quarter points without any very sensible error.

* That is, the mean of two observations at each station of the compass; the contact being changed. The same is to be understood of the deviation with the standard compass.

## EXPERIMENTS

251. *To determine the magnetic deviation caused by a vertical galvanic wire; the length being varied, but the distance constantly* 9 *inches.*

| Deviation by standard compass. | Length of vertical wire. | Observed deviation. $= \Delta$ | | Value of $\frac{2}{d}$ arc. tan $\frac{l}{d}$ $= A$ | Constant product. $A \cot \Delta$ |
|---|---|---|---|---|---|
| | | ° | ′ | | |
| ——* | 36 inches | 22 | 30 | 63·450 | 15318 |
| —— | 24 ditto | 18 | 16 | 53·133 | 16097 |
| —— | 16 ditto | 12 | 0 | 41·633 | 19557 |
| —— | 12 ditto | 8 | 25 | 33·683 | 22764 |
| | | | | Mean | 18220 |

252. These results (except the last) although not so uniform as the above will be found, notwithstanding as nearly so as we have any reason to expect, particularly as we were not able in these to avail ourselves of the use of the standard compass.

I am, however, inclined to attribute the discrepance between the observed deviation and the computed, as the vertical wire shortens, to the approach

* The standard compass cannot be used in these experiments, because the wire by which it is deflected is necessarily shortened with that on which the observations are made.

of the horizontal wire, which has a tendency to increase or decrease the directive power of the needle, according to the pole with which the wire is connected, (as will be seen as we proceed) and thereby rendering the action of the vertical wire more or less effective, according to the circumstances of the connection. (See art. 262.)

253. Having thus far versified our hypothesis by experiment, let us now proceed to the consideration of the deviation in different azimuths.

Let Z (fig. 2.) represent the horizontal section of a vertical wire proceeding from the zinc end of the battery downwards, *o* a particle of the magnetic fluid whose natural direction is in *n s*, join Z *o*, and draw *r t*, perpendicular to Z *o*; then, according to the hypothesis, the direction of the force excited by the wire Z, will be in the line *r t*. Now the intensity of this force to turn the particle about *o*, will vary as sin $\angle$ *t o n*, or as cos S Z *o*, and its intensity in the line *n s*, will vary as sin S Z *o*, which latter force will be additive to the directive power of the terrestrial magnetism. Let the latter force on the horizontal needle be called *m*, and the galvanic force in $r\,t = f$, also the angle S Z $o = \phi$, S being the south point of the horizon.

Then the particle *o*, will be urged by the two rectangular forces.

$m + f \sin \phi$ in the direction $n\,s$

$f \cos \phi$ in the direction perpendicular to $n\,s$, consequently, denoting the angle of the resultant, or the deviation of the particle from the line $n\,s$ by $\delta$, we shall have from the known principle of forces

$$\tan \delta = \frac{f \cos \phi}{m + f \sin \phi} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Let $\Delta$ denote the deviation of the needle at the south point; then, from what has been already demonstrated (equation *i*)

$$f = m \tan \Delta$$

which being substituted for $f$ in the above equation, reduces it immediately to

$$\tan \delta = \frac{\cos \phi}{\cot \Delta + \sin \phi} \quad \ldots\ldots\ldots\ldots \quad (3)$$

From which equation (the deviation $\Delta$ being supposed known) the deviation $\delta$ at every other azimuth may be computed.

254. This formula is as comprehensive as it is simple, and indicates by the changes of the signs in $\sin \phi$ and $\cos \phi$, a variety of cases, the whole of which I have most satisfactorily confirmed by experiments. These may be stated as follow:

First, $\cot \Delta$ may be greater, equal to, or less than unity, accordingly as the observed deviation at the south, is less, equal to, or greater than four points, or 45°. This consideration leads to three distinct cases.

### CASE I. *when* cot $\Delta > 1$.

Here the denominator of the formula is necessarily positive throughout the circle. In the first quadrant of which, sin $\phi$, and cos $\phi$, being both positive, tan $\delta$ is also positive, and the deviation is all one way.

2. When $\phi = 90°$, cos $\phi = 0$; and tan $\delta = 0$; there is therefore no deviation at the east point.

3. In the second quadrant, cos $\phi$ is negative, as is also tan $\delta$; the deviation is therefore now the contrary way, but it is the same in quantity in all equidistant situations north or south of the east.

4. At the north point, sin $\phi = 0$, cos $\phi = -1$, and we have

$$\tan \delta = -\tan \Delta$$

the deviation is therefore the same as at the south, but in an opposite direction.

5. In the third quadrant, cos $\phi$ is still negative, as in the second, but sin $\phi$ is also negative, and therefore the deviation although of the same kind in direction as in the second quadrant, is greater in its amount, the denominator being less.

6. At the west, the cos $\phi$ vanishes, tan $\delta$ becomes zero, and the needle again resumes its natural direction.

7. In the fourth quadrant, cos $\phi$ again becomes positive, the deviation changes in its quality, but is the same in quantity as in the third quadrant.

CASE II. *when* cot $\Delta = 1$.

8. Here the results are precisely the same in the four quadrants with respect to direction, as in those above explained; except that at the west point, where sin $\phi$ and cot $\Delta$, being each equal to unity, and with contrary signs, the denominator vanishes with the numerator, and the needle is indifferent to any direction.

CASE III. *when* cot $\Delta < 1$.

9. Here in the first two quadrants the deviation has the same character as in the preceding cases. But in the third quadrant, the denominator of the fraction vanishes before the needle reaches the west point, tan $\delta$ becomes infinite, and the deviation is 90°; that is, the needle will stand east and west.

10. For the remainder of this quadrant, tan $\delta$ is *plus*, and the character of the deviation changes, till at the west point the needle is found inverted.

11. From this point cos $\phi$ becomes positive, but the denominator being negative, tan $\delta$ is negative, and remains so till it becomes infinitely negative, as on the other side of the west, and the deviation is 270°.

12. Lastly, from this point to the south, the denominator is positive, and tan $\delta$ has the same sign as at first, and at the south point resumes its original deviation, provided the intensity of the battery has been preserved constant.

255. To illustrate this last casé by an example, let us suppose that the deviation at the south point is greater than 45°, as for instance 50°, then since cotan 50° = 0·83909, and sin (180° + 57° 2′) = — 0·83914 ; the denominator will vanish when the compass is placed 57° from the north towards the west; the tan $\delta$ is therefore infinite, or the needle will at this place stand east and west.

Proceeding on towards the west, the deviation will increase more and more till, at the west point itself, the needle will be found inverted. At 57° from the south, or 33° from the west towards the south, the denominator again vanishes, and the needle stands west and east; from which position the deviation decreases till it becomes 50° again at the south point as at first.

Hence it appears that in passing the index which carries the compass from the position west 33° N to west 33° S, that is through 66° only, the needle ought to make a complete semi-revolution on its pivot; whereas if we pass the index the other way, viz. through the north, east and south, we must move it through 294° to produce the same motion in the needle. A single trial will show how correctly this theoretical deduction accords with experiment.

256. In the above case the needle makes a complete revolution on its pivot while it is carried round the wire; but this will not happen if the deviation

at the south be less than 45°. Let us, for example, suppose it to be 40°; then cotan 40° = 1·19175, and sin $\phi$ is never greater than + 1, or less than — 1; consequently, the denominator will not become zero. In this case the deviation will be the greatest when

$$\frac{\cos \phi}{\cot 40^\circ + \sin \phi} \text{ is a maximum,}$$

which happens when sin $\phi$ = — tan 40°, viz. at 33° from the west towards the north and south; but in passing the index through this arc, the north point of the needle will not, as in the former instance, pass through the south, but will fall back towards the north, passing through it as the index passes through the west. Here again the theory is most satisfactorily confirmed by observation.

As any one may repeat these experiments, and make his own remarks, I shall not insist farther upon them in this place.

It is proper, however, to caution the reader that to ensure success, it is necessary to have a short needle, and to work at as great a distance from the wire as the power of the battery will allow of; because the above deductions have been made by supposing the length of the needle inconsiderable in comparison with the distance and length of the wire.

257. The following is one series of numerical results derived from the preceding formula, with the corresponding observations.

## EXPERIMENTS

*On the deviation of the needle caused by a vertical galvani[c] wire at different azimuths, the deviation at the south poi[nt] being* 16° 30′, *and the standard compass showing alwa[ys]* 25°.

| Azimuths. | $\tan\delta = \dfrac{\cos\phi}{\cot.\Delta + \sin\phi}$ Value of | | Corresponding angle of deviation. | | Observed deviation. | | The same observed i[n] points and quarter points. | |
|---|---|---|---|---|---|---|---|---|
| | | | ° | ′ | ° | ′ | p. | qp. |
| South E | + | ·296 | +16 | 30 | +16 | 30 | | |
| S 2 points E | + | ·245 | +13 | 46 | +14 | 4 | 1 | 1 |
| S 4 points E | + | ·173 | + 9 | 49 | + 8 | 26 | 0 | 3 |
| S 6 points E | + | ·089 | + 5 | 6 | + 5 | 37 | 0 | 2 |
| East | | 000 | 0 | 0 | 0 | 0 | 0 | 0 |
| N 6 points E | — | ·089 | — 5 | 6 | — 5 | 37 | 0 | 2 |
| N 4 points E | — | ·173 | — 9 | 49 | — 8 | 26 | 0 | 3 |
| N 2 points E | — | ·245 | —13 | 46 | —14 | 4 | 1 | 1 |
| North | — | ·296 | —16 | 30 | —16 | 47 | 1 | 2 |
| N 2 points W | — | ·389 | —21 | 16 | —22 | 30 | 2 | 0 |
| N 4 points W | — | ·265 | —14 | 51 | —14 | 4 | 1 | 1 |
| N 6 points W | — | ·156 | — 8 | 53 | — 8 | 26 | 0 | 3 |
| West | | 000 | 0 | 0 | 0 | 0 | 0 | 0 |
| S 6 points W | + | ·156 | + 8 | 53 | + 8 | 26 | 0 | 3 |
| S 4 points W | + | ·265 | +14 | 51 | +14 | 4 | 0 | 3 |
| S 2 points W | + | ·389 | +21 | 16 | +22 | 30 | 2 | 0 |
| South | + | ·296 | +16 | 30 | +16 | 47 | 1 | 2 |

Although the aberrations in these results are greater than could be admitted in experiments which allowed of more accurate means of observation, yet they are such as may, I trust with confidence, be adduced as a confirmation of the hypothesis that has been advanced. They will probably be repeated with more accurate means than I possess, and on a larger scale; when a closer approximation will, I have no doubt, be obtained.

258. It may be proper here to observe, that the sign of plus or minus prefixed to the angle of deviation, is wholly arbitrary. I have called it *plus* when the deviation is easterly, and *minus* when it is westerly.

This sign however being thus fixed, it is necessary to give an indication of the course of the needle as it is affeced by the galvanic wire, which at present has only been stated in general terms; viz. that it has a tendency to arrange itself at right angles to the line joining the nearest point of the wire and its axis.

To conceive this effect more particularly, the reader must consider himself as a part of the galvanic circuit, having his head towards the zinc end of the battery, and his face to the needle; then the effect will be to carry the north end of the needle placed before him always to his left hand.*

This is in all cases sufficient to remember, because it necessarily implies that the south end is carried to the right, and that if the wire proceed from the other extremity of the battery, his direction will be reversed, as will also the motion of the needle, and the signs of the angles of deviation.

* This supposes a simple combination of two plates; it is the reverse with a compound battery.

259. We have at present shown no other application of the standard compass than that of its indicating an uniformity of power in the battery at the time of registering the observation; it may, however, as we have already observed, be equally useful in other cases. For example, let us suppose it to be placed (as in the experiments reported above) to the north of the wire, and let its deviation at any given intensity of the battery be D, while that of the other compass at the north or south is $\Delta$, and let its deviation with a different intensity be D′, and the corresponding deviation with the other compass be $\Delta'$; then it is obvious from what has been stated, that

$$\tan D : \tan \Delta :: \tan D' : \tan \Delta'$$

consequently, if the power of the battery between any two observations is such as to alter the deviation of the standard compass from D to D′, that of the principal compass will be found from the equation

$$\tan \Delta' = \frac{\tan \Delta \tan D'}{\tan D}$$

We have therefore only to introduce this value of $\tan \Delta'$ into our general equation,

$$\tan \delta = \frac{\cos \phi}{\cot \Delta' + \sin \phi}$$

which will thus become

$$\tan \delta = \frac{\cos \phi}{\dfrac{\tan D}{\tan \Delta \tan D'} + \sin \phi}$$

a formula which is applicable to all degrees of intensity.

260. Let us now examine the circumstances attending the deviations caused by a horizonal wire placed in the magnetic meridian.

In this case conceive S E N W (fig. 3) to represent a vertical circle in the plane of the section of the wire, and corresponding with its middle point, E and W being its east and west points. Let $o$ be a magnetic particle in a horizontal needle, the direction of which is perpendicular to the plane S E N W. Let the force in the line $r\,t$ be denoted by $f$ as before, and call the angle S Z $o = \phi'$. Resolve $f$ into the two rectangle forces, $f \sin \phi'$, $f \cos \phi'$; the former of which being perpendicular to the horizon will only affect the inclination of the needle; but the other force, $f \cos \phi'$, being horizontal, and in an east and west plane, will be wholly effective in producing its deviation.

Let $\Delta$ be the deviation at S, which will be the same whether the wire be horizontal or vertical, because in both cases the tangential force is horizontal and perpendicular to the needle.

Consequently, as in the former case,

$$f = m \tan \Delta$$

and our two forces become

$$m \tan \Delta \cos \phi', \text{ in the horizontal plane}$$

$$m \tan \Delta \sin \phi', \text{ in the vertical plane}$$

the former, as we have seen, is the only one which affects the bearing of the needle, and is therefore the only one we have to examine.

From this we obtain,

$$\tan \delta = \frac{m \tan \Delta . \cos \phi'}{m} = \tan \Delta \cos \phi'$$

and hence we learn, that as the compass is carried round the wire in a vertical circle, the tangent of the deviation of the needle will vary as the cosine of the angle S *Z* *o*.

261. This cosine being zero at the east point,* the tangent $\delta$ vanishes and the needle stands in its natural direction, but will be inclined downwards by the force

$$\tan \Delta \sin \phi'$$

Beyond the east point, cos $\phi'$ becomes negative, the sign of tan $\delta$ changes, and consequently the deviation is now the contrary way. At N, cos $\phi$ $= - 1$ and tan $\delta = -$ tan $\Delta$, we have therefore here the same deviation as at first, but in an opposite direction.

In the next or third quadrant, cos $\phi'$ is still negative, and the deviation is the same both in quantity and direction as in the second quadrant. At the west point, cos $\phi'$ again vanishes, and the needle returns to its proper direction. In the

* By the east point is meant that point in the circle which is to the east of the wire, and in the same horizontal plane with it.

fourth quadrant cos $\phi'$ is positive, and the deviation is the same both in quantity and direction as in the first quadrant. There is not therefore in this case the same kind of anomalous deviation which takes place in the vertical wire.

The other force tan $\Delta$ sin $\phi$, which affects the needle's inclination, is greater at the east and west points; it is nothing in the zenith and nadir, and in all intermediate positions it varies as the sin $\phi$. All these deductions are perfectly consistent with the general character of the observations of Mr. Œrsted, and with my own, and I have not therefore thought it requisite to submit them to the test of numerical experiments.

262. It has been said by some observers that a horizontal wire arranged east and west has no power on the needle, except to disturb its inclination. But it ought obviously, according to our theory, to produce the same anomalous action as the vertical wire in the case where cot $\Delta$ is equal to or less than unity; because then the galvanic force being equal to, or exceeding the terrestrial directive force, it ought, when the two are opposite, to reverse the direction of the needle; and this will be found to be the case by applying the latter above the upper, or below the lower horizontal wire, when the former is connected with the zinc end of the battery, and the reverse with the opposite connection. It is this effect to weaken or

reverse the direction of the needle that we have alluded to in (arts. 250 and 252.)

263. I might now proceed to a variety of other investigations for different directions of the wire, or even generally for every possible direction, and for a needle freely suspended and susceptible of motion in all directions; but as it would be difficult to submit the results to the test of numerical experiments, I leave the task to those who have more leisure for pursuing the subject, and who may perhaps be disposed to enter upon the investigation in more general terms. My results are necessarily only approximative; because I have throughout supposed the needle indefinitely short in comparison with the distance and length of the wire; but by this means I have rendered the subject perfectly intelligible to every one; whereas had I taken the actual case of the reciprocal action of every particle of the fluid in the wire upon every particle in the needle, and had been able to complete the investigation, it could only have been understood by a few mathematicians; at the same time the minute corrections thus introduced would not have been appreciable in the comparison of the results with experiments; these latter being necessarily both liable to small irregularities and difficult to observe.

264. It will have been noticed that I have only attempted to illustrate the nature of the action which has place between a galvanic wire and the

compass, and not that of one galvanic wire on another. What modification the hypothesis may require to explain the latter class of phenomena, will be examined hereafter. I have hitherto supposed only one species of action in the galvanic wire; but it is highly probable that it is compound, and that while the north end of the needle is carried in one direction, by the action we have supposed, the south end is carried in an opposite direction; not merely as a consequence of the first force, but by a distinct power. This will not, however, in any respect affect our investigation; because both forces lead to similar results.

We have seen a precisely analogous instance in our investigation of the laws of induced magnetism, (art. 158); where it appears that we obtain exactly the same results, whether we consider the magnetic fluid as simple, and acting equally on each extremity of the needle, or as compound, and acting reciprocally on both; and it was only for the sake of certain analogies I was desirous of preserving, that I was induced to adopt the latter hypothesis. Similar reasons may also render it necessary, in this case, to admit the existence of a compound action in the galvanic wire; but which, as we have already stated, will in no respect affect the preceding investigations.

I am well aware of the difficulty of conceiving the mechanical principles by which such a tangential force, as is here assumed, can operate; but on the other hand it must, I think, be conceded, that the simple power of attraction is equally difficult to conceive, and that we admit it, not from having any idea of the *modus operandi*, but because we find that it leads to results that are consistent with actual observations; and I have endeavoured to show, in the preceding pages, that the force we have assumed is admissible upon precisely the same ground.

Let us now see how far the same hypothesis is consistent with the various other facts and phenomena that have been elicited by different philosophers in their pursuit of this interesting inquiry.

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## SECTION III.

### A COURSE OF ELECTRO MAGNETIC EXPERIMENTS.

265. In the preceding sections of this part, I have endeavoured first, to give a concise sketch of what has been effected in this science since its first introduction by Mr. Œrsted; and secondly, to illustrate the theoretical principles on which we have supposed the action to depend. I have also proved, by a comparison of several numerical results, that the theory assumed is consistent with experiments

in the particular cases in question; but it still remains to be shown that it is likewise consistent with the various facts and phenomena that have been elicited by the several experimenters to whom we have already referred.

In following up this view of the subject I shall no longer regard the order in which the several isolated facts have been developed, but shall endeavour rather to be guided by that of their natural dependence on each other, in every case, however, attributing to their proper author the experiments which are due to his ingenuity.

In such a course of experiments as is here proposed, I ought first to commence by showing the action of the galvanic wire on the compass needle, and to elucidate the several peculiarities of action observed by Mr. Œrsted; but as this has been so fully entered upon in the preceding section, I shall content myself with referring the reader to that part, for an explanation of every fact hitherto known of the reciprocal action of a galvanic wire and a magnetic needle, and proceed to the next course of experiments, which have no reference to the deviation of the needle suspended as such, but simply to the reciprocal action of a magnetic bar and the galvanic wire.

## Experiment I.

*To magnetize steel bars with the galvanic battery.*

266. Take a piece of steel wire, as for example, a sewing needle, and dip its ends first into steel or iron filings, in order to ascertain that it has no magnetism already in it, which will be the case if the particles of iron do not adhere to it; if they do, another needle must be tried, till we find one free from every species of magnetic action; this being done, connect the ends of the battery by the conducting wire C Z, and place the needle N S across it (see fig. 4) drawing the latter backward and forward a few times, and it will be found to have acquired the magnetic property; for on immersing its extremities again in the filings they will be found to adhere to it, in the same manner as to a needle magnetized in the usual way.

This very interesting experiment is strictly conformable to our hypothesis; for according to this, the action of the galvanic particles in the wire, being tangential, will act upon the latent magnetic particles in the needle, in the direction of its length, and cause a displacement of them, precisely in the same manner as would be done by a magnet; and also, as in that case, the cohesive power of the steel preventing the return of the fluids to their natural state, the needle will remain magnetic.

This experiment was performed nearly at the same time by Sir H. Davy, and M. Ampere; but Sir H. Davy also succeeded in effecting the same with the common electrical machine, and showed that the magnetism might be excited at considerable distances, and consequently not only without rubbing the needle on the wire as we have described, but even without the contact. It requires, however, to effect this at the distances here alluded to, a very powerful apparatus.

If the needle be made a part of the galvanic circuit, or if it be placed lengthwise of the wire, no perceptible permanent magnetic power will be developed, which is also consistent with the hypothesis; because in this case, the action of the wire will be transverse of the needle, which is the least favorable direction for the development of the magnetic power; the tendency of the action being to place the poles transversely instead of lengthwise.

## Experiment II.

*To ascertain the polarity of needles magnetized as in the last experiment.*

267. The wire and needle being placed as in the last figure; that is, the needle being above the wire, and Z denoting the zinc end of a battery of two

plates only, it will be found that the extremity N will attract the south end of a compass needle, and the extremity S the north end; in short, that the north poles of the latent magnetic particles have been carried towards the left hand, and the south towards the right hand, agreeably to the principles indicated in (art. 258) of the preceding section.

Let now the needle be placed under the wire, instead of being placed over it, and in other respects the process described in the last example repeated, and it will be found that the polarity of the needle will be exactly the reverse of that in the last experiment, which ought to be the case according to the principle of the above article; because by this the north polarity is always carried to the left hand of the observer, who conceives himself to form the galvanic circuit, his head being towards the zinc end, and his face towards the magnet; for thus his position being now the reverse of what it was in the preceding experiment, the polarity ought to be the reverse also.

### Experiment III.

*To magnetize a needle by placing it in a spiral conducting wire.*

268. Let Z C (fig. 5) represent a conducting wire bent into a spiral form, and let the needle *n s* be placed either naked in the spiral, or inclosed in a glass tube, or in a tube of any other matter; make

the connection with the battery, and in an instant it will be found that the needle *n s* has become strongly magnetic, having its poles posited, as shown in the figure, viz. having its north end towards the zinc extremity of the battery.

This is of course precisely similar to Experiment I. the only difference being, that by means of the spiral form given to the wire, the action upon the needle is repeated as many times as there are spires of the wire covered by it; the power excited is therefore proportionally stronger, and the magnetism more quickly communicated. The explanation of the effect produced is exactly the same as in the last experiment. If the direction of the contact be changed by supposing *Z* to communicate with the copper side of the battery, the effect will be in all respects the same, except that the polarity of the needle will be reversed. The end towards *Z*, in this case, becoming the south instead of the north pole.

Or, if a spiral, having its spires turned the contrary way, as shown in (fig. 6) be used, and *Z* be supposed to communicate with the zinc side of the battery, the polarity will also be the reverse of that in the first case; viz. the poles will have the direction marked in the figure; and if here again the contact be changed by connecting *Z* with the copper side, the poles will be once more inverted, and have the same direction as at first. These facts, as we have stated above, are explained exactly in the same manner as those for the single wire.

In performing this experiment, I employed a glass tube about 5 inches in length and half an inch in diameter; and it was observed, when the needle was placed in it, so that one half of it projected beyond the end, that the moment the plates reached the acid,* the needle was drawn instantly to the middle of the tube, and while the contact was continued it was held suspended in the centre of the tube when the latter was held vertically; the suspending power of the spiral exceeding the power of gravity.

This effect is very curious, because the needle here remains suspended in the open space, directly in the axis of the tube, and not attached to either sides as in the usual cases of suspension by attraction.

## Experiment IV.

*To examine the effect of a spiral conducting wire on a floating magnetized needle.*

269. Let a wire be wound about a glass tube of about half or three quarters inch diameter, and hang it within a basin of water, as shown in (fig. 7), so that the surface of the water rises to about the axis

* The connection of the spiral with the conducting wires is here supposed to be made before the plates are immersed in the acid.

of the bore; then having pierced a small piece of cork with a needle previously magnetized, so as just to preserve it from sinking when immersed in the basin, make the connection with the battery. The needle will instantly be agitated, and will soon arrange itself in front of the spiral in a direction parallel to its axis, and then suddenly dart into the interior of the tube with a force nearly sufficient to carry it to the other extremity; it then returns again towards the other end, and at length becomes stationary in the middle of the axis, arranging itself exactly parallel to it.

If the spirals have the direction shown in the figure, and Z communicates with the zinc side, the needle, if placed near the extremity of the tube A, will enter with its south end; if placed near the other extremity, it will enter with its north end; but if the direction of the spiral be changed, the needle will enter in both cases the reverse way, as it will also if the direction of the spires remain the same, but the contact be changed. This experiment will succeed equally well if the tube be placed upright in the water, the needle will then dive like a fish, and remain below till the contact is broken.

This entertaining and instructive experiment is due to Mr. Faraday; the explanation of it by our hypothesis is obvious, for the north pole of the particles of the needle being carried to the left of an observer conceiving himself coinciding with the direction of the wire, and with his head towards *Z*, all the effects ought to take place precisely as above stated. M. Ampere had assimilated a spiral wire of this kind with an actual magnet, and Mr. Faraday instituted the above experiment to prove that there was not that identity which had been assumed; for by suspending a hollow cylindrical magnet in the same way, the needle was always attracted to the nearest extremity of its edge, and indicated no tendency to enter the tube.

## Experiment V.

*To show the effect produced by a galvanic wire on steel or iron filings.*

270. This experiment is performed by strewing a quantity of iron dust or filings on a table, and bringing the connecting wire near to them, when the filings will immediately be affected by the action of the wire, some few flying towards it, and adhering to it as to a magnet; and if the wire be brought into actual contact with them, a very considerable quantity may be taken up by it, exactly the same as at the extremity of a bar magnet; but the moment the contact is broken the filings fall.

In order to produce the best effect in this experiment, the wire intended to be operated upon should be smaller than the conducting part of the circuit. This latter, in all cases, is the better for being stout, at least $\frac{3}{16}$ of an inch in diameter; but in this, as in several other experiments, it is best to have the extremities of the wires terminated by a much smaller wire, wound round the former as a spiral, or by simple contact, for by this means the transmission being made through a smaller space, the intensity of action is proportionally increased.

This experiment, as we have already stated, is due to M. Arago, and it seems at first sight somewhat at variance with our hypothesis; because we have here an appearance of actual attraction between the iron and the wire, whereas we have supposed that there is no attraction between them. A little consideration will, however, show, that instead of contradicting, this fact will serve to confirm the hypothesis in question.

Let us, for example, conceive W (fig. 8) to denote the section of our conducting wire descending vertically from the zinc end of the battery; then, the first and direct action of this wire will be to excite magnetism in any small particle of iron *n s*, according to the direction indicated by the letters in the figure, and agreeably to what has been stated in Experiment I.

After which, the action of the wire will be to urge the point *n* in the line *n n'*, perpendicular to *n* W, and the point *s*, in the line *s s'*, perpendicular to *s* W; and, in consequence of the combined action of these forces, the particle *n s* ought necessarily to approach the wire in the same way as it would do by a direct attractive force. This effect is therefore still consistent with our hypothesis, and strongly confirmatory of it.

We have seen that by giving the conducting wire a spiral form, its power of magnetism is much increased; and in the same way the power of the wire on the iron filings may be rendered very great. The best form for the spiral, however, here, is that in which the wire lies all in one plane, as in (fig. 24). This being connected by its two extremities with the poles of the battery, will take up an astonishing quantity of filings, which, by their reciprocal attraction towards each other, exhibit the most pleasing appearance.

## Experiment VI.

*To exhibit the rotation of a magnet round a galvanic wire.*

271. Let A B E D (fig. 9) represent a cup of glass, wood, or any other non-conductor, and N S a small magnet, having a hole drilled at S, whereby it may be fixed by a short piece of silk S *c'*, to the copper wire *c'* C, passing through the foot of the cup;* and let mercury be poured into the latter

* The small metal cup at C is soldered to the wire, and having a little quicksilver in it, furnishes the best means of

till the needle floats nearly vertical. Conceive, also, Z z′ to be part of the conducting wire, descending from the zinc side of the battery, and slightly immersed in the quicksilver. If now the contact be made at C with the copper side of the battery, the magnet N S begins to rotate about the wire Z z′, passing towards the left hand of the observer, situated according to the principles of (art. 258). This rotation will be greater or less according to the power of the battery, and will continue while there is sufficient force in the latter to overcome the resistance of the quicksilver to the motion of the magnet. If the descending wire proceed from the copper side of the battery, the motion will take place in a contrary direction, that is, from left to right.

Or, if the contact remain the same, and the magnet inverted, then also the motion will be reversed; but if the contact and magnet be both reversed, the rotation will be the same as in the first instance.

This highly curious and important experiment, which is due to Mr. Faraday, of the Royal Institution, is immediately explained by our hypothesis;

making the contact, the ends of the wire being amalgamated for that purpose. It is not, however, actually necessary to employ this mode, as the simple contact of the wires is sufficient; but I have always found the connection shown in the figure to succeed best.

according to which, the extremity N of the magnet is always acted upon by two forces, one the galvanic force, which is tangential to the wire, and the other the tension of the silk S c', in the direction of the needle. Let this latter be resolved into two forces, one vertical and the other horizontal, and we shall find the extremity N under the influence of two horizontal forces, one always central and the other tangential. The result of which must be a rotation of that point about the wire; and it will be made with the position and arrangement shown in the figure, from right to left, the observer supposing himself situated as in (art. 258).

### EXPERIMENT VII.

*To exhibit the rotation of a galvanic wire about the magnet.*

272. Let A B D E (fig. 10) be a cup or vessel of wood or glass, and N S a magnet passing tight through its foot; Z *z* a conducting wire descending from the zinc side of the battery, and rendered free to move by the chain connection at *g*. Let mercury be poured into the vessel till the extremity of the wire is slightly immersed in it. Then the contact being made at C (which by means of the wire D C, communicates with the quicksilver) the wire *g z* will immediately assume a rapid rotatory motion, much greater than in the former

case, the resistance being very considerably diminished by the mode of suspension. The direction of the motion, according to the arrangement in the figure, being from left to right, to a person coinciding in position with the magnet. It may, however, be reversed by reversing the magnet, or by changing the contact, as in the preceding cases.

This experiment is also due to Mr. Faraday, and its explanation is the same as the last; for since when the magnet is free it will, as we have seen, revolve about the wire from right to left, it follows that, when the magnet is fixed and the wire free, the latter will revolve in an opposite direction, (the action and re-action between the wire and the magnet being reciprocal) which is still however towards the left of a person supposed now as coinciding in position with the magnet, and his head to the north.

*The same otherwise.*

273. The resistance being very inconsiderable in this experiment, it may be exhibited in a more simple manner. For instance, instead of piercing the foot of the cup, as in the figure referred to, it will be sufficient to use a tea-saucer, or any other shallow vessel, and to bring a strong magnet as near to it as possible under the table, when the motion will take place precisely in the same manner as above.

By this means also we may establish a most important fact; viz. that it is indifferent, as to the result of the experiment, what may be the position of the magnet; that is to say, if we keep the extremity of it as nearly as possible under the centre of the vessel, we may hold it either vertical or horizontal, or incline it in any angle, and at any azimuth, without greatly changing the rate of the rotation; it being always understood that the magnet should be of considerable length, in order that its other pole may not affect the motion of the wire. This result ought necessarily to be obtained, for in explaining the cause of the motion of the magnet about the wire, in Experiment V, we have made no reference to the position of the magnetic particles themselves; the motion, according to the principles we have adopted, would take place exactly the same (except as far as regards the mechanical difficulty) if the magnet could have been placed horizontally instead of vertically, and therefore the rotation of the wire about the magnet ought to be the same in both cases; viz. with the magnet placed either vertically or horizontally, and consequently also at all intermediate angles of inclination.

### Experiment VIII.

*Exhibiting the two preceding rotations by* Mr. Faraday's *apparatus.*

274. The machine for the exhibition of these

motions, according to Mr. Faraday's construction, is shown in (fig. 12). A B C D is a stand of wood, E F a brass pillar, F G a fore arm or projecting piece of brass, through the extremity of which passes the wire L H K; at L, there is a sort of ball and socket joint; the socket being in the upper part, and the ball fitting it, on the small wire L *m*. Both the socket and ball are amalgamated, and a piece of silk fixed to the ball, or head of the wire, passes through a hole drilled in the wire L H, and by which the smaller wire is suspended, thereby preserving the contact, and leaving to the latter a perfect freedom of motion: *a b* is a glass cup having a hole through its foot, into which is inserted a copper tube, soldered to a copper disc just the size of the bottom of the glass, and which disc is cemented to the foot of the latter.

The wire Z *z* is also soldered to another copper disc, upon which the glass rests; and by which the contact is carried on from Z to the quicksilver in the cup, and thence to the wire *m* L; lastly, a small magnet *n s* is inserted into the copper tube, passing through the stem of the glass above mentioned.

The foot of the cup *c d* is pierced, and discs of copper applied as in the cup *a b*; but the wire passing through the foot is solid, and to it is fixed, by a short string, the small magnet *n s*, which is thus free to revolve about the descending wire

H K; quicksilver, as in the preceding cases, being poured into the cup, till the wire H K is slightly immersed in it at K. The contact with the battery being now made at *Z* and C′, the motions will take place as described in the two last experiments; viz. the magnet *n s* in the one cup will revolve about the wire K, while the wire L *m* will at the same time be revolving about the other magnet *n s*.

If the cup *c d* be placed where the cup *a b* is represented, then the magnet and wire being both free, they will revolve about each other, and thus produce a pleasing variety in the experiment.

A section of this machine is shown in (fig. 13).

275. Mr. Faraday also describes another apparatus, which requires a less galvanic action than the former to produce the rotation. This is shown in (fig. 14); it consists of a piece of glass tube, the bottom part of which is closed by a cork, and through it is passed a small piece of soft iron wire, so as to project above and below the cork. A little mercury is then poured in, to form a channel between the iron wire and the glass tube. The upper orifice is also closed by a cork, through which a piece of platinum wire passes, being terminated within by a loop; another piece of wire hangs from this by a loop, and its lower end, which dips a very little way into the mercury, being amalgamated, it is preserved from adhering either

to the iron wire or the glass. Things being thus arranged, a very minute galvanic power being applied by a contact with the lower and upper end of the apparatus, and the pole of a strong magnet being applied to the external end of the lower iron wire, the moveable wire within begins rapidly to rotate round the temporary magnet thus formed; and which rotation may be inverted either by changing the contact or by inverting the magnet. Mr. Faraday states that this instrument is so sensible that a rotation has been produced in it by two plates, each only one inch square.

### Experiment IX.

*To exhibit the rotation of a magnet on its axis by the effect of a galvanic wire.*

276. Let A B D E (fig. 11. plate 5) represent a cup of glass or wood, N S a magnet, having at its lower extremity a fine steel point, inserted in the agate *a*; *b c* is a thin slip of brass or ivory, having a hole through which the magnet passes freely, and by means of which it is kept perpendicular: at the upper extremity N of the magnet, is a thin cylinder, as a piece of quill, forming a cup or reservoir *z* to receive a small quantity of quicksilver; and into this is inserted the wire Z, amalgamated at its lowest point, and C *c* is a stout wire passing through the side of the cup into the

quicksilver. Then, the contact being made at C and Z, the magnet will begin to revolve on its axis, with a very astonishing velocity, and continue in motion while the power of the battery lasts.

This pleasing experiment is due to M. Ampere, who employs only a piece of platinum attached to the magnet, to produce, by its superior gravity, a vertical position of the latter in the mercury; the upper wire being then inserted into the quicksilver in the cylinder z, and the other wire into the cup C, the motion is produced exactly as above described: the greatest freedom of motion is, however, given by the apparatus shown in the figure. The explanation of this rotation is very obvious according to the hypothesis we have adopted, for the tangential force of the wire acting upon the magnetic particles on the surface of the magnet, must necessarily produce the rotation in question, on precisely the same principles as the magnet is made to revolve about the wire in the fifth experiment.

### Experiment X.

*To exhibit the rotation of a galvanic wire on its axis by the action of a magnet.*

277. Let N S (fig. 15) be a magnet, represented as broken in the figure, but which is fixed, in the experiment, in a foot, in order to keep it vertical, and

let *a b c d* be a light hollow copper or brass cylinder having a steel point passing downwards into the agate cup *f*, fixed to the upper end of the magnet, and let *e* be a small tube or quill fixed on the wire passing through the top of the cylinder, holding a little quicksilver, and receiving into it the descending conducting wire Z. A B is a piece of wood turned to fit on the cylindrical magnet N S, which has a hollow groove on its upper surface to receive a quantity of quicksilver, into which the lower edge of the cylinder *a d* is slightly immersed, the surface being covered with weak dilute nitric acid. A C is a wire passing into the quicksilver. It is obvious that thus (the contact being made at Z and C) the galvanic circuit is carried from Z through the cylinder *a b c d*, thence to the quicksilver, and hence again through the wire A C to the other extremity of the battery, whereby the cylinder *a b c d* is made to become a part of the conducting wire, and it will be found to revolve on its axis with a great velocity, fully equal to that of the magnet in the last experiment; the direction of the motion, with the arrangement shown in the figure, being from left to right, to a person coinciding in position with the magnet. If we conceive the cylinder to consist of an infinite number of wires, the explanation of this motion is the same as in Experiment VII.

## EXPERIMENT XI.

*To exhibit a quicksilver vortex by means of a galvanic wire and magnet.*

278. To perform this experiment it is only necessary to take any shallow non-conducting vessel and put into it a quantity of pure mercury, into which is to be inserted the conducting wires Z, C, proceeding respectively from the zinc and copper sides of the battery. And if now the north end of a strong magnet be brought under the vessel, the quicksilver round the wire C will begin to revolve about the same, forming a beautiful vortex, the direction of the motion being from left to right. If the magnet be removed under the other wire the same kind of motion will be produced, but its direction will be reversed, and the same change of motion will take place, of course, in each case, by changing the end of the magnet.

The explanation here is precisely the same as in the last experiment; the moveable part of the conductor in this case, owing its mobility to its fluid nature, whereas in the former it is due to the peculiar mode of suspension.

This very elegant experiment was first made by Sir H. Davy, and although it is referred to in this place for the sake of arrangement and concatenation, it was made prior to the two former, the last of which I was led to institute from the hints furnished by this.

### Experiment XII.

*To exhibit the rotation of the galvanic wire independently of the galvanic battery.*

279. For this purpose we must employ the apparatus exhibited in (fig. 16) where A B C D is a small copper vessel about 2½ inches high, and the same in diameter; *a b c d* is another small cylinder of copper, of the same height, soldered to the former vessel at its lower end *d c*, a hole being left in the bottom of the former to receive it. The cylinder *a b c d* is therefore open, and will admit a cylindrical magnet to be passed up, and it will at the same time hold a quantity of dilute acid within the space A D *d a b c* B C: *z z′* is a zinc cylinder, very light, of rather less altitude than the copper one. To the cylinders *a b* and *z z′* are soldered two copper wires, as shown in the figure, the upper one having a steel point proceeding from E downwards and resting in a small metal hole at F, and consequently the cylinder *z z′* will be free to move upon its point of suspension at F.

Things being thus prepared, and the acid placed in the cell as above described, insert through the interior cylinder the north end of a strong cylindrical magnet, and balance the whole apparatus upon it; when immediately the zinc cylinder will begin to revolve, with a greater or less velocity, according to the strength of the acid, the freedom of motion, and the power of the magnet. I have frequently with this simple apparatus produced a motion amounting to 120 rotations per minute. The only difference between this and the other rotations we have described is, that the galvanic power is here produced by the apparatus itself, instead of having recourse to the battery.

For it is obvious that the wire from z z′ to E, may be considered as a conductor proceeding from the zinc, and the wire from *a b* to F, as one from the copper side of the battery; and consequently, the same effect is to be expected here as in the preceding cases. It is unnecessary to add, that with the north end of the magnet upwards, the motion is from left to right, and the contrary with the magnet reversed.

This experiment is due to M. Ampere.

*The same otherwise.*

280. A very pleasing addition has been made to this apparatus by Mr. J. Marsh. It consists in having a second point descending from F, which is made to rest in an agate cup, fixed on the top of the magnet, (fig. 17) and upon which the whole machine is balanced, having a perfect freedom of motion; and to preserve this balance, the magnet

is placed vertically in a foot. The machine being now charged with acid, a compound motion takes place, the zinc cylinder revolving in one direction and the copper vessel in another, producing thus a very pleasing effect; the latter however is by no means so rapid as the other, in consequence of the weight of the acid, and in fact that of the whole machine being supported on the lower point.

This young man, to whose ingenuity and industry I am much indebted for the success of my experiments, is at present employed in an inferior situation in the laboratory of the royal arsenal; but his dexterity as a workman, his practical chemical knowledge, and his regular conduct, are qualifications which render him deserving of a more respectable and profitable occupation.

## Experiment XIII.

*To show the effect of a horse-shoe magnet on a freely suspended galvanic wire.*

281. Let Z z (fig. 18) denote a part of the galvanic wire, freely suspended by the chain connection at *o*, proceeding from the zinc end of a battery, its lower extremity being amalgamated and slightly immersed in a reservoir of pure mercury, having a connection at C with the other extremity of the battery. N S is a horse-shoe magnet, posited as shown in the figure.

The contact being now made at C and Z, the hanging part of the wire *o z* will be thrown out of the mercury into the position *o z'*; the contact being thus broken, it falls by its own gravity into the mercury, by which means the contact being renewed it is again projected, and so on with an extraordinary rapidity; and if the position of the magnet be reversed, or the contact be changed, the direction of the motion will be changed also, but the effect will be the same.

This singular motion may be still explained by the hypothesis that has been advanced; for the wire having a tendency to pass round the north end of the magnet to the right hand, and round the south end to the left hand, is urged by equal forces directly in a line with the open space of the magnet, the equality of the two forces preventing the rotatory motion about either, but both conspiring to give to the wire the rectilineal motion which has been described.

This experiment is also due to Mr. J. Marsh.

## Experiment XIV.

*To exhibit a wheel and axle rotation by means of a horse-shoe magnet.*

282. The machine by which this motion is produced is represented in (fig. 19), where A B is a rectangular piece of hard wood, C D an upright wooden pillar, D E a piece of stout brass or

copper wire, and *a b* a somewhat smaller wire, soldered upon it at E, on the lower side of which the wheel W, of thin copper, turns freely; *h f* is a small reservoir for mercury, sunk in the wood, and *g i* a narrow channel running into it: H H is a strong horse-shoe magnet. Mercury being now poured into the reservoir *f g*, till the tips of the wheel are slightly immersed in it, and the surface covered with weak dilute nitric acid, let the connection with the battery be made at *i* and D, and the wheel W will immediately begin to rotate with a great velocity. If the contact be changed, or if the magnet be inverted, the motion of the wheel will be reversed; but in general, the best effect is produced when the wheel revolves inwards. The suspension of the wheel, which I find to answer the best, is shown in (fig. 20). This is a necessary consequence of the motion described in the last experiment, by which it was suggested, and is explained on the same principles.

## Experiment XV.

*To exhibit a compound wheel and axle rotation with two horse-shoe magnets.*

283. The machine for producing this motion is shown in (fig. 21); A B G D is a rectangular piece of board, having two grooves, about half an inch deep, cut in it parallel to its length. C *p*, Z *q*, are two wires having cups for connection

at Z and C, and each passing into its respective groove *a b*, *c d*, filled with mercury; into which are slightly immersed the points of the wheels W, W′; these being fixed on an axle W W′, and resting upon the two supports *m n*, *r s*, brought to a fine edge at *n* and *s*, in order to reduce the friction as much as possible, and to give the greater freedom of motion. N S are two horse-shoe magnets, posited as in the figure, with the like poles interior and exterior of the wheels.

The apparatus being thus prepared, and the contact made at Z and C, the wheels will begin to rotate, and in a very short time will acquire a velocity exceeding very considerably any of the motions hitherto described.

It is unnecessary to say that by changing the contact, or by inverting the magnets, the direction of the rotation will be also changed. The usual precaution of covering the surface of the mercury with weak dilute nitric acid, will increase the rapidity of rotation, but it is not actually necessary in this case.

### Experiment XVI.

*To exhibit the terrestrial directive quality of a galvanic wire.*

284. It was not long after the first experiments of Mr. Œrsted, that the question naturally suggested itself, "Has the galvanic wire a directive,

as well as a general, magnetic power?" This question was soon answered in the affirmative by M. Ampere, who made use of the following ingenious construction:

A B (fig. 22) represents a piece of wood fixed to any convenient support, through which pass the two wires G, E, and where they remain fixed. At their upper and lower extremities are soldered the small metal cups *a*, *b*, *c*, *d*. D H I K, &c. is a part of the conducting wire, bent into the form shown in the figure, having small steel points soldered upon it at *c* and *d*. These points are inserted into the cups *c*, *d*, the upper one only resting on the base of its cup, the other being merely brought into contact with *d*, by a little quicksilver placed in it for that purpose, by which means the rectangle has a great freedom of motion given to it, the only solid contact being on the point *c*. Mercury is also poured into the other cups, for the sake of a more perfect and certain communication than that afforded by the mere juxtaposition of the wires.

The apparatus being thus prepared, the two wires proceeding from the copper and zinc sides of the battery are inserted into the cups *a*, *b*, and thus the connection is established; first by means of the wire G with the cup *c*, thence by means of the contact of the point with the cup and mercury, it is carried forward from *c* through the rectangle, to the cup *d*, whence it proceeds to the cup *a*.

We have already seen that of this connecting wire, the part from *c* to *d* has a perfect freedom of motion upon the point at *c*, and will therefore obey any exciting force. This force, in the experiment in question, is the magnetic influence of the earth, and in consequence of which the rectangle, immediately the contact is made, places its plane perpendicularly to the plane of the magnetic meridian, and to which position it will always return after a few vibrations, if it be drawn out of it by the hand, or otherwise.

This arrangement of the moveable conductor is perfectly consistent with our hypothesis, as is obvious without any farther illustration than what has been given in several preceding experiments.

285. A differently formed wire, and a more simple mode of suspension, is shown in (fig. 24.) Here a brass or copper wire A C, rests at its bent end A, in a cup containing a little mercury, and is very moveable in azimuth round this point. The other end passes through the centre of a circular piece of pasteboard, and then forms spiral turnings in the plane of this circular piece. The wire is attached by thread or silk to the pasteboard disc, and at the point B it turns and descends till its extremity reaches the quicksilver in the cup D.

The communication being now made at A and D with the battery, the spiral will immediately arrange itself, as in the last case, in a plane perpendicular to the magnetic meridian. This experiment is originally due to M. Ampere, but the mode of suspension described is that of Professor Van den Boss. *See Edin. Journ. of Science*, No. XII.

A needle upon a different construction, also due to M. Ampere, is shown in (fig. 23.)

*The same otherwise.*

286. The directive quality of the galvanic wire has been since exhibited in a variety of ways, much more simple than that above described, of which we shall only state the following:

*M. de la Rive's apparatus.*—This consists of a small galvanic combination attached to a cork; the plate of zinc is nearly half an inch wide, and extends about one and a half or two inches below its cork, its upper end passing through the same; the slip of copper is of equal width to the zinc, but passes round it, being thus opposed to both its surfaces, as in Dr. Wollaston's construction; its upper end also appears through the cork. A piece of copper wire, covered with silk thread, is coiled five or six times, and tied together so as to form a ring about an inch in diameter, and the ends of the wire are connected, by solder, one with the zinc, and the other with the copper slip above the cork. See (fig. 25).

When this small apparatus is placed in water, slightly acidulated with sulphuric or nitric acid, the ring becomes highly magnetic, and will arrange itself in a plane perpendicular to the magnetic meridian, or it will at least indicate a tendency to take up that position, but the escape of the bubbles, arising from the decomposition of the water, prevents it from preserving a fixed direction.

Its magnetic qualities, however, are more obviously shown by bringing to it a strong magnet. The one I made use of is cylindrical, about three quarters in diameter, and 18 inches in length. This being applied at the distance of several inches, the ring was immediately attracted, or repelled, accordingly as one or the other of the poles of the magnet was presented, or accordingly as one or the other side of the wire was opposed to the latter. When the result of the application is attraction, the cork will advance towards the extremity of the magnet, and if the latter be held horizontally, and in a line with the centre of the former, this will continue to advance till the pole of the magnet is within the ring, and then proceed with considerable velocity till it reaches the middle of the magnet, where it remains perfectly stationary. If now the magnet be withdrawn, and changed end for end, and re-introduced into the ring, the latter will go off from the magnet, turn itself round when quite free from it, again advance, and settle itself as before in the centre.

This very simple apparatus, which may be made at the expense of about a shilling, throws great light upon the nature of the electro magnetic action, and proves most satisfactorily that, notwithstanding the intimate relation between the electro magnetic and simple magnetic fluids, they are not identical; for no possible arrangement of simple magnets can be made that would lead one of them beyond the pole of another to find its state of equilibrium in the middle of the latter. At the same time all the above facts will be found perfectly consistent with the hypothesis that has been advanced; for it will be seen, when the wire and cork are in equilibrio, as above stated, that an observer, conceiving himself situated as in (art. 258), will have the north end of the magnet to his left hand, and the south to his right, at equal distances, and acting therefore with equal and opposite powers; consequently the wire itself ought to be in equilibrio, and when disturbed from it will have a tendency to regain it, and hence be subject to all the conditions of motions that have been described. This is in fact very similar to experiment 4, the difference only consisting in this, that in the present case the wire is moveable and the magnet fixed, whereas in the former the wire was fixed and the magnet free; the explanation is of course the same in both.

Another form of this apparatus is shown in (fig. 26.)

Both the above apparatuses are much improved by fixing to the cork a light glass cylinder A B to contain the acid, instead of floating them in it; the apparatus may then be floated on common water, and all the facts exhibited as above described.

This appendage to the original construction is due to Mr. James Marsh,* already mentioned.

287. *Apparatus of Prof. Van den Boss.*—Here C D (fig. 27) is a copper plate, E G a similar one of zinc, about an inch square, kept from touching each other by the interposition of some small piece of wood: both plates are attached and suspended to slender brass wires P and R. The wire P enters at P, in the hollow space formed by a case of very thin quills inserted into each other, about 6 or 7 inches long. The end of the wire comes out of the quill at the extremity T, and

* This ingenious workman has just completed a portable electro galvanic apparatus; which within the space of little more than a cubic foot, contains not only the necessary galvanic combination, but also all the instruments necessary for repeating nearly the whole of the experiments detailed in this Section.

returns, being wound as a spiral about it to the other extremity V, where it again enters the quill, and proceeds in a right line to R, where coming out it descends, and is attached to the other plate. The whole is suspended in equilibrio to a piece of untwisted silk X. The plates are now dipped into dilute acid, and the whole is suspended at X, when immediately the magnetic quality of the wire becomes manifest; but, like the former instrument, it is not so sensible to the terrestrial as to the action of a strong artificial magnet, with which its extremities T and V may be attracted or repelled, according as the one or the other pole of the magnet is applied; and which ought necessarily to be the case agreeably to the explanation given in the preceding case.

## EXPERIMENT XVII.

*To examine the inclination of a freely suspended galvanic wire as affected by the terrestrial magnetism.*

288. This is an experiment of M. Ampere, in which he employs the apparatus exhibited in (fig. 28), where the galvanic circuit is carried on from the extremity of the battery towards V, passes by V S, through the steel pivot *k*, placed on the metallic plate N, and thence through the rectangle A B C D; whence, passing through the tube *x y*,

which serves as an axis for the machine, it is carried by means of a second steel pivot to the other extremity of the battery towards R. The moment the connection was made, M. Ampere found the moveable part of this conductor in a state of vibration, which after a short time subsided; when the plane of the rectangle was found to coincide with what has been denominated the magnetic equator, or plane of no attraction; that is, with a plane perpendicular to the direction of the dipping needle.

It will of course be understood, that the axis of the machine must in the first instance be placed very exactly at right angles to the magnetic meridian, that the whole requires to be very nicely balanced, and that a little mercury be placed on the plates M N to render the contact the more perfect.

The lozenge *z w* is made of very light wood, and being fixed on the axis, serves to keep the rectangle in its proper form.

That the machine ought, according to our hypothesis, to assume this direction is obvious from all that has been previously stated, and therefore requires no particular illustration.

## Experiment XVIII.

*To exhibit the action of the terrestrial magnetism upon a galvanic wire freely suspended.*

289. Let A B G D (fig. 29) represent a rectan-

gular piece of hard wood, having two grooves *a b*, *c d*, cut in it, parallel to its length, about half an inch in depth, which are to be filled with quicksilver for the experiment. C *p*, Z *q* are wires fixed in the board and passing each into its respective groove, with cups for making the connection with the battery at Z and C. O *m* is a long piece of silk proceeding from the ceiling, or some other convenient place, and to which is tied the wire *k m n*, bent as in the figure, the points *k* and *n* being slightly immersed in the quicksilver. If now the connection be made at Z and C with the zinc and copper sides of the battery, the moveable part *k m n* of the galvanic circuit, which has a great freedom of motion, will be projected towards the extremity A B of the board, and if the contact be changed, by making the zinc connection at C and the copper at Z, the wire will be driven towards the other extremity. As no magnet is introduced in this experiment, we have a right to attribute the motion to the effect of the terrestrial magnetism, the direction of it corresponding precisely with what we ought to expect from such action. For the terrestrial magnetism of our latitude being of the same kind as that exhibited by the southern pole of a magnet, the moveable wire ought to pass from right to left in the first case, and from left to right in the second, to an observer situated as described in (art. 258); viz. as forming a part of the galvanic circuit, and with his head towards the zinc end of the battery; that is to say, with the first contact the wire ought to be projected towards A B, and with the second towards D G.

To prove that the motion proceeds from this cause, let the south pole of a strong magnet be brought under the board between Z and C, and make the contact again; and the same motion will take place, but in a much stronger degree, the wire being now thrown very forcibly out of the mercury.

The effect therefore being precisely of the same character, but much more powerful in the latter case than in the former, we have a right to conclude that the cause of the motion in both cases is of a like nature, the one proceeding from a southern polarity artificially produced, and the other from the natural magnetic action of the terrestrial sphere, as stated by Mr. Faraday, to whom we are indebted for this interesting experiment.

## Experiment XIX.

*To produce a rotation of the galvanic wire by means of the terrestrial magnetism.*

290. This is also an experiment due to Mr. Faraday, and which proves, in the most satisfactory manner, the influence of the terrestrial magnetism in the production of a rotatory motion. It is per-

formed as follows: a very light copper, or platina wire, about six inches long, is suspended very freely from a larger wire proceeding from either end of the battery, by means of the chain connection described in several of the preceding experiments, and at its lower extremity a small piece of cork is attached in order to keep the wire buoyant on a basin of pure mercury, about 10 inches in diameter. The wire by which the above small moveable piece is suspended, is then so much depressed that the proposed revolving wire slopes at an angle of about 40° with the horizon; in this state the circuit of the battery is completed through the mercury in the basin and the other conducting wire, when immediately the short wire commences a rotation, as it would do about the south end of a magnet, but in a proportionally less degree, as the directive power of the earth is less than that of a magnet of the kind here supposed.

This similarity of action naturally leads us to infer a similar cause, and that this cause is no other than the terrestrial magnetism; still, however, in order to render this conclusion the more indisputable, Mr. Faraday changed the inclination of the wire, making it first equal to the angle of the dip; and when under these circumstances the wire was placed so as to coincide with the dip itself; viz. when placed in the magnetic meridian, sloping from south to north, there was no motion; and when the angle was still farther increased so as to exceed the angle of the dip, it was projected in two different directions according as it was made to slope to the north or to the south, which is precisely what ought to be the case on the supposition of the motion being caused by the magnetism of the earth.

For let *o z*, *o z′*, in (fig. 30 and 31), represent the freely suspended wire in the plane of the meridian, sloping respectively to the north and south: and let N S in both figures denote the direction of the terrestrial magnetism, then it is obvious in the first of these figures, that whether the slope be towards the north or towards the south, it will be always on the same side of the line N S, and will in both cases be projected in the same direction, with respect to the observer, situated as supposed in (art. 258), and consequently in opposite directions as referred to the circular rotation of the extremity *z* or *z′*. But when the slope is less than the dip, then the wire in its two positions being found on opposite sides of the line of direction, and passing still to the same hand of an observer situated in the wire, a rotation will ensue similar to those that have been described in our experiments 7 and 8.

## Experiment XX.

*To exhibit the action of two galvanic wires on each other.*

291. The apparatus which I employed for this purpose is shown in (fig. 32), where A B represents a rectangular board, and D, E, two upright pieces of wood, carrying each a cross piece at top with several holes for receiving the cups *m*, *m′*, *n n′* which by this means may be placed at different distances; a little mercury is poured into each of these so as to communicate with the wires inserted through the side of the cup, and terminate with fine points. The wires *w a a′ w′*, *w b b′ w′* are bent as shown in the figure, and have small holes drilled at *a*, *a′*, *b*, *b′*, whereby they may be hung freely upon the points of the wires *m*, *m′*, &c. and carrying small weights *w w′*, &c. in order to bring the points of suspension to correspond as nearly as possible with the centre of gravity, whereby the wires are moved by the least force. The conducting wires from the extremities of the battery Z and C are terminated as represented in the figure, and being each brought to the respective cups, so that *z z′* are respectively inserted in the cups *m n*, and *c′ c* into the cups *m′ n′*, the circuit will be made through the two wires *a a′*, *b b′* in the same direction, and these being free to move about the points in the respective cups, will

be strongly attracted towards each other, even at the distance of several inches.

Let now the branch *z* of the conducting wire Z *z* be lengthened so that it may pass round the board and be inserted in the cup *n'*, while *z'* is inserted in the cup *m* as before; lengthen also the branch *c* of the conducting wire C *c*, passing it round the board and dipping it into the cup *n*, while *c'* is immersed in *m'* as at first; by this means the circuit passes from *z* to *c* along the wire *b b'*, and from *z'* to *c'* along the wire *a a'*; in short, the circuits in the two wires are now made in opposite directions, and the wires experience and exhibit a mutual repulsion. Hence we learn, that two galvanic wires, parallel to each other, and in which the circuit is made in the same direction, are attracted towards each other; but they are mutually repelled when the circuit passes in opposite directions, a result first deduced by M. Ampere, and which he has made the foundation of his theory of electro magnetism, by assuming that the powers exhibited by artificial and natural magnets are due to currents of the galvanic fluids circulating in planes perpendicular to their axes; and, that those currents, when parallel to each other and passing in the same direction, are attracted, and when in opposite directions, repelled.

292. Whether this hypothesis and that which I have advanced be under different forms only one and

the same, and if not, which may be considered as the most conclusive and satisfactory are not for me to determine: they are now both in the hands of philosophers, who will judge of them impartially, and adopt that which seems to answer best to the various facts and phenomena that have been, and that may still be, elicited by the ingenious experimenters at present engaged in this interesting inquiry: I must say that I cannot, on M. Ampere's doctrine, satisfactorily explain several of the phenomena exhibited in the preceding experiments; and the following is another case which seems to be at variance with the theory in question; viz.—

293. Let only one of the bent wires, shown in the figure last referred to, be employed, and let it be made a part of the galvanic circuit. If now a long magnet be placed horizontally, with one pole a little below the horizontal part of the wire, and perpendicular to the same, the wire will be strongly attracted, or repelled, according to the pole that is presented. Let us suppose that the wire is attracted; this may be explained by the assumed attraction of the current in the wire, and the parallel currents in the same direction in the magnet, agreeably to M. Ampere's theory; and if it be repelled, the explanation will still subsist by supposing the parallel currents in opposite directions; but if, now, instead of keeping the magnet perpendicular to the direction of the wire, we place it

parallel to it, keeping the same extremity still under the wire, the very same effect is produced; although in this case the supposed magnetic currents, *if before parallel* to that in the wire, are now necessarily *perpendicular to it:* and if, again, the magnet be held vertically, keeping the extremity presented to the wire in its situation, or as nearly so as possible, the same attraction still takes place; and this, whether the extremity in question be above or below; in short, while the pole of the magnet presented to the wire is kept in its position, whatever direction be given to the magnet itself, whether in azimuth or inclination, the same motion takes place, which certainly appears to me to be wholly at variance with the doctrine that M. Ampere has endeavoured to establish. And if, instead of using the magnet, we leave the wire to the action of the terrestrial magnetism only, a similar effect, but in a less degree, is produced every time the connection with the battery is established: and it is the same whether the wire be placed at N and S, E and W, or at any azimuth whatever; a fact which seems to be equally at variance with M. Ampere's theory of terrestrial magnetism.

Whether this ingenious author, for whose talents I entertain the highest respect, will be able to reconcile these phenomena with his theory, I am unable to say. If he can, no one will be more ready than myself to admit his doctrine; being fully aware of the great advantages which philosophy derives from the reduction of a variety of classes of phenomena to one general principle: at the same time we must be careful not to generalize too quickly; nor in our anxiety to avoid the introduction of a force, hitherto unknown in nature, allow ourselves to leave imperfectly explained some of the most interesting facts yet elicited by experimental philosophy.

# ADDENDA

TO

## SECTION XII. AND XIII.—PART I.

### ON THE MAGNETIC EFFECTS OF IRON MASTS ON THE COMPASS.

It being in contemplation to employ hollow iron masts in ships of war in lieu of those at present in the service, I received a letter from Sir Byam Martin, requesting me to state my opinion as to the probable disturbance which such masts might be expected to produce on the compass. My reply was to this effect, that as the centre of attraction of the iron masts, viz. main-mast and fore-mast, would be considerably above the horizontal plane of the needle, and as all the other iron of the vessel was below that plane; it would follow, that while the latter attracted the north end of the needle in any direction, the effect of the former would be to bring the south end towards the same direction; and that, in consequence, it was not improbable the two powers might so nearly balance each other as to destroy the effects of both at those points which are in these latitudes those of greatest attraction; but I stated, at the same time, my apprehension whether the power of the masts might not so far exceed that of all the other iron, as to produce as great a deviation as the latter, in addition to the counteraction, but in an opposite direction—a circumstance that might be attended with some danger; because there is no doubt that seamen, in one way or other, (from long practice) actually make an allowance for the usual local attraction, although it is in nine cases out of ten attributed to some other cause. If, therefore, this allowance were made as usual, while the effect was in reality reversed, the worst consequences might be apprehended.

I proposed, however, in order not to leave the determination to a mere matter of opinion, to have my model of a 74-gun ship, mentioned at page 88, fitted up with an iron main-mast, fore-mast and bowsprit, to the proper scale, and thus to ascertain from actual experiment the probable amount of the deviation in question. Having done this, I found, as I had expected, that the introduction of the main-mast had raised the centre of attraction from an angle of 50° below the horizontal plane of the compass, to about 20° above it, and that the power was such as to produce a deviation in the needle to nearly the same amount as before, but in an opposite direction.

The only danger therefore to be apprehended by the use of iron masts is, that those allowances which long habit has introduced, and the necessity for which is attributed to any cause but the right one, will still continue to be made after the cause itself is reversed: should this be the case, some evil consequences might perhaps follow; and the only means that I am ware of to prevent it, is to urge the necessity of accurate observation, and to employ the means of correction explained in this work, or a better if it can be found.

*Simplification of the method of correction described in* Section xiii.

The above experiments and deductions, relative to the effect of iron masts, led me to reconsider the principles on which the method of correction, illustrated in the above section, depended. In the course of which it occured to me, that as by the introduction of the iron masts I had changed the place of the centre of attraction from an inclination of about 50° below the horizontal plane to nearly 20° above it, it might be possible in all cases to introduce the usual correcting plate, or a larger surface of iron, at a greater distance, in such a situation aft of the compass as to bring the common centre of attraction vertically below the pivot of the needle; in which case every species of deviation would be completely counteracted and destroyed, and the needle be as free and stand as true as if there were no iron on board.

I lost no time in submitting this idea to the test of experiment; and even on the first trial I had every reason to believe that it was correctly founded, and was much gratified on a second trial to find it completely successful; the needle under every direction of the model standing as truly in the meridian as it would have done had there been no iron on board. But still, after the caution I have observed in the several deductions in the preceding parts of this work, I am unwilling to offer a positive opinion on the efficacy of this method, although I should much like to have a trial of it made in a ship at large. One difficulty doubtless is, that, by the means proposed, the centre of attraction will necessarily fall very near the needle, and consequently a little inaccuracy of adjustment, or even the rolling or inclination of the vessel, may so far displace its verticality as to produce irregularities in the results, which are not easily detected under the more favourable and uniform action of the model. The suggestion, however, will not I hope be thought wholly undeserving of attention.

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# APPENDIX.

*Containing an account of the experiments made on board H. M. Ships Leven, Conway, and Griper, for correcting the local attraction of those vessels, agreeably to a principle proposed by Peter Barlow, F. R. S., of the Royal Military Academy. Addressed to my Lords Commissioners of the Admiralty.*

My Lords,

As the patrons and protectors of nautical science, I beg to submit to you the results of certain experiments, made with the permission and by the order of your lordships, relative to a method of correcting the local attractions of vessels, which I had the honour to propose in the year 1819. My attention was first called to the inquiry by a very useful little treatise on the variation of the compass, published by Mr. Bain, a master in the Royal Navy, in which the discovery and experiments of Captain Flinders, relative to this source of error, and the subsequent observations of other navigators, are intelligibly stated, as are also the serious consequences that might, and which doubtless have, arisen in many instances for want of a proper attention being paid to this subject. The voyages of discovery which were made about the same time to the northward confirmed, in a striking degree, the truth of Mr. Bain's remarks; and a paper, by Captain Sabine, in the "Philosophical Transactions, for 1819," and the observations recorded in the Appendixes to the Voyages of Captains Ross and Parry, demonstrated that the errors arising from this cause, in high latitudes, were such as to render the compass almost or entirely useless; unless some practicable method could be devised for correcting the discrepancy in question.

The acknowledged importance of this subject, both as immediately applicable to navigation, and as laying the foundation of a more precise view of the laws of terrestrial magnetism, by correcting our tables and charts of variation, induced me to undertake a course of experiments directed to this inquiry: and I may perhaps be allowed to say, that I succeeded in establishing some principles of magnetic action, not before clearly developed. It resulted from these experiments, as far as I was able to pursue them, that whatever might be the form of a mass of iron, or of a system of iron bodies, a very close approximation might be made to the action of the same on the compass, by assuming it to proceed from two centres, indefinitely near to each other in the general centre of attraction of the mass or system, a deduction which constitutes the fundamental principle of the method of correction I had the honour to propose; but, before this could be admitted as an established fact, it was necessary to submit it to the test of experiments in other latitudes. This has now been done, by order of your lordships, through an arc of terrestrial latitude exceeding 140°; viz. from latitude 60° 56′ S. to 79° 50′ N.; and the results which I shall have the honour to detail will, I trust, be found as satisfactory as can be desired or expected in observations of this kind.

The above principle alone, however, would not have been sufficient for correcting the error arising from local attraction; but I fortunately also discovered that, in iron bodies, the magnetic power is all resident on the surface; so that with a sheet of iron, of small weight, a considerable magnetic action might be obtained. From the first of these principles, it followed that the centre of action of all the iron in a ship, and the line which may be conceived to join this centre with the centre of the needle would remain constant in all parts of the world; and, by means of the second, a plate of iron might be so placed, in the said line, that its action on the needle should be equal to that of the vessel; and, therefore, by observing at any time the effect produced by the plate, that of the vessel would become known, the two, by the hypothesis, being always equal to each other. As, however, the method of correction is fully described in my "Essay on Magnetic Attractions, &c." it would be useless in this place to enter into further explanation of it, my object being here simply to state the results of the experiments that have been made in the vessels named at the head of this article: it will therefore be sufficient to state that, having laid my propositions before your lordships, requesting permission to have the idea submitted to the test of experiments, I received a letter from J. W. Croker, Esq. informing me that your lordships, having referred my communication to Dr. Young, and received his report upon it, you were pleased to permit the experiments to be made.

The first opportunity which offered of availing myself of this permission, was in the voyage of H. M. S. Leven, to the western coast of Africa, in which instance, during a voyage of sixteen months, the experiment was in every respect perfectly satisfactory; and, on the return of the ship, I received a numerous set of observations from Captain Baldey, Lieutenant Mudge, and from the master, Mr. Higgs, but these being principally made between the tropics, over a portion of the Atlantic, contained in the general course of experiments made in the Conway, I shall merely detail the series furnished me by Captain Baldey, together with the letter with which they were accompanied.

*No.* 1, *Bath-place, New Road,*
*August* 13, 1821.

Dear Sir,

I have left for you, in care of Lieutenant Mudge, a copy of the result of a series of observations made by me, on board H. M. S. Leven, with your correcting plate attached to Gilbert's patent azimuth compass, the original having been already transmitted to my Lords Commissioners of the Admiralty, and I beg to congratulate you on the success which has attended your experiments.

You will perceive that, in several instances, our binnacle compasses differed from each other a half to three-quarters of a point; which, however, we were always able to correct by your plate; and in all cases our place by reckoning, when thus corrected, agreed as closely with observations as we could have any reason to expect. Indeed little need be said to show how very erroneous a place by reckoning must be found after a run of several hours—five, six, or seven degrees out of the supposed course. At sea such error, although very considerable, is not perhaps of much importance; but in making land, on entering a channel, and in narrow seas; it might be, and doubtless has been, frequently attended with the most fatal consequences: under this impression, and being convinced from experience of the simplicity and efficacy of your experiments, I beg that you will make any use of this letter which you think will be of the greatest service in bringing your method of correction into general practice. I have only further to add, that I have no doubt that the officers who at present remain on board the Leven, will allow you every facility you may desire, to make such extracts from the log, as you may think essential for pointing out more particularly the advantages of your mode of correction.

I am, Dear Sir,

Your sincere well-wisher,

(Signed) W. Baldey.

*To P. Barlow, Esq., Woolwich.*

## EXPERIMENTS

*Made on board H. M. S. Leven, with* Mr. Barlow's *Plate for correcting the local attraction of that vessel, by* Captain W. Baldey.

| ...th. ...y. | Latitude. | Longi-tude. | Ship's Head. By Barlow's compass. | By Star-board compass. | By Lar-board compass. | Variation. Without the Plate. | With the Plate. | Differ-ence. | True Variation |
|---|---|---|---|---|---|---|---|---|---|
| ...20. | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ ″ | ° ′ | ° ′ | ° ′ |
| ... 1 | 22 50N | 17 20W | S 23 W | .... | .... | 18 37 20 W | 19 37W | 0 44 | 17 53W |
| 2 | 20 39 | 17 50 | S 85 W | .... | .... | 19° 12′ | 20 30 | 1 18 | 17 54 |
| 8 | 17 22 | 22 45 | S 40 W | S 43 W | S 39 W | 15 46 | 16 13 | 0 27 | 15 19 |
| 10 | 16 41 | 23 0 | N 43 E | N 45 E | N 45 E | 14 41 | 13 40 | 1 1 | 15 42 |
| 12 | 16 8 | 22 56 | N 40 20 E | N 42 15 E | N 44 E | 14 22 | 12 59 | 1 23 | 15 45 |
| 17 | 14 41 | 24 0 | S 11 E | .... | .... | 15 8 | 14 49 | 0 19 | 15 27 |
| 18 | 14 51 | 24 37 | N 55 E | .... | .... | 13 12 | 12 36 | 0 36 | 13 48 |
| 21 | 14 46 | 24 53 | N 30 W | N 31 E | W 31 W | 15 8 | 16 24 | 1 16 | 13 52 |
| 30 | 16 36 | 25 0 | N 5 E | .... | .... | 14 33 | 14 7 | 0 26 | 14 59 |
| ...y 6 | 16 37 | 24 50 | N 45 E | .... | .... | 14 4 | 12 20 | 1 24 | 15 28 |
| ...g. 5 | .... | .... | N 48 E | .... | .... | 14 7 | 13 7 | 1 0 | 15 7 |
| 11 | 18 48 | 26 4 | N 2 E | N 8 30 E | N 3 E | 16 32 | 16 13 | 0 19 | 16 51 |
| 14 | 24 56 | 30 30 | N 20 W | .... | .... | 16 52 | 18 2 | 1 10 | 15 42 |
| 14 | 26 0 | 31 12 | N 27 W | .... | .... | 16 39 | 17 51 | 1 12 | 15 27 |
| 15 | 27 0 | 32 7 | N 23 E | .... | .... | 15 58 | 14 47 | 1 11 | 17 9 |
| 15 | 27 52 | 32 20 | North | .... | .... | 16 58 | 16 46 | 0 12 | 17 10 |
| 16 | 28 30 | 32 50 | North | .... | .... | 17 6 | 17 16 | 0 10 | 16 56 |
| 18 | 30 40 | 35 0 | N 2 W | .... | .... | 17 58 | 17 49 | 0 9 | 18 7 |
| 18 | 31 22 | 35 6 | North | .... | .... | 17 30 | 17 53 | 0 23 | 17 7 |
| 19 | 31 39 | 36 0 | W N W | .... | .... | 19 49 | 21 27 | 1 38 | 18 11 |
| 20 | 32 22 | 33 10 | N 87 E | East | East | 17 21 | 14 14 | 3 9 | 20 32 |
| 21 | 31 40 | 32 10 | S 64 E | S 62 E | S 65 E | 17 38 | 16 2 | 1 36 | 19 14 |
| 23 | 36 50 | 31 50 | N 55 E | N 56 E | N 59 E | 20 4 | 17 56 | 2 8 | 22 12 |
| 24 | 37 38 | 30 50 | N 83 E | N 84 E | N 85 E | 21 3 | 17 58 | 3 5 | 24 8 |
| 24 | 37 38 | 30 50 | N 83 E | N 84 E | N 85 E | 21 7 | 18 7 | 3 0 | 24 7 |
| 30 | 38 37 | 27 10 | S 27 W | .... | .... | 23 48 | 24 52 | 1 4 | 22 44 |
| ...pt. 2 | 38 29 | 24 30 | N 48 W | N 51 W | N 48 W | 26 42 | 29 10 | 2 28 | 24 14 |
| 9 | 37 43 | 25 44 | S 25 W | .... | .... | 24 55 | 25 5 | 0 10 | 24 45 |
| 11 | 38 16 | 25 2 | N 3 W | N 2 30 W | North | 24 54 | 25 31 | 0 37 | 24 17 |
| 15 | 36 6 | 21 10 | East | East | N 88 E | 22 39 | 20 8 | 2 31 | 25 10 |
| 19 | 34 21 | 18 32 | South | S 4 W | S 4 E | 23 24 | 23 10 | 0 14 | 23 38 |
| 20 | 32 38 | 17 54 | S 3 W | S 7 W | South | 23 10 | 23 13 | 0 3 | 23 7 |
| ...ct. 12 | 30 26 | 16 5 | S by W | S 16 W | S 11 W | 21 25 | 21 55 | 0 30 | 21 55 |
| 13 | 30 9 | 15 56 | N 67 W | N 68 W | N 66 W | 22 32 | 24 42 | 2 10 | 20 22 |
| 18 | 28 28 | 16 15 | S 81 E | S 85 E | S 81 E | 18 52 | 17 53 | 0 59 | 19 51 |
| 23 | 27 28 | 15 53 | S 9 E | S 4 E | S 11 E | 18 41 | 18 30 | 0 11 | 18 52 |
| 26 | 26 29 | 14 13 | N 72 E | N 70 E | N 74 E | 19 5 | 17 58 | 1 7 | 20 12 |
| ...ov. 4 | 28 28 | 16 15 | N 65 E | N 64 E | N 66 E | 19 43 | 18 39 | 1 4 | 20 47 |
| 8 | 26 8 | 14 32 | N 54 E | N 54 E | N 54 E | 18 54 | 17 34 | 1 20 | 20 14 |
| 11 | 26 8 | 14 32 | S 70 E | S 67 E | S 71 E | 19 25 | 18 35 | 0 50 | 20 15 |
| 15 | 23 52 | .... | West | West | West | 21 18 | 23 1 | 1 43 | 19 35 |
| 20 | 23 35 | 15 17 | N 69 E | N 70 E | N 70 E | 17 53 | 16 16 | 1 37 | 19 30 |
| 21 | .... | .... | N 60 E | N 59 E | N 59 E | 17 58 | 16 18 | 1 40 | 19 38 |
| 23 | .... | .... | N 43 E | .... | .... | 18 3 | 16 45 | 1 18 | 19 21 |
| ...ec. 2 | 22 22 | 16 40 | N 49 E | N 50 E | N 51 E | 18 16 | 16 39 | 1 37 | 19 53 |

## EXPERIMENTS

*Made on board H. M. S. Leven, with* Mr. Barlow's *Plate for correcting th[e] local attraction of that vessel, by* Captain W. Baldey.

| Month. Day. | Latitude. | Longitude. | Ship's Head. By Barlow's compass. | By Starboard compass. | By Larboard compass. | Variation. Without the Plate. | With the Plate. | Difference. | Tru[e] Varia[tion] |
|---|---|---|---|---|---|---|---|---|---|
| 1820. | | | | | | | | | |
| Dec. 3 | 22° 22′ N | .... | N 58° E | N 58° E | N 59° E | 18° 38′W | 17° 18′W | 1° 20′ | 19° 5[illegible] |
| 8 | 22 23 | 16 40W | N 45 E | N 47 E | N 47 E | 18 55 | 17 27 | 1 28 | 20 2[illegible] |
| 8 | Ditto | 16 40 | .... | .... | .... | 18 46 | 17 21 | 1 25 | 20 1[illegible] |
| 9 | Ditto | 16 40 | N 78 E | N 80 E | N 78 E | 18 30 | 16 24 | 2 6 | 20 3[illegible] |
| 9 | Ditto | 16 40 | .... | .... | .... | 18 20 | 16 30 | 1 50 | 20 1[illegible] |
| 12 | 20 48 | 17 0 | N 47 E | N 51 E | N 46 E | 18 37 | 17 1 | 1 36 | 20 1[illegible] |
| 12 | .... | .... | .... | .... | .... | 18 19 | 16 39 | 1 40 | 19 59 |
| 15 | 20 8 | 18 36 | N 69 W | W N W | W N W | 20 5 | 22 5 | 2 0 | 18 5 |
| 15 | .... | .... | .... | .... | .... | 19 50 | 21 2 | 1 12 | 18 38 |
| 18 | 16 8 | 22 56 | N 55 E | N E by E | N E by E | 14 6 | 12 19 | 1 47 | 15 53 |
| 24 | 14 53 | 23 34 | N 66 E | N 67 E | N 65 E | 14 44 | 13 40 | 1 4 | 15 48 |
| 28 | .... | .... | N 64 E | N 64 E | N 65 E | 14 33 | 12 57 | 1 36 | 16 9 |
| 30 | .... | .... | N 60 E | N 60 E | N 60 E | 14 47 | 13 45 | 1 2 | 15 49 |
| 1821. | | | | | | | | | |
| Jan. 8 | 16 4 | 21 38 | North | North | North | .... | .... | .... | 17 10 |
| 9 | 16 48 | 22 14 | S 78 E | S 75 E | S 78 E | 15 38 | 13 52 | 1 46 | 17 24 |
| 11 | 19 12 | 23 10 | N 13 E | N 13 E | N 14 E | 16 23 | 15 56 | 0 27 | 16 30 |
| 14 | 16 51 | 19 43 | S 67 E | S 64 E | S 67 E | 16 44 | 15 40 | 1 4 | 17 48 |
| 18 | 16 14 | 22 24 | N 3 W | N 3 W | N 3 W | 17 22 | 17 13 | 0 9 | 17 13 |
| 18 | .... | .... | .... | .... | .... | .... | .... | .... | 17 11 |
| 18 | 16 25 | 22 45 | S 34 E | S 30 E | S 31 E | 15 34 | 14 58 | 0 36 | 16 10 |
| 19 | 16 36 | 22 24 | N 15 W | N 14 W | N 15 W | 16 59 | 17 21 | 0 32 | 16 27 |
| 20 | 17 0 | 21 50 | S 37 E | S 35 E | S 39 E | 16 4 | 15 19 | 0 45 | 16 49 |
| 24 | 19 47 | 20 13 | North | North | North | .... | .... | .... | 17 24 |
| 26 | 19 11 | 20 37 | N 34 W | N 34 W | N 33 W | 18 28 | 19 20 | 0 50 | 17 38 |
| 27 | 19 17 | 20 45 | S 69 E | S 67 E | S 69 E | 17 28 | 16 9 | 1 19 | 18 47 |
| 27 | 19 12 | 20 34 | N 33 W | N 33 W | N 33 W | 19 3 | 19 46 | 0 43 | 18 20 |
| 28 | 19 39 | 21 9 | S 37 E | S 35 E | S 39 E | 17 35 | 16 48 | 0 47 | 18 22 |
| 29 | 20 3 | 21 2 | S 30 E | S 28 E | S 31 E | 17 51 | 16 42 | 1 9 | 19 0 |
| Feb. 1 | 20 0 | 20 29 | S 32 E | S 29 E | S 34 E | 18 0 | 16 51 | 1 8 | 19 8 |
| Mar. 3 | 14 40 | 17 27 | N 33 E | N 35 E | N 33 E | 16 28 | 15 33 | 0 55 | 17 23 |
| 8 | 14 20 | 17 3 | N 51 W | N50 30W | N 51 W | 18 41 | 19 45 | 1 4 | 17 37 |
| 12 | Off the | Gambia | N46 30W | N W | N W | 18 31 | 19 28 | 0 57 | 17 34 |
| 15 | Cape Ro | xo E. 3 or | 4 miles | N 48 W | N48 30W | 18 31 | 19 13 | 0 42 | 17 49 |
| June 17 | 24 25 N | 16 0W | N 81 30E | E ¾ N | E ¾ N | 18 4 | 16 33 | 1 31 | 19 35 |
| 19 | 25 10 | 16 0 | S 82 30E | S 84 E | S 81 E | 18 1 | 16 55 | 1 6 | 19 7 |
| 22 | 26 12 | 14 45 | N N W | N N W | N N W | 21 11 | 21 51 | 0 40 | 20 31 |
| 23 | 27 39 | 15 55 | N66 40W | N 67 W | N 69 W | 21 40 | 22 42 | 1 2 | 20 38 |
| July 3 | 31 15 | 18 40 | N 10 W | N 10 W | N ¾ W | 22 30 | 23 0 | 0 30 | 22 0 |
| 7 | 35 39 | 18 0 | N 42 E | N 42 E | N 42 E | 21 55 | 20 25 | 1 30 | 23 25 |
| 10 | 38 12 | 17 12 | North | North | N 2 E | .... | .... | .... | 24 14 |
| 12 | 40 36 | 15 44 | N 45 E | N 44 E | N 45 E | 23 50 | 22 30 | 1 20 | 25 10 |
| 14 | 43 30 | 12 29 | N 81 E | N 81 E | N 82 E | 24 11 | 21 36 | 2 35 | 26 46 |
| 18 | 47 50 | 11 50 | N 33 E | N 33 E | N 35 E | 25 52 | 24 28 | 1 24 | 27 16 |

The best test we have of estimating the accuracy of the corrected variations, or the efficacy of the plate for this determination, is by comparing those variations with each other which were made on the same, or on subsequent days, while the latitude and longitude remained nearly the same; first, as found in the usual way without the plate, and then with the plate, the ship's head being on opposite sides of the meridian; when although some difference (while the ship is changing her place) must be expected in the resulting variations, yet that change day by day will be but small, and we shall not fail to consider those results to be the most accurate, which agree nearest with each other. Several such examples may be selected out of the preceding table.

| Experiments. | Diff. in the variation without Plate. | Diff. in the variation with Plate. | Experiments. | Diff. in the variation without Plate. | Diff. in the variation with Plate. |
|---|---|---|---|---|---|
| | ° ′ | ° ′ | | ° ′ | ° ′ |
| 3 and 4 | 1 5 | 0 23 | 40 and 41 | 1 53 | 0 40 |
| 7 8 | 1 56 | 0 4 | 65 66 | 1 25 | 0 17 |
| 15 16 | 1 0 | 0 1 | 70 71 | 1 35 | 0 27 |
| 25 26 | 2 41 | 1 23 | 71 72 | 1 28 | 0 2 |
| 26 27 | 2 54 | 1 30 | 75 76 | 2 13 | 0 14 |
| 29 30 | 2 15 | 0 53 | 80 81 | 3 10 | 1 24 |
| 34 35 | 3 40 | 0 31 | | | |

There can be no question from the above results, and from the general character of the table, that the plate in all these cases served to reduce the amount of the errors produced by the iron of the vessel, but the corrections are inconsiderable in comparison to what they would be in higher latitudes, as will be seen in the report from the GRIPER, at the same time it must be observed, that the results, as shown in the table, are not a correct measure of the actual correction. It will be seen, for example, that the compasses in the binnacle, differed from each other 5°, 6°, or 7°, and these being the instruments by which the vessel is steered, are those which stand most in need of correction, and it appears by Captain Baldey's letter, that it was in this respect the correcting plate was of the greatest use. If constantly employed in azimuth observations, there can be no doubt we should soon have more correct variation charts: but the greatest advantage would be found in making use of it for the correction of the courses steered, as in the following example.

In consequence of the suggestions contained in Captain Baldey's letter, Lieutenant Mudge furnished me with several instances, showing the close approximation by reckoning with the plate compass course; but as the cases furnished in the late voyage of the Griper in latitudes where the local attraction is much greater, are still more important, I shall merely state the following, with which I had already been supplied by the same gentleman.

"On the 22d of May, at noon, we were in latitude 41° 46′ N., and long. by chronometer 9° 53′ W. Taking this as our departure, we sailed by the starboard compass S. 46° W. 183 miles; this placed the ship on the 23d (allowing the variation 21° W.) in lat. 38° 58′ N. and long. 11° 26′ W. Whereas, the observation at noon for latitude, gave 38° 39′ N. and long. 10° 58′ W. So great a difference in 24 hours was attributed to a current, till I compared the steering or starboard compass with the one with your plate, when I found no less than 7° error, to be subtracted from the course steered, making the true course S. 17° W., instead of S. 24° W., which had been taken as correct. By allowing the 7° which we had found subtractive from the course, our latitude was by reckoning 38° 41′ N., and long. 11° 02′ W., which agree with observation as closely as we can ever expect it to do under any circumstances."

An important question however, relative to this method of correction still remained to be decided. Captain Flinders had observed, that with an equal north and south dip he found an equal quantity of local deviation, but in a contrary direction, the north end of the needle in the one instance, and the south in the other, being drawn forward by the action of the iron in the vessel; and it was of course of the highest importance to ascertain how far the power of the plate was competent to correct this strongly marked difference in the action of the ship. This point has however been completely answered by the observations made on board H. M. S. Conway, by Captain Basil Hall, in a voyage from England, round Cape Horn to different parts on the western side of America, in the years 1820, 1821, and 1822.

It will perhaps, be best to give the detail of these experiments by copying the report forwarded to me by Captain Hall, on the return of the vessel to England, the original having been (I believe) already transmitted to your lordships.

" *Magnetical Observations made on board H. M. S. Conway, at Portsmouth Harbour and on the South American station, by Captain Basil Hall and Mr. Henry Foster, Master's Mate of that ship, in* 1820, 1821, *and* 1822.

" *Experiments on the Local Attraction of H. M. S. Conway, in Portsmouth Harbour.*

" On the 24th of July, 1820, Professor Barlow, of the Royal Military Academy at Woolwich, came on board to superintend these experiments, which were instituted at his suggestion, and by permission of the Lords Commissioners of the Admiralty.

" The object was to ascertain the amount of the deviation in the direction of the magnetic needle, by the combined action of all the attracting matter on board the ship; and as it was required to determine this quantity at various positions of the ship's head, she was warped to one of the transporting buoys in the middle of the harbour, round which, as a fixed centre, she was successively drawn, by means of hawsers, and held steadily at the required points while the observations were made."

Captain Hall here proceeds to particularize the nature of this operation and the amount of the local attraction observed at each point, which being given at length in my "Essay on Magnetic Attractions, &c.;" may, for the sake of abridgement, be passed over here. I shall therefore proceed to that part of the report which relates to the practical operations at sea.

"In practice the following is the method we pursued.

"A set or several sets of azimuths were taken without the plate, then another set or sets with the plate affixed, the ship's head and all other circumstances remaining the same: the variation of the compass was computed from these observations; that variation resulting from the first azimuths, taken without the plate, is affected simply by the local attraction of the ship, and may be termed the *deviated variation:* that resulting from the azimuths when the plate was affixed, by an action twice as great; first by the ship and next by the plate, and may be termed the *double deviated variation*. The difference between these variations is the amount of the local attraction or the deviation, and this applied to the deviated variation gives the correct magnetic variation.

"It is easy to see how this correction is to be applied, by merely observing whether the north end of the needle has been drawn to the west or to the east, by the application of the plate, and considering that the ship's attraction must have had a similar effect on the needle.

"The following observations were made at sea by Mr. Foster, under my superintendance and occasional assistance. The instrument used was an azimuth compass, made by Messrs. W. and T. Gilbert of London, lent to me by the makers, at the suggestion of Professor Barlow. It is so constructed that the observer reads off the angle at the same time that he observes the object, and is in other respects admirably suited for practice, not only on such occasions as this, where much delicacy is required: but also in surveying and in piloting ships by means of charts and bearings. The azimuth compasses at present supplied to H. M. ships are altogether unfit for any of these purposes, even the most common.

(Signed) "BASIL HALL."

*Observations made at sea, in order to determine the amount of local attraction in different latitudes, (from* 51° N. *to* 60° S.) *by means of Mr. Barlow's Plate. By Mr. H. Foster, H. M. S. Conway.*

"It will save trouble to assign the following letters to the different elements in these experiments.

"(d v) Is the deviated variation, or that observed without the plate.

"(d d v) Is the double deviated variation, or that observed with the plate affixed.

"(c) Is the correction or deviation to be applied to (d v.)

"(v) Is the correct variation of the compass, or that freed from the effect of local attraction."

(1) Aug. 11, 1820, lat. 49⅜° N., long. 5¼° W. ship's head by compass W. S. W.

| | | |
|---|---|---|
| (d v) | = 30° 6′ W. | |
| (d d v) | = 32 26 W. | |
| (c) | = 2 20 | Westerly deviation. |
| (d v) | = 30 6 W. | |
| (v) | = 27 46 W. | True variation. |

(2) Aug. 12, lat. 47° N., long. 8° 20′ W. ship's head by compass W. S. W.

| | | |
|---|---|---|
| (d v) | = 29°20′ W. | |
| (d d v) | = 32 54 W. | |
| (c) | = 3 34 | Westerly deviation. |
| (d v) | = 29 20 W. | |
| (v) | = 25 46 West. | |

**(3) Aug. 13, lat. 45° N., long. 11° W.**
**ship's head S. W. by W.**

| | |
|---|---|
| (d v) | = 29° 13′ W. |
| (d d v) | = 33 16 W. |
| (c) | = 4 3 Westerly deviation. |
| (d v) | = 29 13 W. |
| (v) | = 25 10 West. |

**(4) Aug. 14, lat. 43½° N., long. 12° W.**
**ship's head by compass S. W. by W.**

| | |
|---|---|
| (d v) | = 28° 11′ W. |
| (d d v) | = 30 42 W. |
| (c) | = 2 31 Westerly deviation. |
| (d v) | = 28 11 W. |
| (v) | = 25 40 West. |

**(5) Aug. 17, lat. 40° 4′ N., long. 14° 30′ W.**
**ship's head by compass S. W.**

| | |
|---|---|
| (d v) | = 28° 13′ W. |
| (d d v) | = 29 55 W. |
| (c) | = 1 42 Westerly deviation. |
| (d v) | = 28 13 W. |
| (v) | = 26 31 West. |

**(6) Aug. 19, lat. 36° 11′ N., long. 14° 53′ W.**
**ship's head by compass S.**

| | |
|---|---|
| (d v) | = 23° 56′ W. |
| (d d v) | = 23 54 W. |
| (c) | = 0 2 Easterly deviation. |
| (d v) | = 23 56 W. |
| (v) | = 23 58 West. |

**(7) Aug. 20, lat. 35° 11′ N., long. 14° W.**
**ship's head by compass S. S. E.**

| | |
|---|---|
| (d v) | = 21° 20′ W. |
| (d d v) | = 21 12 W. |
| (c) | = 0 8 Easterly deviation. |
| (d v) | = 21 20 W. |
| (v) | = 21 28 West. |

**(8) Aug. 22, lat. 30° 7′ N., long 15° 47′ W.**
**ship's head by compass S. W.**

| | |
|---|---|
| (d v) | = 23° 7′ W. |
| (d d v) | = 25 8 W. |
| (c) | = 2 1 Westerly deviation. |
| (d v) | = 23 7 W. |
| (v) | = 21 6 West. |

August 23, anchored off the town of Santa Cruz, (island of Teneriffe,) made observations for the dip, but, owing to the ferruginous matter contained in the stone of the island, which is all lava, our endeavours to obtain the amount of the dip were ineffectual.

(9) Aug. 28, lat. 27° 20′ N., long. 17° W. ship's head by compass S. W. by W.

(d v) = 22° 1′ W.
(d d v) = 24 19 W.

(c) = 2 18 Westerly deviation.
(d v) = 22 1 W.

(v) = 19 43 West.

(10) Aug. 28, lat. 26° 20′ N., long. 18° W. ship's head by compass S. W. by W.

(d v) = 21°52′ W.
(d d v) = 23 52 W.

(c) = 2 0 Westerly deviation.
(d v) = 21 52 W.

(v) = 19 52 West.

(11) Aug. 29, lat. 24° N., long. 19¾° W. ship's head by compass S. W. by W.

(d v) = 21° 5′ W.
(d d v) = 22 26 W.

(c) = 1 21 Westerly deviation.
(d v) = 21 5 W.

(v) = 19 44 West.

(12) Aug. 30, lat. 21° 40′ N., long. 21°40′ W. ship's head by compass S W by W.

(d v) = 19°43′ W.
(d d v) = 20 42 W.

(c) = 0 59 Westerly deviation.
(d v) = 19 43 W.

(v) = 18 44 West.

## *Experimental observations for the variation under different directions of the ship's head.*

(13) August 31, lat. 20° N., long. 23° 12′ W. The variation was observed with the ship's head directed to the S. W. by W.; S. and W. ½ N. by compass.

(1) Ship's head S. W. by W.

(d v) = 18°38′ W.
(d d v) = 19 44 W.

(c) = 1 6 Westerly deviation.
(d v) = 18 38 W.

(v) = 17 32 West.

(2) Ship's head S.

(d v) = 16°58′ W.
(d d v) = 17 14 W.

(c) = 0 16 Westerly deviation.
(d v) = 16 58 W.

(v) = 16 42 West.

(3) Ship's head W. ½ N.

(d v) = 18°37′ W.
(d d v) = 20 17 W.

(c) = 1 40 Westerly deviation.
(d v) = 18 37 W.

(v) = 16 57 West.

Hence it appears that the variation at the several points, when

The plate was not fixed, were

| | | | |
|---|---|---|---|
| Ship's head | S. W. by W. | = 18°38′ | W. |
| | South | = 16 58 | |
| | W. ½ N. | = 18 37 | |
| | Greatest difference | 1 40 | |

When Mr. Barlow's plate was attached.

| | | | |
|---|---|---|---|
| Ship's head | S. W. by W. | = 17°32′ | W. |
| | South | = 16 42 | |
| | W. ½ N. | = 16 57 | |
| | Greatest difference | 0 50 | |

The greatest difference being when the plate was not fixed.

(14) Sept. 1, lat. 18½°N., long. 24¾° W. ship's head by compass S. W. by W.

(d v) = 17°10′ W.
(d d v) = 18 8 W.
(c) = 0 58 Westerly deviation.
(d c) = 17 10 W.
(v) = 16 12 West.

(15) Sept. 3, lat. 15¼° N., long. 25° 40′ W. ship's head by compass S.

(d v) = 14° 2′ W.
(d d v) = 13 56 W.
(c) = 0 6 Easterly deviation.
(d v) = 14 2 W.
(v) = 14 8 West.

(16) Sept. 9, lat. 8° 51′ N., long. 19½° W. ship's head by compass S. E. by S.

(d v) = 14°37′ W.
(d d v) = 14 26 W.
(c) = 0 11 Easterly deviation.
(d v) = 14 37 W.
(v) = 14 48 West.

(17) Sept. 16, lat. 0° 30′ S., long. 24° W. ship's head by compass S. W.

(d v) = 12°31′ W.
(d d v) = 12 31 W.
(c) = 0 0
(d v) = 12 31 W.
(v) = 12 31 West.

(18) Sept. 17, lat. 1° 24′ S., long. 25° W. ship's head by compass S. W.

(d v) = 11°25′ W.
(d d v) = 11 23 W.
(c) = 0 2 Easterly deviation.
(d v) = 11 25 W.
(v) = 11 27 West.

(19) Sept. 20, lat. 9° 50′ S., long. 31¼° W. ship's head by compass S. by W. ½ W.

(d v) = 6°13′ W.
(d d v) = 5 57 W.
(c) = 0 16 Easterly deviation.
(d v) = 6 13 W.
(v) = 6 29 West.

(20) Sept. 22, lat. 14° S., long. 33¼° W.
ship's head by compass S. by W. ½ W.

(d v) = 4°28′ W.
(d d v) = 4 6 W.
(c) = 0 22 Easterly deviation.
(d v) = 4 28 W.
(v) = 4 50 West.

(22) Sept. 25, lat. 18° 40′ S., long. 36° 40′ W.
ship's head by compass S. W. ½ S.

(d v) = 0°46′ W.
(d d v) = 0 26 W.
(c) = 0 20 Easterly deviation.
(d v) = 0 46 W.
(v) = 1 6 West.

(24) Oct. 15, lat. 23° 18′ S., long. 43° 12′ W.
ship's head by compass S. S. E.

(d v) = 4°0′ E.
(d d v) = 4 0 E.
(c) = 0 0 Westerly deviation.
(d v) = 4 0 E.
(v) = 4 0 East.

(26) Oct. 17, lat. 27° S., long. 46° 10′ W.
ship's head by compass S. S. W. ½ W.

(d v) = 5°40′ E.
(d d v) = 5 31 E.
(c) = 0 9 Westerly deviation.
(d v) = 5 40 E.
(v) = 5 49 East.

(21) Sept. 23, lat. 15° 52′ S. long. 34° W.
ship's head by compass S. by W. ½ W.

(d v) = 3°47′ W.
(d d v) = 3 17 W.
(c) = 0 30 Easterly deviation.
(d v) = 3 47 W.
(v) = 4 17 West.

(23) Oct. 11, lat. 22° 55′ S., long. 43¾° W.
ship's head by compass W. S. W.

(d v) = 4°2′ E.
(d d v) = 4 0 E.
(c) = 0 2 Westerly deviation.
(d v) = 4 2 E.
(v) = 4 4 East.

(25) Oct. 18, lat. 25° 35′ S., long. 44° W.
ship's head by compass S. S. W. ½ W.

(d v) = 4°59′ E.
(d d v) = 4 52 E.
(c) = 0 7 Westerly deviation.
(d v) = 4 59 E.
(v) = 5 6 East.

(27) Oct. 18, lat. 28° 41′ S., long. 46° 40′ W.
ship's head by compass S. S. W.

(d v) = 7°24′ E.
(d d v) = 7 20 E.
(c) = 0 4 Westerly deviation.
(d v) = 7 24 E.
(v) = 7 28 East.

October 24, at anchor off the town of Buenos Ayres. The variation was observed to be 14° 30′ easterly. The plate being affixed, no difference could be observed, ship's head by compass N. W.

(28) Nov. 23, lat. 52½° S., long. 64° 40′ W. ship's head by compass S. by E.

(d v) = 21° 17′ E.
(d d v) = 21 16 E.
(c) = 0 1 Westerly deviation.
(d v) = 21 17 E.
(v) = 21 18 East.

(29) Nov. 25, lat. 55° 40′ S., long. — W. ship's head by compass S. by W. ½ W.

(d v) = 23° 49′ E.
(d d v) = 24 38 E.
(c) = 0 49 Easterly deviation.
(d v) = 23 49 E.
(v) = 23 00 East.

(30) Nov. 26, lat. — S., long. — W. Diego Rameirez N. 79° E. 6 or 7 miles. ship's head by compass S. W.

(d v) = 26° 28′ E.
(d d v) = 28 24 E.
(c) = 1 56 Easterly deviation.
(d v) = 26 28 E.
(v) = 24 32 East.

(31) Nov. 30, lat. 60° 46′ S., long. 72° W. ship's head by compass N. by E.

(d v) = 27° 37′ E.
(d d v) = 27 21 E.
(c) = 0 16 Westerly deviation.
(d v) = 27 37 E.
(v) = 27 53 East.

(32) Dec. 1, lat. 60° 56′ S., long. 72½° W. ship's head by compass S. W. by S.

(d v) = 30° 3′ E.
(d d v) = 32 27 E.
(c) = 2 24 Easterly deviation.
(d v) = 30 3 E.
(v) = 27 39 East.

(33) Dec. 3, lat. 60° 36′ S., long. 77¼° W. ship's head by compass W. by N. ½ N.

(d v) = 30° 31′ E.
(d d v) = 33 15 E.
(c) = 2 44 Easterly deviation.
(d v) = 30 31 E.
(v) = 27 47 Easterly.

(34) Dec. 7, lat. 57° 38′ S., long. 84° 10′ W. ship's head by compass W. N. W.

(d v) = 28° 18′ E.
(d d v) = 30 35 E.
(c) = 2 17 Easterly deviation.
(d v) = 28 18 E.
(v) = 26 1 East.

(35) Dec. 14, lat. 43° 20′ S., long. 79½° W. ship's head by compass N. ¼ W.

(d v) = 18° 50′ E.
(d d v) = 19 14 E.
(c) = 0 24 Easterly deviation.
(d v) = 18 50 E.
(v) = 18 26 East.

(36) Dec. 16, lat. 39° 7′ S., long. 78° W. ship's head by compass N. by E.

| | | |
|---|---|---|
| (d v) | = 17°16′ E. | |
| (d d v) | = 17 20 E. | |
| (c) | = 0 4 | Easterly deviation. |
| (d v) | = 17 16 E. | |
| (v) | = 17 12 East. | |

(37) Dec. 17, lat. 36½° S., long. 75° 40′ W. ship's head by compass N. N. E.

| | | |
|---|---|---|
| (d v) | = 15°57′ E. | |
| (d d v) | = 15 43 E. | |
| (c) | = 0 14 | Westerly deviation. |
| (d v) | = 15 57 E. | |
| (v) | = 16 11 East. | |

In this place Mr. Foster gives a statement of some observations made on *shore*, at Valparaiso, for determining the dip and variation. The results were, dip 38° 47′ south; variation 14° 43′ east. The ship was also swung at this place to get the local attraction, as at Portsmouth; the results, to prevent breaking the series of sea observations, are given in a subsequent page.

(38) Feb. 12, 1821, lat. 12° 3′ S., long. 77° 5′ W. ship's head by compass S. by E. ½ E.

| | | |
|---|---|---|
| (d v) | = 9°37′ E. | |
| (d d v) | = 9 24 E. | |
| (c) | = 0 13 | Westerly deviation. |
| (d v) | = 9 37 E. | |
| (v) | = 9 50 East. | |

(39) March 1, lat. 12° 27′ S., long. 78° W. ship's head by compass S. W.

| | | |
|---|---|---|
| (d v) | = 9°26′ E. | |
| (d d v) | = 9 38 E. | |
| (c) | = 0 12 | Easterly deviation. |
| (d v) | = 9 26 E. | |
| (v) | = 9 14 East. | |

(40) Mar. 2, lat. 14° 18′ S., long. 80° 20′ W. ship's head by compass S. W.

| | | |
|---|---|---|
| (d v) | = 10°16′ E. | |
| (d d v) | = 10 38 E. | |
| (c) | = 0 22 | Easterly deviation. |
| (d v) | = 10 16 E. | |
| (v) | = 9 54 East. | |

(41) Mar. 4, lat. 18° 57′ S., long. 85° W. ship's head by compass S. S. W.

| | | |
|---|---|---|
| (d v) | = 10° 10′ E. | |
| (d d v) | = 10 30 E. | |
| (c) | = 0 20 | Easterly deviation. |
| (d v) | = 10 10 E. | |
| (v) | = 9 50 East. | |

(42) Mar. 6, lat. 23° 30′ S., long. 87° 52′ W.
ship's head by compass S. by W.

| | | |
|---|---|---|
| (d v) | = | 10°26′ E. |
| (d d v) | = | 10 26 E. |
| (c) | = | 0 0 |
| (d v) | = | 10 26 E. |
| (v) | = | 10 26 East. |

(43) June 7, lat. 18° 28′ S., long. 70¼° W.
ship's head by compass S. W.

| | | |
|---|---|---|
| (d v) | = | 10°25′ E. |
| (d d v) | = | 11 3 E. |
| (c) | = | 0 38 Easterly deviation. |
| (d v) | = | 10 25 E. |
| (v) | = | 9 47 East. |

The above are the whole of the sea observations, and therefore all that are essential to my purpose, except those referred to above as having been made at Valparaiso. The results of which are as follow:

## EXPERIMENTS

*On the local attraction of H. M. S. Conway, at Valparaiso.*

| Position of the ship's head. | Deviated bearing of the shore station. | Correct bearing of compass from the shore. | Local attraction + when N. end is drawn W.; — when E. | Position of the ship's head. | Deviated bearing of the shore station. | Correct bearing of compass from the shore. | Local attraction + when N. end is drawn W.; — when E. |
|---|---|---|---|---|---|---|---|
| South | S49° 10′W | S49° 39′W | — 0° 29′ | North | S52° 0′W | S52° 37′W | — 0° 37′ |
| S by W | 50 0 | 50 18 | — 0 18 | N by E | 52 5 | 52 23 | — 0 18 |
| S S W | 50 0 | 49 28 | + 0 32 | N N E | 52 15 | 52 5 | + 0 10 |
| S W by S | 49 0 | 48 35 | + 0 25 | N E by N | 51 40 | 51 23 | + 0 47 |
| S W | 48 30 | 48 54 | — 0 24 | N E | 51 10 | 50 44 | + 0 26 |
| S W by W | 50 20 | 49 59 | + 0 21 | N E by E | 49 0 | 48 37 | + 0 23 |
| W S W | 50 0 | 50 40 | — 0 40 | E N E | 48 50 | 47 56 | + 0 54 |
| W by S | 51 20 | 52 9 | — 0 49 | E by N | 46 15 | 45 27 | + 0 48 |
| West | 51 30 | 52 32 | — 1 2 | East | 44 50 | 43 57 | + 0 53 |
| N by W | 52 40 | 53 9 | — 0 29 | E by S | 44 10 | 43 18 | + 0 52 |
| W N W | 52 40 | 53 15 | — 0 35 | E S E | 43 30 | 42 37 | + 0 53 |
| N W by W | 53 0 | 52 50 | + 0 10 | S E by E | 42 50 | 42 31 | + 0 19 |
| N W | 53 0 | 52 10 | + 0 50 | S E | 42 30 | 42 46 | — 0 16 |
| N W by N | 52 50 | 52 5 | + 0 45 | S E by S | 43 0 | 43 42 | — 0 42 |
| N N W | 52 20 | 53 14 | — 0 54 | S S E | 49 0 | 48 8 | + 0 52 |
| N by W | 52 20 | 52 47 | — 0 27 | S by E | 49 0 | 48 56 | + 0 4 |

Having thus given a verbatim extract from Captain Hall's report, of all the experiments made on ship board with my correcting plate, I propose, before making any remarks on the results, to draw all his deductions into a tabulated form; because they will thus be brought more collectively under the eye of the reader, and their very exact agreement with the general nature of the results obtained by Captain Flinders will be more distinctly exhibited; and to render this the more obvious, I have added two columns to the table, one, of the dip of the needle at each place of observation, as given in Hansteen's chart, and the other, showing the end of the needle, which according to the observations with the plate, was in each case drawn forward by the vessel.

*Tabulated results of the proceeding observations with the correcting plate.*

| | Latitude. | Longitude. | Dip by Hansteen's chart. | Observed variation | Corrected variation | Local attraction | Direction of ship's head. | End of the needle drawn forward. |
|---|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | | |
| 1 | 49 30 N | 5 15 W | 72 0 N | 30 6 W | 27 46 W | 2 20 W | W S W | North |
| 2 | 47 0 N | 8 20 W | 71 0 N | 29 20 W | 25 46 W | 3 34 W | W S W | North |
| 3 | 45 0 N | 11 0 W | 70 0 N | 29 13 W | 25 10 W | 4 3 W | S W by W | North |
| 4 | 43 30 N | 12 0 W | 69 0 N | 28 11 W | 25 40 W | 2 31 W | S W by W | North |
| 5 | 40 4 N | 14 30 W | 69 0 N | 28 13 W | 26 31 W | 1 42 W | S W | North |
| 6 | 36 11 N | 14 53 W | 65 0 N | 23 56 W | 23 58 W | 0 2 E | South | ...... |
| 7 | 35 11 N | 14 0 W | 65 0 N | 21 20 W | 21 28 W | 0 8 E | S S E | North |
| 8 | 30 7 N | 15 47 W | 63 0 N | 23 7 W | 21 6 W | 2 1 W | S W | North |
| 9 | 27 20 N | 17 0 W | 60 0 N | 22 1 W | 19 43 W | 2 18 W | S W by W | North |
| 10 | 26 20 N | 18 0 W | 60 0 N | 21 52 W | 19 52 W | 2 0 W | S W by W | North |
| 11 | 24 0 N | 19 45 W | 60 0 N | 21 5 W | 19 44 W | 1 21 W | S W by W | North |
| 12 | 21 40 N | 21 40 W | 55 0 N | 19 43 W | 18 44 W | 0 59 W | S W by W | North |
| 13 | 20 0 N | 23 12 W | 55 0 N | In th | ree obser | vations.. | ........... | North |
| 14 | 18 30 N | 24 45 W | 53 0 N | 17 10 W | 16 12 W | 0 58 W | S W by W | North |
| 15 | 15 45 N | 25 40 W | 50 0 N | 14 2 W | 14 8 W | 0 6 E | South | ...... |
| 16 | 8 51 N | 19 30 W | 40 0 N | 14 37 W | 14 48 W | 0 11 E | S E by S | North |
| 17 | 0 30 S | 24 0 W | 25 0 N | 12 31 | 12 31 W | 0 0 | S W | ...... |
| 18 | 1 24 S | 25 0 W | 22 0 N | 11 25 W | 11 27 W | 0 2 E | S W | South |
| 19 | 9 50 S | 31 45 W | 9 0 N | 6 13 W | 6 29 W | 0 16 E | S by W ½ W | South |
| 20 | 14 0 S | 33 15 W | 0 0 | 4 28 W | 4 50 W | 0 22 E | S by W ½ W | South |
| 21 | 15 52 S | 34 0 W | 3 0 S | 3 47 W | 4 17 W | 0 30 E | S by W ½ W | South |
| 22 | 18 40 S | 36 40 W | 3 0 S | 0 46 W | 1 6 W | 0 20 E | S W ½ S | South |
| 23 | 22 55 S | 43 15 W | 20 0 S | 4 2 E | 4 4 E | 0 2 W | W S W | North |
| 24 | 23 18 S | 43 12 W | 21 0 S | 4 0 E | 4 0 E | 0 0 | S S E | ...... |
| 25 | 25 35 S | 44 0 W | 25 0 S | 4 59 E | 5 6 E | 0 7 W | S S W ½ W | North |
| 26 | 27 0 S | 46 10 W | 30 0 S | 5 40 E | 5 49 E | 0 9 W | S S W ½ W | North |
| 27 | 28 41 S | 46 40 W | 30 0 S | 7 24 E | 7 28 E | 0 4 W | S S W | North |
| 28 | 52 30 S | 64 40 W | 62 0 S | 21 17 E | 21 18 E | 0 1 W | S by E | South |
| 29 | 55 40 S | .... | .... | 23 49 E | 23 0 E | 0 49 E | S W ½ W | South |
| 30 | .... | .... | .... | 26 28 E | 24 32 E | 1 56 E | S W | South |
| 31 | 60 46 S | 72 0 W | 70 0 S | 27 37 E | 27 53 E | 0 16 W | N by E | South |
| 32 | 60 56 S | 72 30 W | 70 0 S | 30 3 E | 27 39 E | 2 24 E | S W by S | South |
| 33 | 60 36 S | 77 45 W | 70 0 S | 30 31 E | 27 47 E | 2 44 E | W by N ½ N | South |
| 34 | 57 38 S | 84 10 W | 70 0 S | 28 18 E | 26 1 E | 2 17 E | W N W | South |
| 35 | 43 20 S | 79 30 W | 65 0 S | 18 50 E | 18 26 E | 0 24 E | N ¼ W | South |
| 36 | 39 7 S | 78 0 W | 57 0 S | 17 16 E | 17 12 E | 0 4 E | N by E | North |
| 37 | 36 30 S | 75 40 W | 50 0 S | 15 57 E | 16 11 E | 0 14 W | N N E | South |
| 38 | 12 3 S | 77 5 W | ....S | 9 37 E | 9 50 E | 0 13 W | S by E ½ E | South |
| 39 | 12 27 S | 78 0 W | ....S | 9 26 E | 9 14 E | 0 12 E | S W | South |
| 40 | 14 18 S | 80 20 W | ....S | 10 16 E | 9 54 E | 0 22 E | S W | South |
| 41 | 18 57 S | 85 0 W | ....S | 10 10 E | 9 50 E | 0 20 E | S S W | South |
| 42 | 23 30 S | 87 52 W | ....S | 10 26 E | 10 26 E | 0 0 | S by W | ...... |
| 43 | 18 28 S | 70 15 W | ....S | 10 25 E | 9 47 E | 0 38 E | S W | South |

On examining the numbers contained in the above tabulated results, their general agreement with the deductions of Captain Flinders will be immediately obvious. That distinguished officer found, that with equal dips, north and south, he had equal local attractions, but reversed in direction: and the whole of the foregoing table indicates the same change. The north end of the needle being drawn forward, while the dip is north; and the south when the dip is south, at least the exceptions are only in places near the magnetic equator, and the amount of the difference in these cases never exceeds a few minutes of a degree. The general decrease of effect from England to the equator, the increase again from the equator to Cape Horn, and the decrease thence as the southern latitudes diminish, are striking instances of the accuracy of the method of correction proposed. To which I may also add, as a still stronger case, the variations as found with and without the plate, in experiments (31) (32) (33.)

In which the greatest difference,

Without the plate, is . . 2° 53′

With the plate, only . . 0 14

It is thus rendered obvious, that the plate, as fixed in Portsmouth Harbour, in lat. 50° 47′ north, will correct the local attraction of a vessel in lat. 60° 56′ S.; the dip in the former case being 70° north, and in the latter about the same south.

In short it is rendered evident from the experiments made in the CONWAY, that the method of correction proposed, is applicable through all navigable latitudes, from 50° north to the highest approachable southern regions.

*Mr. Foster's experiments on board H. M. S. Griper, Captain D. C. Clavering, for correcting the local attraction, in a voyage from England to Spitzbergen in* 1823.

As the experiments which had hitherto been made, were principally in regions where the local attraction is least considerable, it was desirable that they should be repeated in high northern latitudes, where it had already been ascertained by Captains Ross and Parry, that the disturbance from this cause was very great. An opportunity of making this trial occurred in the recent voyage of H. M. S. Griper to Spitzbergen; and the results will, I trust, be found highly important, and fully confirmatory of the general applicability of the method of correction in question. It may be proper to observe however, that it had occurred to me before the return of the Conway, that the method proposed might be simplified, particularly in high northern latitudes (where it is of most importance) by placing the plate aft of the compass, thereby neutralizing, instead of doubling the original effect of the vessel.

The success of this severe trial of the application of the correcting plate, will fully appear from the following letter from Captain Clavering, and the report of Mr. Foster, which are too important to admit of any abridgement.

*Extract of a Letter from Captain D. C. Clavering, of H. M. S. Griper, to* J. BARROW, Esq. *dated Sea Reach,* 18*th December,* 1823.

"Having been directed by their lordships to make trial of Mr. Barlow's plate, under Mr. Foster's direction, I forward that gentleman's report, which it will be unnecessary for me to comment upon further than to acknowledge the extreme practical utility of it, as found during the whole of the voyage; as when once fixed abaft the compass (thereby neutralizing the effect of the iron on board,) nothing further was necessary than to allow the variation of the place.

"The very great local attraction in this ship is also something remarkable, and as it is now considerably greater than in the former voyage, when with Captain Parry, we can only account for it by the addition of the patent capstan, and chain cables, which can be proved before paying off by trial of the compasses when it is hoisted out.

Should this be the case, it will be well for ships to be aware of the liability of this error. Our binnacle compass has not been of the smallest use, and at present it differs with the ship's head at (east and west *) points; besides traversing extremely sluggish.

(Signed) "D. C. Clavering."

I must not miss this opportunity of publishing also Captain Clavering's letter to me, which I trust will be found highly satisfactory.

*No.* 6, *Frith-street, Soho-square,*
*January* 15, 1824.

Dear Sir,

"I am sorry for the cause that prevented me from having the pleasure of seeing you on board the Griper, and am glad to find you are so fast recovering from your severe indisposition; but for the rest, whatever facilities I have been able to give Mr. Foster, and whatever attention I have myself paid to the subject of your experiments, I have only fulfilled the instructions received from my Lords Commissioners and my own wishes, in promoting what I consider to be a highly valuable improvement in nautical service.

"You have seen by my report to the Admiralty,

* This blank is filled up in a subsequent letter, by stating the difference to be 14° *plus* at west, and 14° *minus* at east.

that the local attraction of the Griper before we left the Nore was 14° *plus*, with the ship's head at west and 14° *minus* at east, making a difference of 28° before we left England, and which soon after increased to 20° at each of those points, or more, viz. (ultimately to 37°) making in the latter case an extreme difference of about six points. Under such circumstances it is obvious that the compass would have been altogether useless, (as indeed it has always been admitted to be in these high latitudes,) but for your valuable correcting plate, with which, as I have already stated in my report, we found the compass to which the apparatus was attached, as serviceable in these latitudes as in any other; for having once neutralized the local effect of the vessel at the Nore, we had only during the remainder of the voyage to allow for the variation of the place, and were quite unembarrassed with any effect from local attraction.

"I should also state, that independently of the latter disturbance, we found all our other compasses so extremely sluggish that they would stand in any direction whatever. The compass supplied to the Griper by Messrs. W. and T. Gilbert, is certainly a most excellent instrument. The card you sent with Mr. Foster, with three parallel needles,*

* This construction was suggested by Mr. Pullman, Superintendent-Master in Woolwich Dock-yard.

also answered extremely well.—The idea is simple, and obvious, for of two cards and needles of the same weight there can be no doubt that that which has the greatest directive force and the least weight to carry must be the best. In the common compass cards the needle is too light and the card too heavy—you have preserved the same total weight, but thrown the greatest part of it into the needles; it is therefore equally steady with the former and true to its direction; whereas, the other needle has not power to bring the card to the proper bearing.

"I remain, Sir, yours truly,
"D. C. CLAVERING."

The following is Mr. Foster's report alluded to in the above letter:

*Report of the experiments made on the local attraction of H. M. S. Griper, by Mr. H. Foster.*

In consequence of a communication from my Lords Commissioners of the Admiralty, addressed to Captain D. C. Clavering, I was by him desired to attend to such experiments on Magnetism, as Mr. Barlow (one of the Professors of Mathematics at the Royal Military Academy Woolwich) might suggest: he wished that the amount of the local attraction, or the deviation in the direction of the needle produced by the combined action of all the attracting matter on board the Griper might be ascertained.

To determine this with the ship's head at all the various points of the compass, would have required more time, than could conveniently be bestowed on this occasion. The nature of the service on which we were about to be employed, rendering it necessary, that our departure should be as early as possible. Mr. Barlow then considered, that if the amount of the deviation were ascertained at the four cardinal points, it would be sufficient for the present, until opportunities offered for making more numerous and consequently more satisfactory observations hereafter.

At the above-mentioned points this amount could be readily obtained, as the ship swung, with her head from east to west, *via* south, every change of tide, so that it only became necessary to lay a kedge out, by which her head could be brought to the northward at slack water, and to select some remote object, whose bearing could be observed when the ship's head was on those different points of the compass: in this instance, the western end of a clump of trees, situated on the high land, about twelve miles to the S. W. of Sheerness, was fixed upon, so that the consideration of parallax in the bearings taken, arising from a change of position of the ship, during the operation, might be safely neglected.

The following is a detailed statement of the experiments made on the local attraction of H. M. S. Griper, at the Little Nore; in performing which two methods were adopted.

First, by carefully observing the bearing of the object selected, with the ship's head in opposite directions, (as for example east and west,) the mean of the difference of the bearings so observed being accounted the local attraction at those points.

Secondly, by taking an astronomical bearing of the object chosen, and from thence finding its correct magnetic bearing, by the application of the variation of the compass; the difference between the correct magnetic bearing so found, and that actually observed on board, when the ship's head was at the various points specified, being the angular aberration in the position of the needle caused by the local attraction of the ship, which, for distinction, is designated by the sign −, minus, when the observed bearing was less than the correct magnetic bearing of the object, and +, plus, when it was greater. The former of course taking place when the north end of the needle was drawn towards the east, and the latter when it was drawn toward the west, by the local attraction of the ship.

The following table exhibits the amount of the effect produced, when the ship's head was at the various points therein specified.

| Position of the Ship's Head. | Deviated or Compass bearing of the object. | Correct Magnetic bearing of the object. | Deviation + when N. end of the Needle was drawn to the Westward; – when ditto was drawn to the E. | Position of the Ship's Head. | Deviated or Compass bearing of the object. | Correct Magnetic bearing of the object. | Deviation + when N. end of the Needle was drawn to the Westward; – when ditto was drawn to the E. | Difference of opposite bearing. | Local Attraction, or mean of opposite bearing. |
|---|---|---|---|---|---|---|---|---|---|
| North | S 66° 0′W | S 64° 56′W | + 1° 4′ | South | S 63° 0′W | S 64° 56′W | – 1° 56′ | 3° 0′ | –1° 30′ |
| N E | 54 30 | ditto | 10 26 | *S W | .... | ditto | .... | .... | .... |
| E N E | 52 0 | ditto | 12 56 | W S W | 76 0 | ditto | + 11 4 | 24 0 | + 12 0 |
| East | 51 20 | ditto | 13 36 | West | 78 30 | ditto | + 13 34 | 27 10 | + 13 35 |
| E S E | 52 0 | ditto | 12 56 | W N W | 77 20 | ditto | + 12 24 | 25 20 | + 12 40 |
| S E | 55 20 | ditto | 9 36 | N W | 75 0 | ditto | + 10 4 | 19 40 | + 9 54 |

From the above table, it is obvious that the north end of the needle was always drawn forward, or towards the body of the ship lying before the compass, by the local attraction, so that when her head was to the eastward, the north end of the needle was drawn to the eastward, or the observed bearing of the object on shore, was lessened; and vice versa.

The object of swinging the ship round from point to point being to enable us to fix a circular iron plate in such a position, with respect to the

* With the ship's head at S. W. the object on shore could not be seen.

needle of the card used in the foregoing experiments, as will produce at the different points a similar set of deviations with those already obtained in the preceding table, which position was found, after numerous trials, when the centre of the plate was $7\frac{3}{8}$ inches below the horizontal plane of the compass card, and $8\frac{1}{4}$ inches from the perpendicular line passing through its point of support.

When this iron plate, which is 44 inches in circumference, is fixed in the above position abaft the compass, in the line passing through the vertical line of support of the card, and the point where all the various local attraction of the ship may be supposed united; Mr. Barlow conceives that it will annihilate those deviations arising from the attractive mass lying before the compass, and consequently leave the needle in its correct magnetic position; how far this may obtain will be seen in the cases that follow; where the variation ascertained with the plate so fixed, will be the true variation of the compass; and that obtained without the plate will be the variation affected by the amount of the local attraction at that point on which the ship's head might happen to be during the observation, and may be termed the deviated variation.

It may save trouble to assign the following letters to the different elements in these experiments, viz.

(d v) Deviated variation, or that observed without the plate.

(v) Variation of the compass, or that freed from local attraction by fixing the plate.

(1.)

Sunday, May 18, 1823, when in latitude 65° 6′ N. and longitude 6° 54′ E. at 5h 30m P. M. Azimuths of the sun were observed, with and without the plate, when the ship's head was N. and N. E. by compass.

Ship's head North.

(d v) = 26° 1′ Westerly.
(v) = 24 23 W.

Difference = 1 38 or local attraction.

Ship's head N. E.

(d v) = 11°28′ Westerly.
(d) = 25 2 W.

Difference = 13 34 or local attraction.

It will be seen that the variations obtained with the plate fixed, differ but little from each other, whilst those ascertained without the plate differ 14° 33′.

(2.)

May 20, A. M. ship's head North by compass, in latitude 66° 57′ N., longitude 7° 20′ E. the following variations were obtained, with and without the plate.

(d v) = 24°53′ Westerly.
(v) = 25 30 W.

Difference = 0 37

(3.)

May 20, P. M. 1823, ship's head E. ½ N. by compass, in latitude 66° 15′ N. longitude 8° 0′ E. the following variations were obtained.

(d v) = 2° 14′ Westerly.
(v) = 21 15 W.

Difference = 19 1

(4.)

May 21, P. M. 1823, ship's head N. E. ½ E. by compass, in latitude 66° 35′ N. and longitude 9° 12′ E. the following variations were ascertained from azimuths taken with and without the plate.

(d v) = 11° 58′ Westerly.
(v) = 22 43 W.

Difference = 10 45

(5.)

May 23, A. M. 1823, in latitude 67° 21′ N. and longitude 9° 4′ E. the following variations were obtained when the ship's head was N. E. ½ E. and West by compass, with and without the plate.

First ship's head N. by E. ½ E. by compass.

(d v) = 18° 4′ Westerly.
(v) = 22 12 W.

Difference = 4 8

Second ship's head West by compass.

(d v) = 43° 5′ Westerly.
(v) = 20 0 W.

Difference = 23 5

(6.)

From the near agreement of the variations with each other when the plate was fixed, and the discordances in those ascertained without the plate, it was thought necessary permanently to fix a compass with the centre of its card in the same relative situation with respect to the centre of the plate, as that used in these experiments, by which the winds, courses steered, and bearings taken, might be hereafter registered in the ship's log.

The following is an extract from the log board of H. M. S. Griper, given as an example of the efficacy of this mode of fixing the plate in these latitudes, and may also serve to explain what in other vessels might be ascribed to currents, or other causes.

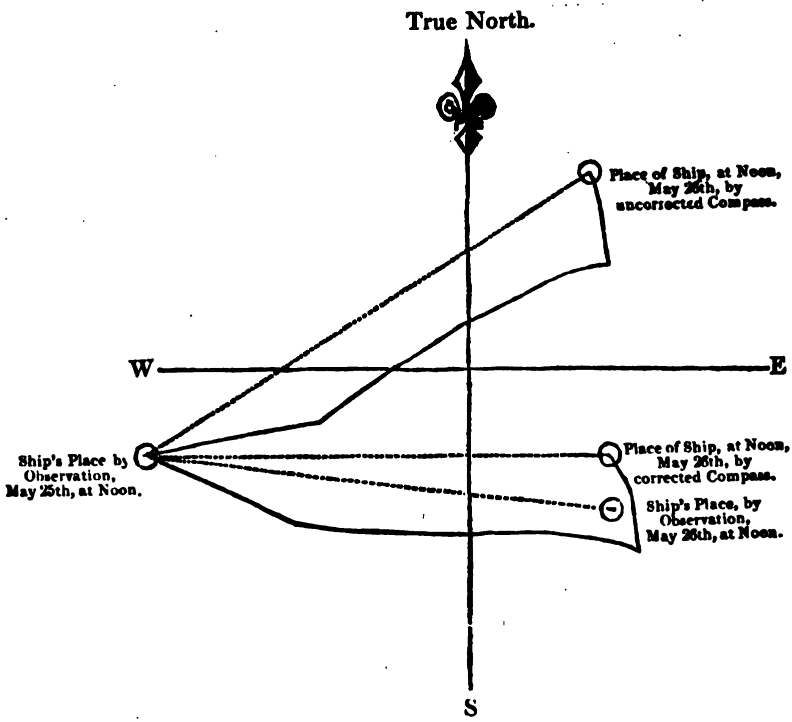
The day's run is between two places ascertained by observation, one in latitude 69° 16¼′ N., longitude by chronometer 7° 54′ E.; the other in latitude 69° 12′ 10″ N. and longitude by chronometer 10° 14½′ E.

The first column in the following table contains the hour; the second, knots; and the third, fathoms; the fourth shows the courses steered by the compass having the plate fixed; and the fifth, the courses steered by the compass without the plate; the sixth contains the magnetic direction of the wind; and the seventh is the leeway allowed on the courses steered; in the eighth column are the officers of the watches' initials.

| *H. M. S. Griper at Sea, 25th May, 1823.* | | | | | | | | Lat. 69° 16¼′ N., Long. by Chr. 7° 54′ E. |
|---|---|---|---|---|---|---|---|---|
| H. | K. | F. | Courses with Plate Compass. | Courses by Compass without Plate. | Winds by Plate Compass. | Lee-way. | Officers Initials | REMARKS, &c. |
| 1 | 3 | .. | E S E | E by N | | 2 pts. | | P. M. |
| 2 | 3 | .. | | | N E | | | Fresh breezes and cloudy weather. |
| 3 | 3 | 4 | | | | | P. G. | 4. Fresh breezes with a head swell. |
| 4 | 3 | 4 | | | | | | |
| 5 | 3 | .. | | | | | | |
| 6 | 3 | .. | E by S ½ S | E by N ½ N | | ditto | T. D. | Variation 2 points west. |
| 7 | 3 | .. | | | | | | |
| 8 | 3 | .. | E by S | E N E | N E by N | ditto | H. F. | 8. Squally weather. |
| 9 | 3 | 2 | E by S ½ S | E by N ½ N | | 1 pt. | | More moderate—set top-gallant sails. |
| 10 | 3 | 2 | E by S | E N E | | ditto | | |
| 11 | 3 | .. | E ½ S | E N E | | ditto | P. G. | Midnight, moderate, and fine. |
| 12 | 2 | 6 | | | | | | |
| 1 | 3 | .. | E by S | E by N ½ N | N E by N | ½ pt. | | A. M. May 26, moderate and fine. |
| 2 | 3 | .. | E S E | E by N | | ditto | | |
| 3 | 3 | .. | | | | | | |
| 4 | 3 | .. | | | | | T. D. | 4. Fine clear weather—set royals. |
| 5 | 2 | 6 | | | | | | |
| 6 | 2<br>1 | 4<br>.. | S E by E ½ E | E | | ditto | | 6h 30m tacked. |
| 7 | 1 | .. | N by E | N by E ½ E | E by N | None | | |
| 8 | 1 | 6 | | | | | H. F. | 8. Moderate and fine. |
| 9 | 1 | 6 | | | | | | |
| 10 | 1 | 6 | | | | | | Got spare sails up to dry. |
| 11 | 2 | .. | N ½ W | N ½ E | E N E | | P. G. | Variation 23° westerly. |
| 12 | 2 | .. | | | | | | Noon moderate and clear. |

Lat. observed at noon 69° 12′ 10″ N., Long. by Chr. 10° 14′ 15″ E.

(The annexed diagram shows the apparent course of the vessel by both compasses, P. B.)




The numerical results stand as follows:

Course and distance made good between the observations on the 25th and 26th of May, 1823.

Course = S. 85° E., distance 50 miles.

By the plate compass course = E., distance 51 miles.

By the compass without the Plate } Course = N. 58° E., distance 58 miles.

Latitude observed May 26, = 69° 12′ 10″ N., longitude by chronometer 10° 14′ E.

Latitude by the plate compass = 69° 16′ 00″ N., longitude 10° 17′ E.

Latitude by the compass without the plate ....... } = 69° 47′ N., longitude 10° 11′ E.

Making a difference in the latitude of 35 miles.

(7.)

May 28, 1823, in latitude 69° 8′ N. and longitude 14° 30′ E. the ship's head being N. E. and afterwards West, by compass; azimuths of the sun were observed, from which the following variations were obtained.

First ship's head N. E.
(v) = 17° 19′ W.
(d v) = 13 35 W.

Second ship's head W.
(v) = 14° 28′ W.
(d v) = 40 37 W.

Difference of variations obtained; first,
With the plate fixed .... 2° 51′
Secondly, without the plate 27 2

(8.)

*Hammerfest, June* 7, 1823.

To determine the amount of the effect of the local attraction produced here, the Griper was swung, by means of warps, so arranged as to admit of her head being turned round the compass from point to point successively, and there steadied whilst the bearing of the most distant object seen was taken, whose correct magnetic bearing had been, or could afterwards be obtained, the difference between which and that observed when the ship's head was at the various points of the compass, being accounted the local attraction at those points, and is, as before explained, designated by the signs +, plus, and –, minus, according as the compass or deviated bearing of the object was greater or less than the correct magnetic bearing of the same.

The following table exhibits the amount of the effect produced, in which the first column shows the position of the ship's head as indicated by the compass, with which the bearings were observed; the second column contains the compass or deviated bearing of the object selected; and the third, is the correct magnetic bearing of the same; the fourth column is made up of the differences between the second and third columns, which is the local attraction of the ship at those points where her head was during the observation.

*Hammerfest, Latitude* 70° 40′ *N. Longitude* 23° 45′ *E. Variation* 11° 26′ *W. Dip* 77° 15′ *N.*

| Position of Ship's Head. | Compass or deviated Bearing of object. | Correct Magnetic Bearing of object. | Local Attraction. | Position of Ship's Head. | Compass or deviated Bearing of object. | Correct Magnetic Bearing of object. | Local Attraction. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | ° ′ | | ° ′ | ° ′ | ° ′ |
| South | S 58 30 W | S 62 30 W | − 4 0 | North | S 61 30 W | S 62 30 W | − 1 30 |
| S by W | 63 40 | ditto | + 1 10 | N by E | 57 50 | ditto | − 4 40 |
| S S W | 67 0 | ditto | + 4 30 | N N E | 53 40 | ditto | − 8 50 |
| S W by S | 70 50 | ditto | + 8 20 | N E by N | 49 0 | ditto | −13 30 |
| S W | .. .. | ditto | .. .. | N E | 43 0 | ditto | −19 30 |
| S W by W | 79 0 | ditto | +16 30 | N E by E | 42 30 | ditto | −20 0 |
| W S W | 81 40 | ditto | +19 10 | E N E | 41 0 | ditto | −21 30 |
| W by S | 83 0 | ditto | +20 30 | E ½ N | 38 40 | ditto | −23 50 |
| West | 86 40 | ditto | +24 10 | E ½ S | 38 20 | ditto | −24 10 |
| W by N | 87 0 | ditto | +24 30 | E by S | 37 0 | ditto | −25 30 |
| W N W | 85 30 | ditto | +23 0 | E S E | 39 40 | ditto | −22 50 |
| N W by W | 81 30 | ditto | +19 0 | S E by E | 41 40 | ditto | −20 50 |
| N W | .. .. | ditto | .. .. | S E | 44 0 | ditto | −18 30 |
| N W by N | 77 0 | ditto | +14 30 | S E by S | 47 40 | ditto | −14 50 |
| N N W | 71 40 | ditto | + 9 10 | S S E | 49 40 | ditto | −12 50 |
| N by W | 69 0 | ditto | + 6 30 | S by E | 56 15 | ditto | − 6 15 |

*Note.* The dip is supplied by Captain Sabine throughout.

By a comparison of the above table with that resulting from swinging the ship at the Little Nore, it will be seen that the maximum deviation or local attraction produced here, is nearly double that obtained in England.

Now if the plate were fixed in its assigned situation, and the ship swung round, all those deviations, agreeably to Mr. Barlow's conception, ought to be annihilated; but, as we had not sufficient time when at the Nore to fix the plate properly, and swing the ship afterwards, it was deemed best to endeavour to find, experimentally, that situation for the plate here, in which it would correct those deviations that are observable in the compass bearing of an object, by a change of position of the ship's head only. Accordingly the plate and compass were carried on shore, and the maximum deviation was produced by the plate when its centre was $7\frac{5}{8}$ inches below the horizontal plane of the card, and $7\frac{1}{2}$ inches from the vertical line passing through its point of support. In this situation of the plate, with respect to the compass card, the ship was again swung, after the manner already described, with her head directed to each point of the compass successively; at the same time the bearing of the distant object before referred to was taken, and that being compared with its correct magnetic bearing, are differences that may be ascribed to not having placed the centre of the plate diametrically opposite the point to which all the attracting matter on board is referred, or that the plate is not placed sufficiently distant from the needle.

The differences in the fourth column of the following table are marked with similar characters, and after the same manner that the local attractions are in the corresponding columns of the preceding tables.

| Position of the Ship's Head by Plate Compass. | Bearing of the Object by Plate Compass. | Correct Magnetic Bearing of Object. | Difference. | Position of the Ship's Head by Plate Compass. | Bearing of the Object by Plate Compass. | Correct Magnetic Bearing of Object. | Difference. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | ° ′ | | ° ′ | ° ′ | ° ′ |
| South | S 58 20 W | S 62 30 W | −4 10 | North | S 63 0 W | S 62 30 W | +0 30 |
| S by E | 61 20 | ditto | −1 10 | N by W | 64 40 | ditto | +2 10 |
| S S E | 64 40 | ditto | +2 10 | N N W | 62 40 | ditto | +0 10 |
| S E by S | 63 30 | ditto | +1 0 | N W by N | 63 20 | ditto | +0 50 |
| S E | 64 20 | ditto | +1 50 | N W | 64 10 | ditto | +1 40 |
| S E by E | 63 20 | ditto | +0 50 | N W by W | 65 0 | ditto | +2 30 |
| E S E | 61 40 | ditto | −0 50 | W N W | 65 0 | ditto | +2 30 |
| E by S | 60 20 | ditto | −2 10 | W by N | 63 40 | ditto | +1 10 |
| East | 61 0 | ditto | −1 30 | West | 64 40 | ditto | +2 10 |
| E by N | 60 40 | ditto | −1 50 | W by S | 64 40 | ditto | +2 10 |
| E N E | 63 40 | ditto | +1 10 | W S W | 59 40 | ditto | −2 50 |
| N E by E | 62 0 | ditto | −0 30 | S W by W | 59 0 | ditto | −3 30 |
| N E | 64 0 | ditto | +1 30 | S W | 56 0 | ditto | −6 30 |
| N E by N | 64 40 | ditto | +2 10 | S W by S | 55 0 | ditto | −7 30 |
| N N E | 65 40 | ditto | +3 10 | S S W | 55 0 | ditto | −7 30 |
| N by E | 64 0 | ditto | +1 30 | S by W | 57 30 | ditto | −5 0 |

The results in the foregoing table were obtained when the leg of the tripod to which the plate was fixed stood aft, making an angle with the keel of 8° on the starboard side; but in consequence of the differences in the S. S. W. quarter, the leg carrying the plate was shifted more to starboard, so as to make an angle of $1\frac{1}{2}$ points with the keel, and the ship was again swung with the plate in that position.

The following table contains the observations which were taken by Captain Clavering, except in one or two instances, when they were observed by myself.

| Position of the Ship's Head by Plate Compass. | Bearing of the Object by Plate Compass. | Correct Magnetic Bearing of Object. | Difference. | Position of the Ship's Head by Plate Compass. | Bearing of the Object by Plate Compass. | Correct Magnetic Bearing of Object. | Difference. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | ° ′ | | ° ′ | ° ′ | ° ′ |
| South | S 64 10 W | S 62 30 W | +1 40 | North | S 61 30 W | S 62 30 W | −1 0 |
| S by E | 63 30 | ditto | +1 0 | N by W | 61 30 | ditto | −1 0 |
| S S E | 65 30 | ditto | +3 0 | N N W | 61 40 | ditto | −0 50 |
| S E by S | 65 30 | ditto | +3 20 | N W by N | 61 50 | ditto | −0 40 |
| S E | 64 10 | ditto | +1 40 | N W | 62 50 | ditto | +0 20 |
| S E by E | 62 40 | ditto | +0 10 | N W by W | 63 30 | ditto | +1 0 |
| E S E | 61 30 | ditto | −1 0 | W N W | 64 40 | ditto | +2 10 |
| E by S | 61 20 | ditto | −1 10 | W by N | 65 0 | ditto | +2 30 |
| East | 60 0 | ditto | −2 30 | West | 64 20 | ditto | +1 50 |
| E by N | 60 10 | ditto | −2 20 | W by S | 63 40 | ditto | +1 10 |
| E N E | 62 30 | ditto | 0 0 | W S W | 63 40 | ditto | +1 10 |
| N E by E | 63 30 | ditto | +1 0 | S W by W | 58 20 | ditto | −4 10 |
| N E | 62 20 | ditto | −0 10 | S W | 59 0 | ditto | −3 30 |
| N E by N | 63 0 | ditto | +0 30 | S W by S | 58 20 | ditto | −4 10 |
| N N E | 62 20 | ditto | −0 10 | S S W | 60 0 | ditto | −2 30 |
| N by E | 63 0 | ditto | +1 0 | S by W | 61 20 | ditto | −1 10 |

Captain Clavering being desirous of seeing what would be the effect of the local attraction on a compass placed at the mast-head, in order to know how far bearings taken from that elevation (56 feet above the deck) would be serviceable to us during the voyage, caused the Griper to be swung round, after the usual manner, and the position of the ship's head noted by a person at the mast-head, whilst the situation of the ship's head was taken on deck by the compass, with the plate fixed abaft it, at the same time taking the bearing of a distant object on shore, whose bearing was already known; by which means the correct magnetic situation of the ship's head can be deduced; and that, being compared with the position of the ship's head, indicated by the compass aloft, will give the local attraction at the various points observed at the mast-head.

The first column in the following table shows the position of the ship's head by the plate compass on deck; the second, the bearing of the object, taken with the same compass; the third column contains the correct magnetic bearing of the object; and the fourth, the correct magnetic bearing of the ship's head; in the fifth is the bearing of the ship's head by the mast-head compass; and the sixth is composed of the differences between the fourth and fifth columns, which is accounted the local attraction at the mast-head.

| Position of Ship's Head by Plate Compass | Bearing of Object by Plate Compass | Correct Magnetic Bearing of Object. | Correct Magnetic Bearing of Ship's Head. | Bearing of Ship's Head, by Mast-head Compass. | Difference of two last Columns, or Local Attraction. |
|---|---|---|---|---|---|
| S 45° W | S 59° 10′ W | S 62° 30′ W | S 48° 20′ W | S 50° 0′ W | + 1° 40′ |
| S 36 W | 58 40 | ditto | 39 50 | 42 0 | + 2 10 |
| S 27 W | 58 30 | ditto | 31 0 | 37 0 | + 6 0 |
| S 22½ W | 60 0 | ditto | 25 0 | 22 30 | − 2 30 |
| S 11¼ W | 61 30 | ditto | 12 15 | 11 15 | − 1 0 |
| South | 64 30 | ditto | 2 0 | S 6 0 E | − 8 0 |
| S 11¼ E | 63 50 | ditto | S 9 55 E | 22 30 | −12 35 |
| S 22½ E | 66 0 | ditto | 19 0 | 37 0 | −18 0 |
| S 33¾ E | 65 10 | ditto | 31 0 | 48 0 | −17 0 |
| S 45 E | 64 40 | ditto | 42 20 | 56 0 | −14 0 |
| S 56¼ E | 63 0 | ditto | 55 45 | 67 0 | −11 15 |
| S 67½ E | 62 0 | ditto | 68 0 | 79 0 | −11 0 |
| S 78¾ E | 61 30 | ditto | 79 45 | 84 0 | − 4 15 |
| East | 60 0 | ditto | N 87 30 E | N 82 0 E | − 5 30 |
| N 78¾ E | 60 0 | ditto | 76 15 | 62 0 | −14 15 |
| N 67½ E | 62 30 | ditto | 67 30 | 56 0 | −11 30 |

The high wind that sprung up shortly after the commencement of the operation rendered it unsafe to make a complete revolution ; but, as far as the experiment goes, it seems to indicate that if a compass be placed at the mast-head, it is not sufficiently freed from local attraction for bearings taken therefrom to be depended upon.

July 3, 1823, at anchor, in Fair Haven, Spitzbergen, the Griper was swung round, after the manner already described at Hammerfest, to get the amount of the local attraction produced at this place.

The first column in the following table contains the correct magnetic position of the ship's head, deduced from angular distances, taken with a sextant between a distant point of land, whose bearing had been obtained, and the ship's head;* the second is the deviated compass bearing of the object chosen; and the third is the correct magnetic bearing of the same; in the fourth column is the local attraction, marked +, plus, when the observed bearing is greater than the correct magnetic bearing of the object, and —, minus, when less.

*Fair Haven, Latitude 79° 50′ N. Longitude 11° 40′ E. Variation 25° 12′ W. Dip 81° 11′ N.*

| Correct Magnetic Position of Ship's Head | Compass Bearing of Object on Shore. | Correct Magnetic Bearing of Object. | Local Attraction +, when Compass Bearing is greater than Correct Bearing; and —, when less. | Correct Magnetic Position of Ship's Head | Compass Bearing of Object on Shore. | Correct Magnetic Bearing of Object. | Local Attraction +, when Compass Bearing is greater than Correct Magnetic Bearing; and —, when less. |
|---|---|---|---|---|---|---|---|
| ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| N 2 12 W | N 21 50 E | N 19 18 E | + 2 32 | S 8 12 E | .... | N 19 18 E | ... |
| 14 27 | 24 40 | ditto | + 5 22 | 19 12 | North | ditto | −19 38 |
| 21 42 | 27 0 | ditto | + 7 42 | 24 42 | N 10 40 W | ditto | −29 58 |
| 33 42 | 33 0 | ditto | +13 42 | 28 2 | 6 0 | ditto | −25 18 |
| 45 42 | 37 0 | ditto | +17 42 | 38 12 | 8 0 | ditto | −27 18 |
| 55 42 | 40 20 | ditto | +21 2 | 49 12 | 8 40 | ditto | −27 58 |
| 66 42 | 44 0 | ditto | +24 42 | 60 12 | 10 0 | ditto | −29 18 |
| 77 42 | 46 0 | ditto | +26 42 | 71 12 | 7 0 | ditto | −26 18 |
| 88 42 | 48 30 | ditto | +29 12 | 82 12 | 4 0 | ditto | −23 18 |
| S 80 18 W | 54 0 | ditto | +34 42 | N 86 48 E | 5 0 | ditto | −24 18 |
| 68 48 | 55 0 | ditto | +35 42 | 75 48 | 1 50 | ditto | −21 8 |
| 57 48 | 55 40 | ditto | +36 22 | 64 48 | North | ditto | −19 18 |
| 46 48 | 56 30 | ditto | +37 12 | 53 48 | N 1 0 E | ditto | −18 18 |
| 35 48 | 53 50 | ditto | +34 32 | 43 48 | 3 0 | ditto | −16 18 |
| 24 48 | .... | ditto | .... | 31 48 | 8 0 | ditto | −11 18 |
| 13 48 | 32 0 | ditto | +12 42 | 19 18 | 12 0 | ditto | − 7 18 |
| 2 48 | 26 0 | ditto | + 6 42 | 8 3 | 17 30 | ditto | − 1 48 |

* It may be proper to observe, that this is in fact the only method by which the correct bearing of the ship's head can be ascertained. P. B.

Immediately afterwards the ship was again swung round, with the view of seeing how far the plate, when fixed in the same position as at Hammerfest, would counteract the effect of the local attraction of the ship.

The fourth column in the following table shows the differences between the correct magnetic bearing of the object, and that obtained by the compass with the plate fixed, and are marked +, plus, when the observed bearing is greater than the correct magnetic bearing of the object, and −, minus, when less.

| osition of the p'sHead, shown by the ite Compass. | Bearing of Object on Shore by the Plate Compass. | Correct Magnetic Bearing of Object. | Differences of two last Columns +, when observed Bearing is greater than computed; and −, when less. | Position of the Ship's Head, as shown by the Plate Compass. | Bearing of Object on Shore by the Plate Compass. | Correct Magnetic Bearing of Object. | Differences of two last Columns +, when observed Bearing is greater than computed; and −, when less. |
|---|---|---|---|---|---|---|---|
| orth | N 10° 0' E | N 19° 18' E | − 9° 18' | South | N 23° 30' E | N 19° 18' E | + 4° 12' |
| by E | 12 0 | ditto | − 7 18 | S by W | Object not seen | ditto | ...... |
| N E | 12 20 | ditto | − 6 58 | S S W | 23 0 | ditto | + 3 42 |
| E by N | 13 40 | ditto | − 5 38 | S W by S | 23 30 | ditto | + 4 12 |
| E | 14 20 | ditto | − 4 58 | S W | 22 0 | ditto | + 2 42 |
| E by E | 13 20 | ditto | − 5 58 | S W by W | 23 20 | ditto | + 4 2 |
| N E | 10 0 | ditto | − 9 18 | W S W | 22 30 | ditto | + 3 12 |
| by N | 9 20 | ditto | − 9 58 | W by S | 24 30 | ditto | + 5 12 |
| ast | 8 0 | ditto | −11 18 | West | 25 30 | ditto | + 6 12 |
| by S | 9 0 | ditto | −10 18 | W by N | 25 40 | ditto | + 6 22 |
| S E | 16 10 | ditto | − 3 8 | W N W | 22 30 | ditto | + 3 12 |
| E by E | 16 0 | ditto | − 3 18 | N W by W | 22 50 | ditto | + 3 32 |
| E | 11 30 | ditto | − 7 48 | N W | 22 20 | ditto | + 3 2 |
| E by S | 20 30 | ditto | − 1 12 | N W by N | 18 0 | ditto | − 1 18 |
| S E | 24 40 | ditto | − 4 22 | N N W | 14 0 | ditto | − 5 18 |
| by E | 23 0 | ditto | − 3 42 | N by W | 12 0 | ditto | − 7 18 |

The circumstances under which the foregoing experiments were performed on the local attraction of the Griper, in Fair Haven, were not so favourable as could have been wished, in consequence of the quantity of ice drifting about us, which rendered it difficult to steady the ship at many of the points, and the object whose bearing was taken being only $2\frac{3}{4}$ miles distant, but it was the most remote that could be seen from the ship; however, there will be something due to parallax in the observations.

The compass used in the foregoing experiments was taken on shore, and placed on the top of a pedestal, so fitted that the plate could be fixed in any position with respect to the centre of the card of the compass placed on the top, as well as to admit of its being turned round in azimuth to form the various angles with the magnetic meridian required.

Hackluyt's headland was the best defined object seen from this station, its bearing was therefore carefully taken by the compass, and noted down, after which the plate was fixed to the pedestal, with its centre $7\frac{5}{8}$ inches below the horizontal plane of the card, and $7\frac{1}{2}$ inches from the vertical line passing through its point of support; in that position, the plate was directed towards each point of the compass successively, at the same time the bearing of the headland was taken. In the fourth column of the following table, is the amount of the deviation which the plate produced at the different points, and the sign +, plus, is prefixed when the north end of the needle was drawn to the westward, and —, minus, when it was drawn to the eastward by the plate.

| Magnetic Position of Plate. | Bearing of Hackluyt's Headland, with Plate fixed. | | Correct Magnetic Bearing of Hackluyt's Headland. | | Amount of Deviation produced with Plate on Shore, + when N. end drawn W.; — when E. | | Magnetic Position of Plate. | Bearing of Hackluyt's Headland, with Plate fixed. | | Correct Magnetic Bearing of Hackluyt's Headland. | | Amount of Deviation produced by Plate on Shore, + when N. end drawn W.; — when E. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ° | ′ | ° | ′ | ° | ′ | | ° | ′ | ° | ′ | ° | ′ |
| North | N 84 | 0 W | N 84 | 0 W | − 0 | 0 | South | N 84 | 10 W | N 84 | 10 W | − 0 | 10 |
| N by E | 89 | 20 | ditto | | − 5 | 20 | S by W | 61 | 0 | ditto | | + 23 | 0 |
| N N E | S 86 | 40 W | ditto | | − 9 | 20 | S S W | 53 | 20 | ditto | | + 30 | 40 |
| N E by N | 79 | 50 | ditto | | −16 | 10 | S W by S | 49 | 0 | ditto | | + 35 | 0 |
| N E | 73 | 30 | ditto | | −22 | 30 | S W | 50 | 20 | ditto | | + 33 | 40 |
| N E by E | 68 | 40 | ditto | | −27 | 20 | S W by W | 47 | 0 | ditto | | + 37 | 0 |
| E N E | 67 | 40 | ditto | | −28 | 20 | W S W | 46 | 40 | ditto | | + 37 | 20 |
| E by N | 61 | 50 | ditto | | −34 | 10 | W by S | 46 | 0 | ditto | | + 38 | 0 |
| East | 60 | 0 | ditto | | −36 | 0 | West | 45 | 40 | ditto | | + 38 | 20 |
| E by S | 60 | 40 | ditto | | −35 | 20 | W by N | 48 | 40 | ditto | | + 35 | 20 |
| E S E | 59 | 10 | ditto | | −36 | 50 | W N W | 52 | 40 | ditto | | + 31 | 20 |
| S E by E | 61 | 0 | ditto | | −33 | 0 | N W by W | 56 | 10 | ditto | | + 27 | 50 |
| S E | 62 | 10 | ditto | | −33 | 50 | N W | 60 | 10 | ditto | | + 23 | 50 |
| S E by S | 62 | 10 | ditto | | −34 | 0 | N W by N | 67 | 10 | ditto | | + 16 | 50 |
| S S E | 64 | 20 | ditto | | −31 | 40 | N N W | 71 | 40 | ditto | | + 12 | 20 |
| S by E | 69 | 10 | ditto | | −26 | 50 | N by W | 77 | 40 | ditto | | + 6 | 20 |

October 15, 1823. In ascertaining the amount of the local attraction of the Griper, at Drontheim, the following method was adopted.

The azimuth compass to be used in these experiments was taken on shore, and placed accurately in the meridian, by means of Captain Sabine's transit instrument, the bearing of the meridian mark was then carefully taken, and found to be exactly S. 20° 40′ W. The compass was now removed, and the repeating circle fixed precisely in the same spot, with the verniers on the horizontal circle clamped at 20° 40′, and the cross wire in the telescope bisecting the meridian mark; in that position of the instrument, the horizontal circle evidently represents a compass card, with zero at the correct magnetic south.

Now, by unclamping the verniers from the horizontal circle, the telescope can be directed towards any object required, and, consequently, the intercepted arc between zero, on the horizontal circle, and the object, is its correct magnetic bearing from the south.

The compass was now taken on board, and placed on its stand, before the mizen-mast, which was sufficiently high to be seen from the station on shore. All being ready, the ship's head was brought on a certain point, by means of warps previously arranged, and the bearing of the repeating circle taken; at the same time a signal was made to Captain Sabine, who immediately brought the compass on board into the centre of the field of his telescope; the arc thus measured on the horizontal circle, is the correct magnetic bearing of the compass on board from the station on shore, or that uninfluenced by local attraction, whilst the deviated magnetic direction of the same line would be given by the compass on board.

The ship's head was then warped round to the next point, and another bearing taken in the same way, both from the ship and repeating circle, and so on round the compass.

The following table contains the details of these experiments, of which it may be necessary to state, that the first column shows the correct magnetic bearing of the ship's head, obtained by taking angular distances with a sextant, between an object on shore, whose correct magnetic bearing was known, and the ship's head; in the second column is the compass or deviated bearing of the repeating circle; and in the third is the correct magnetic bearing of the compass on board from the repeating circle; in the fourth is the amount of the local attraction, produced at the various points, to which the sign +, plus, is prefixed, when the north end of the needle was drawn to the westward; and —, minus, when drawn to the eastward.

*Drontheim, Latitude 63° 26′ N. Longitude 10° 22′ E. Variation 20° 40′ W. Dip 74° 42′.*

| Correct Magnetic Position of Ship's Head | Compass or deviated Bearing of Repeating Circle. | Correct Magnetic Bearing of Compass on board from Repeating Circle. | Local Attraction + when N. end of Needle was drawn to the W.; — when to the E. | Correct Magnetic Position of Ship's Head | Compass or deviated Bearing of Repeating Circle. | Correct Magnetic Bearing of Compass on board from Repeating Circle. | Local Attracti[illegible] + when end o[illegible] Needle [illegible] drawn [illegible] the W. — when the E. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | ° ′ | | ° ′ | ° ′ | ° [illegible] |
| North | S 67 40 W | N 62 29 E | + 5 11 | South | S 62 0 W | N 64 46 E | − 2 4[illegible] |
| N by E | 64 20 | 62 25 | + 1 55 | S by W | 68 20 | 64 38 | + 3 4[illegible] |
| N N E | 60 0 | 62 50 | − 2 50 | S S W | 76 0 | 64 25 | + 11 3[illegible] |
| N E by N | 58 20 | 63 2 | − 4 42 | S W by S | 77 0 | 64 22 | + 12 2[illegible] |
| N E | 55 10 | 63 10 | − 8 0 | S W | 78 10 | 64 15 | + 13 5[illegible] |
| N E by E | 53 20 | 63 21 | − 10 1 | S W by W | 82 30 | 63 32 | + 18 5[illegible] |
| E N E | not seen. | 63 49 | ...... | W S W | 84 30 | 63 34 | + 20 5[illegible] |
| E by N | 48 40 | 63 42 | − 15 2 | W by S | 84 10 | 63 33 | + 20 3[illegible] |
| East | 47 10 | 63 50 | − 16 40 | West | 84 40 | 63 17 | + 21 2[illegible] |
| E by S | 46 30 | 64 5 | − 19 35 | W by N | 83 20 | 63 6 | + 20 1[illegible] |
| E S E | 45 0 | 64 31 | − 19 31 | W N W | 82 0 | 62 43 | + 19 1[illegible] |
| S E by E | 46 20 | 64 42 | − 18 22 | N W by N | 79 0 | 62 27 | + 16 3[illegible] |
| S E | 47 30 | 64 52 | − 17 22 | N W | 78 0 | 62 30 | + 15 3[illegible] |
| S E by S | 50 30 | 64 59 | − 14 29 | N W by N | 74 30 | 62 32 | + 11 5[illegible] |
| S S E | 53 10 | 65 4 | − 11 54 | N N W | 72 30 | 62 38 | + 9 5[illegible] |
| S by E | 58 0 | 65 4 | − 7 4 | N by W | 70 0 | 62 30 | + 7 3[illegible] |

The ship was again swung round, after the manner just described, and the bearings of the repeating circle were taken from the ship with the compass having the plate fixed, in order to see how far it would correct the local attraction.

The differences between the correct magnetic bearing of the repeating circle and that given by the plate compass are inserted in the fourth column of the following table, and are marked with similar characters, and after the same manner, that the local attractions are in the corresponding column of the preceding table.

| Correct Magnetic Position of Ship's Head | Bearing of Repeating Circle by the Plate Compass. | Correct Magnetic Bearing of Compass on board from Repeating Circle. | Difference. | Correct Magnetic Position of Ship's Head | Bearing of Repeating Circle by the Plate Compass. | Correct Magnetic Bearing of Compass on board from Repeating Circle. | Difference. |
|---|---|---|---|---|---|---|---|
| North | S 62° 10′ W | N 62° 25′ E | −0° 15′ | South | S 70° 0′ W | N 64° 52′ E | +5° 8′ |
| N by E | 62 0 | 62 30 | −0 30 | S by W | 69 20 | 64 40 | +4 40 |
| N N E | 62 0 | 62 48 | −0 48 | S S W | 66 40 | 64 46 | +1 54 |
| N E by N | 61 0 | 62 55 | −1 55 | S W by S | 66 20 | 64 38 | +1 42 |
| N E | 60 30 | 63 7 | −2 37 | S W | 65 30 | 64 12 | +1 18 |
| N E by E | 60 0 | 63 19 | −3 19 | S W by W | 65 10 | 63 57 | +1 13 |
| E N E | ...... | 63 30 | ...... | W S W | 65 0 | 63 50 | +1 10 |
| E by N | 61 0 | 63 38 | −2 38 | W by S | 65 30 | 63 39 | +1 51 |
| East | 60 20 | 63 52 | −3 32 | West | 67 20 | 63 26 | +3 54 |
| E by S | 62 0 | 63 58 | −1 58 | W by N | ...... | ...... | ...... |
| E S E | 63 0 | 64 19 | −1 9 | W N W | 67 40 | 62 44 | +4 56 |
| S E by E | 65 30 | 64 26 | +1 4 | N W by W | 66 30 | 62 42 | +3 48 |
| S E | 68 0 | 64 26 | +3 14 | N W | 66 0 | 62 2 | +3 58 |
| S E by S | 70 0 | 64 39 | +5 21 | N W by N | 65 0 | 62 2 | +2 58 |
| S S E | 72 30 | 64 42 | +1 48 | N N W | 63 0 | 62 6 | +0 54 |
| S by E | 72 0 | 64 46 | +7 14 | N by W | 62 30 | 62 21 | +0 1 |

The plate and compass were now carried on shore, and fixed to the pedestal, after the manner already described in the detailed statement of the experiments at Spitzbergen.

The fourth column in the following table shows the effect the plate produced on the compass, when its centre was $7\frac{5}{8}$ inches below the horizontal plane of the card, and $7\frac{1}{2}$ inches from the vertical line passing through its point of support. The sign +, plus, is prefixed when the north end of the needle was drawn to the westward, and —, minus, when it was drawn to the eastward by the plate.

| Magnetic Position of the Plate. | Bearing of the Object, with the Plate fixed. | Correct Magnetic Bearing of the Object. | Deviation + N. end of Needle drawn W.; — when drawn E. | Magnetic Position of the Plate. | Bearing of the Object, with the Plate fixed. | Correct Magnetic Bearing of the Object. | Deviation + N. end of Needle drawn W. — when drawn E. |
|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | ° ′ | | ° ′ | ° ′ | ° ′ |
| North | N 43 0 E | N 42 30 E | + 0 30 | South | N 42 0 E | N 42 30 E | — 0 30 |
| N by E | 39 20 | ditto | — 3 10 | S by W | 55 0 | ditto | + 12 30 |
| N N E | 34 20 | ditto | — 8 10 | S S W | 57 55 | ditto | + 15 25 |
| N E by N | 29 50 | ditto | — 12 40 | S W by S | 60 30 | ditto | + 18 0 |
| N E | 26 0 | ditto | — 16 30 | S W | 62 0 | ditto | + 19 30 |
| N E by E | 22 40 | ditto | — 19 50 | S W by W | 63 20 | ditto | + 20 50 |
| E N E | 20 10 | ditto | — 22 20 | W S W | 63 40 | ditto | + 21 10 |
| E by N | 19 50 | ditto | — 22 40 | W by S | 63 40 | ditto | + 21 10 |
| East | 19 30 | ditto | — 23 0 | West | 64 50 | ditto | + 22 20 |
| E by S | 21 0 | ditto | — 21 30 | W by N | 64 10 | ditto | + 21 40 |
| E S E | 21 0 | ditto | — 21 30 | W N W | 65 20 | ditto | + 22 50 |
| S E by E | 21 0 | ditto | — 21 30 | N W by W | 62 20 | ditto | + 19 50 |
| S E | 22 10 | ditto | — 22 20 | N W | 60 10 | ditto | + 17 40 |
| S E by S | 24 0 | ditto | — 18 30 | N W by N | 57 10 | ditto | + 14 40 |
| S S E | 26 50 | ditto | — 15 40 | N N W | 52 10 | ditto | + 9 40 |
| S by E | 31 20 | ditto | — 11 10 | N by W | 49 40 | ditto | + 7 10 |

It may not be unnecessary to state that some alteration in the stowage of the iron utensils on board had taken place since the plate was fixed at Hammerfest; but the most material was the spare and stream anchors that were outside in the main chains, within 11 feet of the compass; being removed forward, on the loss of the best bower and kedge anchors, in Greenland.

(Signed) HENRY FOSTER,
Admiralty Midshipman.

*Supplement, containing a report of the experiments on board H. M. S. Griper, in the basin at Deptford, January 6, 1824, with a view of ascertaining the magnetic effect of the patent capstan; the tanks, cables, &c. having been previously removed. By Mr. H. Foster.*

| Ship's Head. | Bearing of Compass on Shore. | Bearing of Compass on Board. | Difference or Local Attraction. | Ship's Head. | Bearing of Compass on Shore. | Bearing of Compass on Board. | Difference or Local Attraction. | Local Attraction due to the Spindle. |
|---|---|---|---|---|---|---|---|---|
| | ° | ° | ° | | ° | ° | ° | ° |
| North | N 36 E | N 34 E | − 2 | North | N 34½ E | N 33½ E | − 1 | − 1 |
| N E | 33 | 41½ | + 8½ | N E | 35 | 38 | + 3 | + 5½ |
| East | 34½ | 46 | + 11½ | East | 36½ | 41½ | + 5 | + 6½ |
| S E | 39⅜ | 45½ | + 6⅛ | S E | 42½ | 45½ | + 3 | + 3⅛ |
| South | 43⅛ | 43 | + 0⅛ | South | 43 | 45 | + 2 | − 1⅞ |
| S W | 48⅝ | 42 | − 6⅝ | S W | 41 | 41½ | − ½ | − 6 |
| West | 49⅛ | 38 | − 11 | West | 34½ | 33½ | − 1 | − 10 |
| N W | 44 | 34½ | − 9½ | N W | 37½ | 34½ | − 3 | − 6½ |

The compass was placed seven feet abaft the capstan, and a little above the top of the spindle, the dimensions of the spindle being,

| | | Inches. |
|---|---|---|
| In length . . . . . . . . | 10 feet | 9 |
| Diameter upper end . . . | | 6 |
| Diameter middle . . . . | | 6 |
| Lower end . . . . . . . . | | 3¾ |

(Signed) H. Foster.

The following are a set of directions drawn up by Lieutenant Foster, to facilitate the application of this method of correction in His Majesty's Navy; and in other vessels.

*Directions for using Mr. Barlow's plate for correcting the local attraction of ships.*

"Let a proper place be selected by the Captain for the azimuth compass to be fixed in for observation during the period of her being in commission. It will then be necessary to ascertain the local attraction of the vessel, which may be done in the following manner:

"The ship being moored, or laying with a short scope of cable, must have anchors so arranged as to admit of the ship's head being directed to each point of the compass successively, and there steadied whilst the bearing of a remote object is taken (the more distant the better) to avoid the parallax which would otherwise effect the observations. It will then be found that the bearings thus observed will differ from each other according to the attractive power of the needle from 6° or 8° to 26° or 28°, a difference which is caused by the iron of the ship attracting the needle out of its proper direction to the eastward, with the ship's head towards the east; and to the west with the ship's head towards the west.

"On examining these several bearings there will be found two at opposite points of the compass that will nearly agree with each other, the mean of which must be accounted the correct magnetic bearing of the object, and these points will also indicate the line of no attraction, and in which the plate is ultimately to be fixed.

"By comparing the correct magnetic bearing of the object as above found with the observed bearing at the several points, the amount of the local attraction at each point will be ascertained.

"It now remains to determine the position of the plate in which it will correct the above observed deviations. This will now be readily done by means of a small table, which Mr. Barlow intends to supply with every plate, for that purpose. In this table will be found a variety of local attractions, comprehending all possible limits for every class of vessels, and in which will be found those of the vessel in question, corresponding to which will be found two numbers, one being the distance of the centre of the plate below the pivot of the needle; and the other its distance from the plum-line passing through the same: at this depth and distance in the line of no attraction already mentioned, the plate must be fixed abaft the compass, in which position it will be found to correct those deviations caused by the great mass of iron lying before the compass, so that if the vessel be again swung no discrepances will be found in the bearing of any object in this or any other part of the world."

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*General remarks on the preceding experiments.*

The nature of the observations, and the judicious arrangement which Lieutenant Foster has given to the results obtained in the Griper, render it quite unnecessary for me to offer any remarks to show the success and utility of the experiments in this case. It is only requisite to state, that the local attraction of this vessel having been so much greater than I had contemplated, (viz. 14° at east and west) the plate which I sent was not so powerful as it ought to have been; it was therefore necessary to bring it so near to the compass as to produce some irregularities with the ship's head near the north and south points, in which position of the vessel there was but little more than four inches between the needle and plate. This is a circumstance I have mentioned at page 56, of the first edition of my "Essay on Magnetic Attractions," where it is stated, that when the needle and iron approach near to each other, the general laws of action fail; and to this circumstance, more than to the greatly diminished power of the needle, is (in my opinion) to be attributed the anomalies noticed in the experiments at Spitzbergen, and at the points in question. But, after all, I am convinced that, in the present infant state of this practice, the experiments will be deemed as satisfactory as there could be any reason to expect. It appears then, that from latitude 80° N. to 60° 56′ S., viz. through the entire range of all the navigable latitudes on the globe, the experiments have (even in the first three trials that have been made) been attended with the most favourable results, and there can be no doubt that further practice would lead to greater accuracy, and give a value to the mariner's compass which it never yet possessed, and a degree of accuracy to our magnetic charts, which would probably lead to the most interesting deductions relative to the laws of terrestrial magnetism.

The importance of this principle of correction, even for the purpose of keeping the reckoning at sea, is sufficiently demonstrated in the two cases given by Lieutenants Mudge and Foster, (page 11 and 39,) where, in the former case, the error by the common compass course was nineteen miles in latitude, and twenty-eight miles in longitude; while by the corrected compass course the error was reduced to two miles in latitude, and four miles in longitude; and in the instance furnished by Lieutenant Foster, the error in latitude alone was thirty-five miles, which almost wholly disappeared on the corrected course.

I am aware that seamen depend very little upon the reckoning by compass, while they can make the requisite astronomical observations, but as it frequently happens that many days may pass without their obtaining such observations, it cannot but be of considerable importance to them, in such cases, to possess a means of approximating the nearest possible to their true place. It is not however at sea that this method is of greatest use, it is in narrow channels, in piloting ships by means of charts and bearings,* and in marine surveying, that it finds its most valuable application; in these instances nothing can supply the place of the compass, and it cannot but be important in such cases that its directive power should be freed from all irregularity.

Every reader, whether a nautical man or not, must be aware of the great amount of error, and

* The Norwegian pilot who took the Griper into Drontheim, although by no means easy at observing an iron plate so near the compass, expressed his entire approval of the action of that card: at the same time that he showed his opinion of the binnacle compass, by placing his hat upon his finger, implying that it would be as useful as the compass in question. H. F.

the fatal consequences which might arise in a few hours to a vessel in the channel, in a dark and blowing night, having for its only guide a compass subject to an error of 14 degrees in opposite directions at east and west, the very courses on which she would be endeavouring to steer; and who can say how many of the mysterious wrecks which have taken place in the channel are to be attributed to this source of error: of which the most recent, that of the Thames, Indiaman, is a serious example. This vessel, besides the usual materials, guns, &c. had a cargo of more than 400 tons of iron and steel, and it may easily be imagined, that such a cargo would produce an effect on the compass at least equal to that of the Griper and Barracouta; and this alone would be quite sufficient to account for the otherwise unaccountable circumstance, that after having Beachy-head in sight at six o'clock in the evening, the vessel should have been wrecked upon the same spot at one or two o'clock in the morning, without the least apprehension of being at all near shore.

These subjects are, unquestionably deserving of the attention of the first maritime nation in the world; and I am willing to hope that the labour and attention I have bestowed on this inquiry, for the last five years, will be found advantageous to nautical science, and entitled to the favourable consideration of those public boards which are its natural patrons and protectors.

PETER BARLOW.

*Royal Military Academy,*
*February* 14, 1824.

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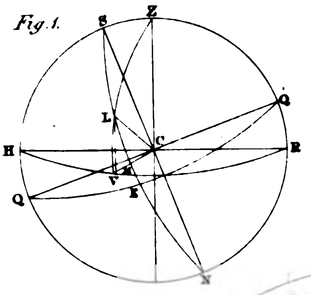
Fig. 1.

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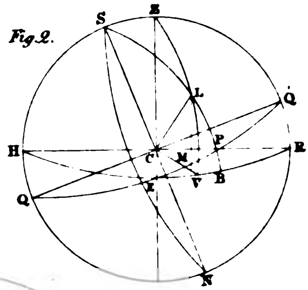


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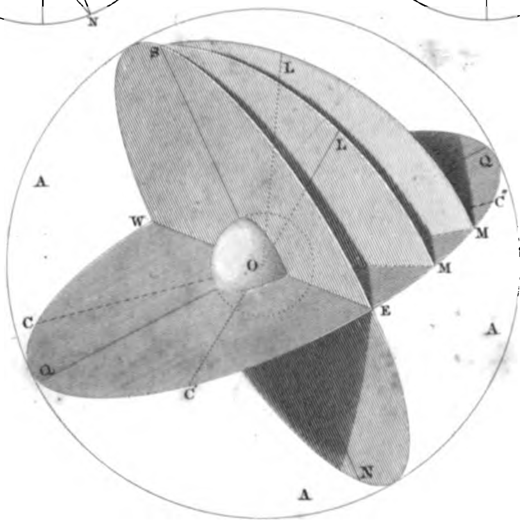


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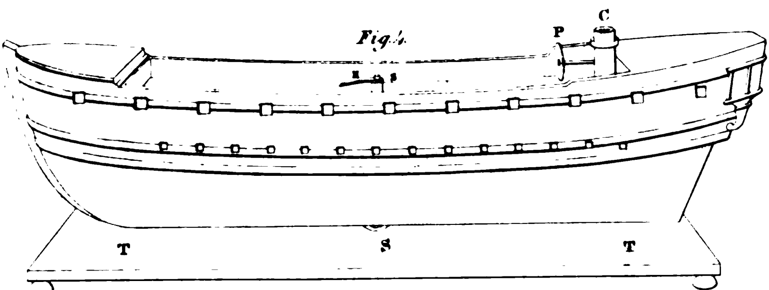


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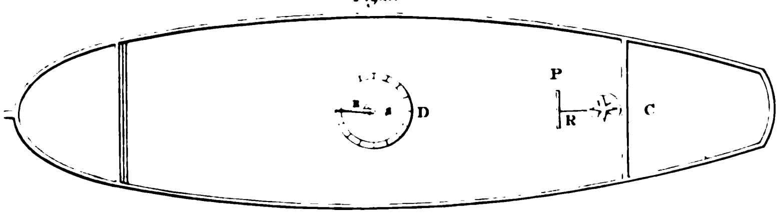
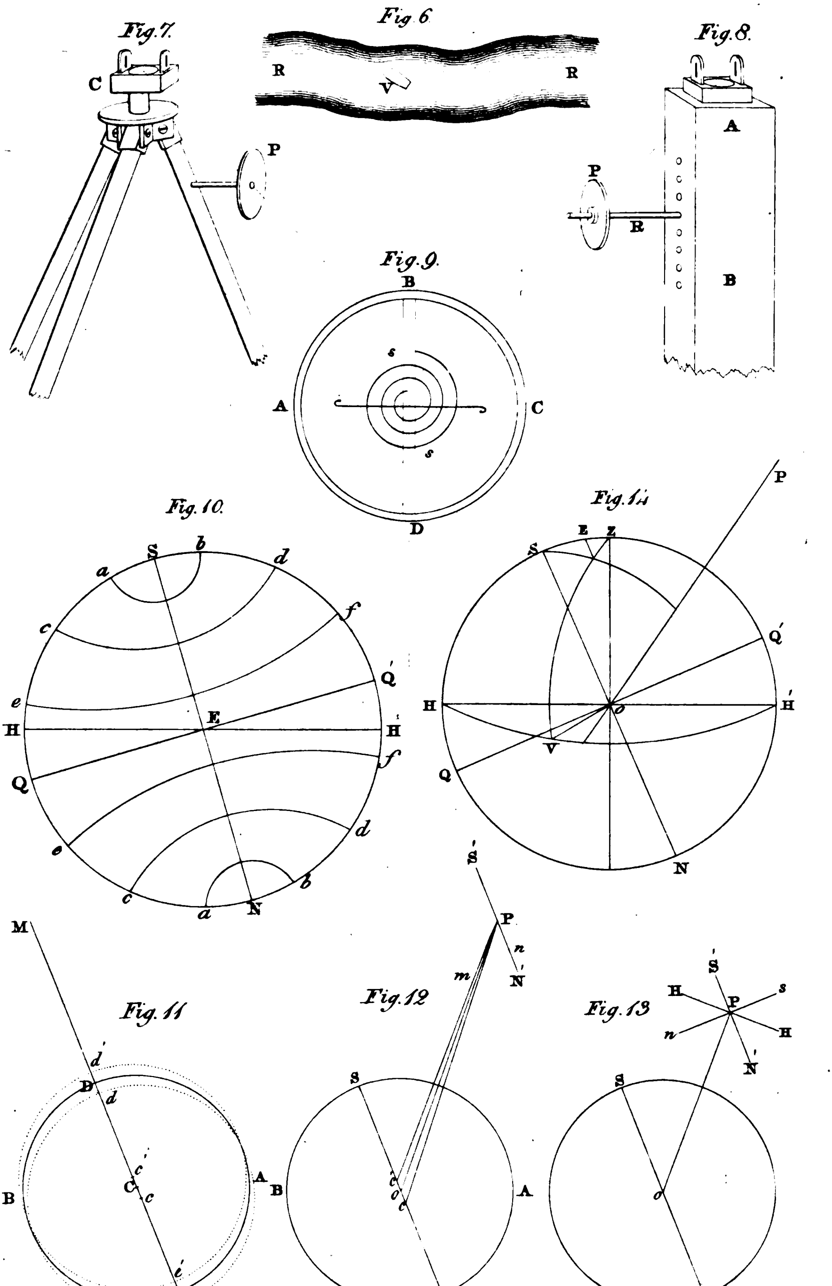



Barlow del. W. Lowry sculp.

# Magnetism.






Barlow. del.

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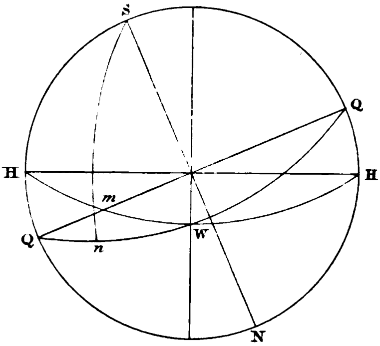
Fig. 15

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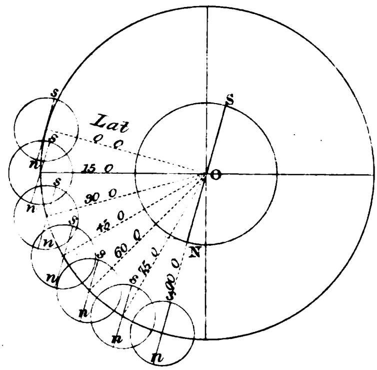


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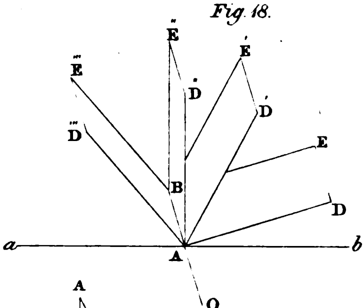



Fig. 19.

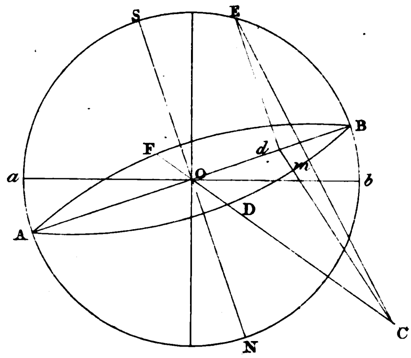
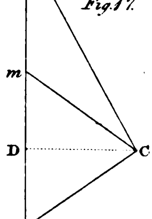



Fig. 17.

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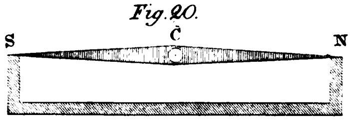


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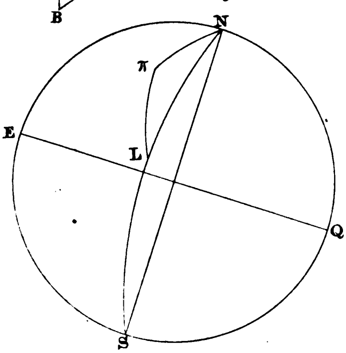


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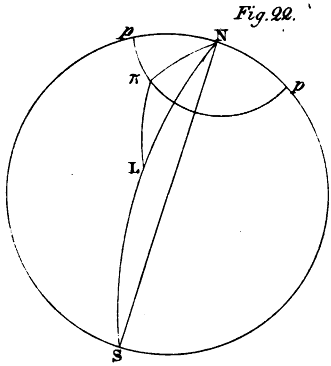


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## Electro Magnetism.

Plate.4

Fig.4

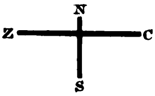
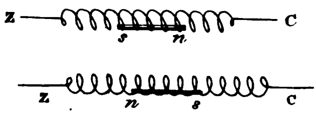



Fig.6

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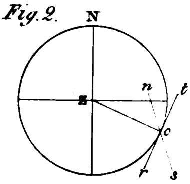


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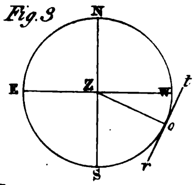


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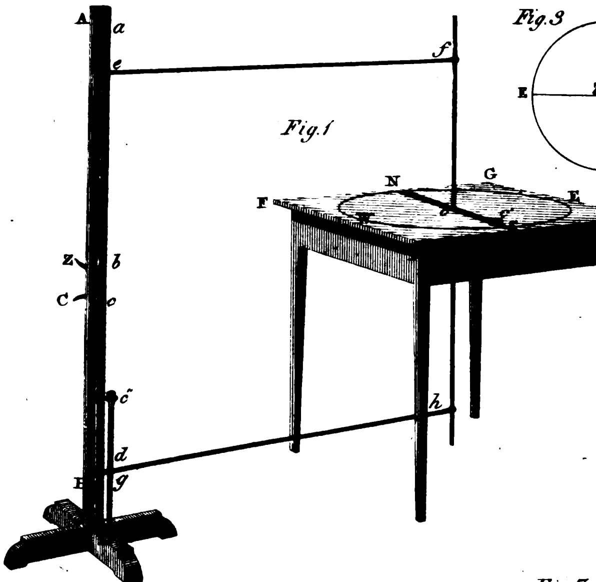
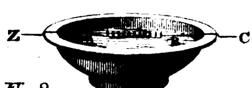



Fig.7

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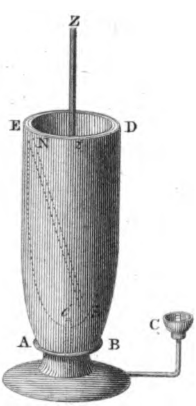


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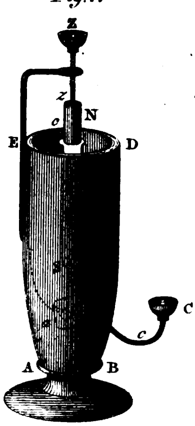


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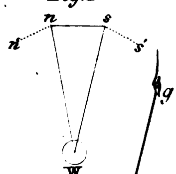


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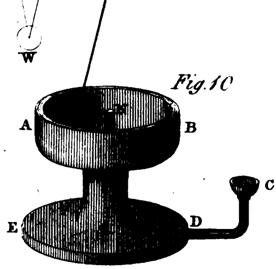


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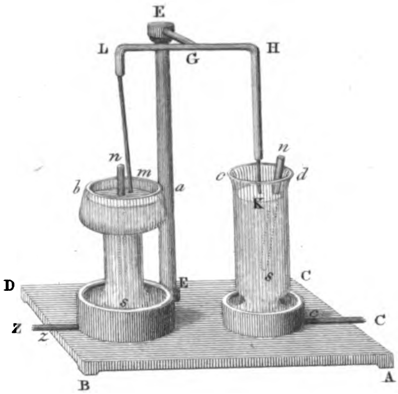
*Fig. 12*

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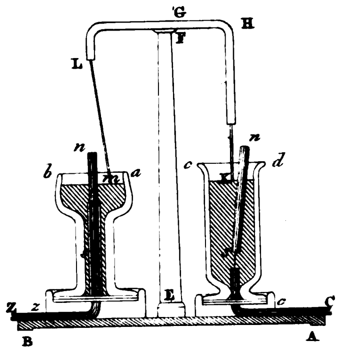


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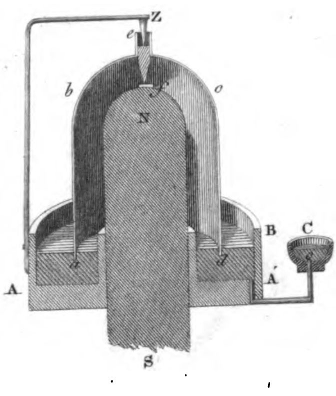


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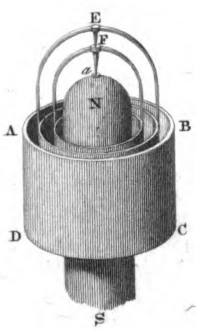


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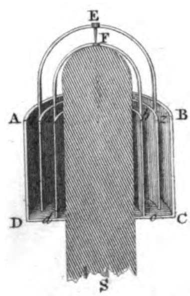


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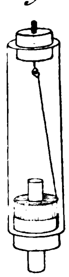

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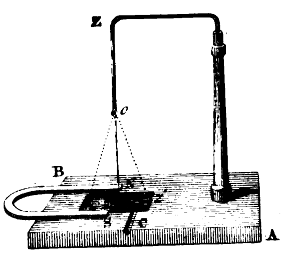


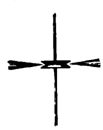

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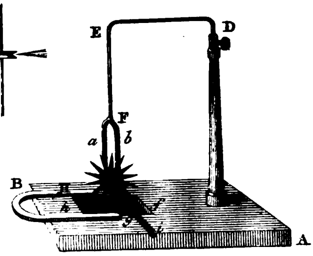


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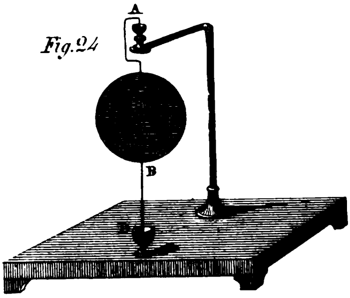
Fig. 24

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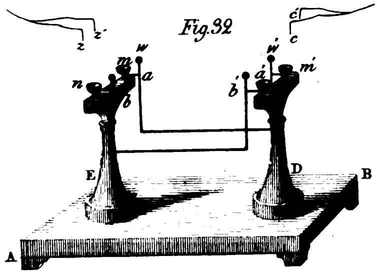


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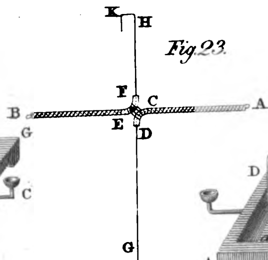


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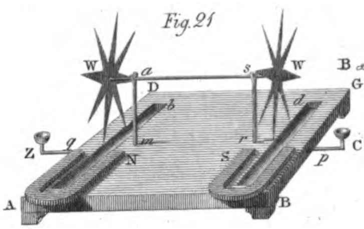


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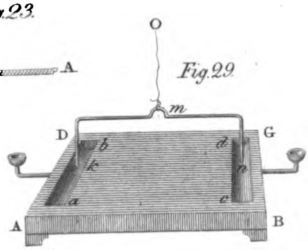
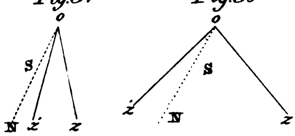



Fig. 31 Fig. 30

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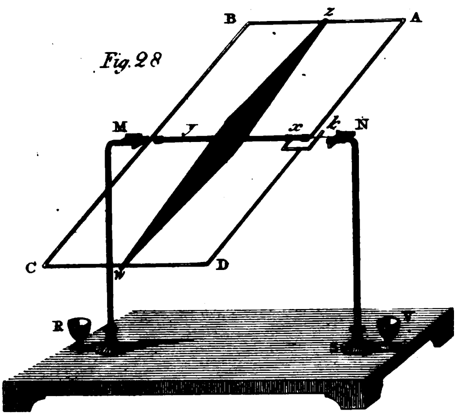


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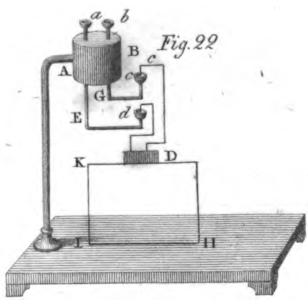


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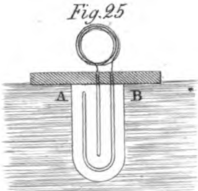



Fig. 26

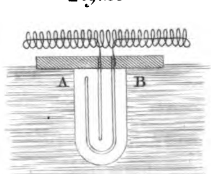
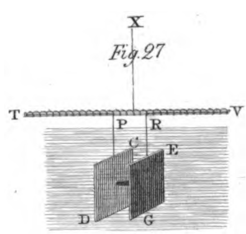



Fig. 27

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## ADDITIONAL ERRATA.

Page 81, *for* $(\tan x + a)$ *read* $\tan (x + a)$.

200, for *see*, read *sec*.

204, two lines were left out; this page and pages 239—242 have been reprinted, and may be had at the Publishers.

211, line 11, from bottom, *for* log 1·65642, *read* —1·65642.

239, *for* $\frac{1}{d} - \frac{1}{\sqrt{(d^2 + l^2)}}$ *read* $\frac{1}{d}$ arc. tan $\frac{l}{d}$

This occurs only in a few copies; see above, p. 204.

*Works published by the same Author.*

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## *Extracts from Reviews*

### OF THE ESSAY

# ON MAGNETIC ATTRACTIONS.

"The whole of this developement of facts appears to have been so skilfully conducted, and the successive links in the chain of induction so cautiously united, that it would seem reasonable to expect a satisfactory issue of the proposed experiment in any part of the world .... Every thing which tends to throw new light upon things long known, or to develope new facts, has its value; and when the discoveries brought forward relate to matters of daily and extensive use, it is the fault of the nation among whom they are first promulgated, if they are permitted to remain unproductive of permanent and general benefit."—*British Review,* No. 30.

"It is surprising, considering the interest which the science of magnetism has for more than a century excited, that no course of experiments of this kind has been before undertaken; and that instead of examining in all cases the action of magnet on magnet, the inquiry had not suggested itself, of determining the laws between iron and the compass. Such however appears to be the case, and Mr. Barlow has in consequence the honour of having discovered several important laws, which promise to throw considerable light upon this mysterious subject."—*Phil. Magazine, Feb.* 1820.

"Mr. Barlow, sensible of how much real importance a formula founded on accurate principles for correcting the deviation produced by a change in direction of the ship's head, in all approachable latitudes, would be to science and navigation, and indeed to mankind in general, has at length arrived at the conclusion, after a long, laborious, and patient investigation of the laws of magnetic attraction, his situation and place affording the most ample opportunity and means for experiments no less honourable to himself than beneficial to science and practical navigation."—*Blackwood's Magazine, Feb.* 1822.

"Attempts to produce and prescribe formulæ are necessarily futile, unless our principles are self-evident, or equally irrefragable; for they can only accidentally hit the truth: but rules, resulting from principles properly attested, and produced by a proficient in mathematical reasoning, are infallible. Now we have no hesitation in pronouncing the rules furnished by the present author to be of the latter character, and therefore entitled to implicit confidence: for though we have at present but a paucity of evidence as to their efficacy on ship board, yet they have produced such a series of approximations to the several tests, as cannot fail to astonish those who are best acquainted with the nature of the task which has been (as it were) at once so effectually performed."—*Monthly Review, May,* 1820.

"But though the correction of this deviation was the principal object of Mr. Barlow's labours, he did not neglect to consider the phenomena of magnetism under a scientific point of view, and he has made a discovery, which if it prove correct, must be admitted to be of the first-rate importance, and will tend more to bring magnetism into a state of an accurate science, than any fact respecting it yet brought to view."—*Annals of Philosophy, Oct.* 1820.

"From an abstract principle the author has brought into action a simple yet most effectual remedy, for an evil, whose cure had long been an almost hopeless desideratum; and by the adoption of which (as its success can scarcely admit of a doubt) many valuable lives will probably be saved, or at least much distress, labour, uncertainty and delay, be spared. It is an invention which, if no serious practical objection be found, will go down to posterity ranked with the safety-lamp of Sir H. Davy, and claiming for its inventor the same well merited praise."—*British Critic, May,* 1821.

"We have no hesitation in stating, that, as far as our knowledge of magnetism extends, all the laws which we have been describing are new facts in that science. By means of them we may compute, and by the most simple rules, the effect which a mass of iron will produce on the compass in any part of the world."—*Edinburgh Philosophical Journal, Oct.* 1821.

"It was reserved for Mr. Barlow, by a series of most ingenious and satisfactory experiments, to discover the laws of this variation, and then to reduce his philosophical investigations to practical utility, by the invention of an apparatus of extreme simplicity, by which all mistakes in navigation, arising from this source, are completely avoided. The intrinsic merit of the discovery, and its peculiar value to a country ranking first amongst the maritime powers, have induced the Society to confer unusual marks of their approbation on Mr. Barlow."*—*Preface to Vol.* 39 *of the Transactions of the Society of Arts.*

* The Author was elected perpetual member of the Society, and honoured with their gold medal, and a complete set of the Society's Transactions.