may very easily happen, then, that in the calculation likewise, the error of one minute may be committed; which, added to that of a minute committed in the observation of the moon's place, will double that which results from it respecting the longitude of the place where we are; and, consequently, it may possibly amount to a whole degree: it is proper farther to remark, that if the moon in 24 hours should change her relative situation more than 12 degrees, the error in the longitude would be less considerable. The means may perhaps be discovered of diminishing still farther the errors into which we are liable to fall, in the observation and in the calculation; and then we should be able to ascertain the longitude to a degree, or less. Nay, we ought not to despair of attaining a still higher degree of precision. We have only to make several observations, which can be easily done by remaining several days together at the same place. It is not to be apprehended, in that case, that all the conclusions should be equally defective; some will give the longitude sought too great, others too small, and by striking a medium between all the results, we may rest assured that this longitude will not be one degree removed from the truth.

The English nation, generously disposed to engage genius and ability in this important research, has proposed three prizes for ascertaining the longitude, one of L. 10,000, one of L. 15,000, and one of L. 20,000. The first of these is to be bestowed on the person who shall determine the longitude to a degree, or about it, so as to give perfect assurance that the error shall not exceed one degree at most. The second is to be given to him who shall discover a method still more exact, so that the error shall never exceed two-thirds of a degree, or 40 minutes. The highest prize is destined to the man who shall

ascertain the longitude so exactly that the error shall never exceed half a degree, or 30 minutes; and a higher degree of precision is hardly to be expected. No one of these prizes has hitherto been allotted: I do not take into the account the gratification bestowed on the artist who pretended to it from his construction of perfect time-pieces. *Mr. Mayer* is at this moment claiming the highest, and I think he is entitled to it.*

3*d October* 1761.

Letter LIV.—On the Mariner's Compass, and the properties of the Magnetic Needle.

You are by this time sufficiently informed respecting the discovery of the Longitude: I have had the pleasure of explaining the various methods which have been employed for the determination of it.

The first, and most natural, is carefully to observe the quantity of space which we have gone over, and the direction in which we moved; but the currents and tempests to which sea voyages are exposed, render this method impracticable.

The second requires the construction of a time-piece so perfect as to go always uniformly, notwithstanding the agitation of a ship at sea; which no artist has hitherto been able to accomplish.

The third is founded on the observation of the eclipses of the moon, which would completely answer every purpose, were not opportunities of employing it too rare, and least in our power when the necessity may be most urgent.

* The widow of Professor Mayer received from the British Parliament a reward of L. 3000 Sterling; and Euler himself received L. 300 for furnishing the theorems on which Mayer's Tables are founded. The latter received also a reward from the French Government, and gained several prizes for his improvement of the Lunar Theory.—Ed.

The fourth refers to the eclipses of the satellites of Jupiter, which would answer the purpose extremely well, had we the means of employing, at sea, telescopes of a certain description, without which they are invisible.

Finally, observations of the moon herself furnish a fifth method, which appears the most practicable, provided we were able to observe the moon's place in the heavens so exactly, that the error in calculation (and error is unavoidable) should never exceed one minute, in order to be assured that we are not mistaken above one degree in the determination of the longitude.*

To one or the other of these five methods persons engaged in this research have chiefly directed their speculations: but there is still a sixth, which seems likewise adapted to the solution of the problem, were it more carefully cultivated; and will perhaps one day furnish us with the most certain method of discovering the longitude; though as yet we are far, very far, short of it.

It is not derived from the heavens, but is attached to the earth simply, being founded on the nature of the magnet, and of the compass. The explication of it opens to me a new field of important physical observation, for your amusement and instruction, on the subject of magnetism; and I flatter myself you will attend with delight and improvement to the elucidations which I am going to suggest.

My reflections shall be directed only to the main subject of our present research, I mean the discovery of the longitude. I remark in general, that the magnet is a stone which has the quality of attracting iron, and of disposing itself in a certain direction;

* This method is now brought to very great perfection, not only by the improvement of the Lunar Tables, but by the perfection of the sextants and circles with which the Moon's place in the heavens is observed.—Ed.

and that it communicates the same quality to iron and steel, by rubbing, or simply touching them with a magnet; proposing afterwards to enter into a more minute discussion of this quality, and to explain the nature of it.

I begin, then, with the description of a magnetic needle, which, mounted in a certain manner, for the use of mariners, is denominated the *Compass.*

For this purpose, we provide a needle of good steel, nearly resembling *Fig.* 2. of Plate V., one extremity of which B terminates in a point, the better to distinguish it from the other A; it is furnished at the middle C with a small cap, hollowed below, for the purpose of placing the needle on a pivot or point D, as may be seen in the second figure.

The two ends are adjusted in such a manner, that the needle, being in perfect equilibrium, can revolve freely, or remain at rest, on the pivot, in whatever situation it may be placed. Before the magnet is applied, it would be proper to temper the needle, in order to render it as hard as possible; then by rubbing or touching it with a good loadstone, it will instantly acquire the magnetic virtue. The two extremities will no longer balance each other, but the one D will descend, as if it had become heavier; and in order to restore the equilibrium, something must be taken away from the extremity B, or a small weight added to the end A. But the artists, foreseeing this change produced by magnetism, make the end B originally lighter than the end A, that the magnetized needle may of itself assume the horizontal position.

It then acquires another property still more remarkable: it is no longer indifferent to all situations, as formerly; but affects one in preference to every other, and disposes itself in such a manner that the extremity B is directed to the north nearly, and the extremity A toward the south; and the direction of the magnetic needle corresponds almost with the meridian line.

You recollect that, in order to trace a meridian line, which may point out the north and the south, it is necessary to have recourse to astronomical observations, as the motion of the sun and stars determines that direction; and when we are not provided with the necessary instruments, and especially when the sky is overclouded, it is impossible to derive any assistance from the heavens toward tracing the meridian line; this property of the magnetic needle is, therefore, so much the more admirable, that it points out, at all times, and in every place, the northern direction, on which depends the others, toward the east, south, and west. For this reason the use of the magnetic needle, or compass, is become universal.

It is in navigation that the advantages resulting from the use of the compass are most conspicuous; it being always necessary to direct the course of a vessel toward a certain quarter of the world, in order to reach a place proposed, conformably to geographic or marine charts, which indicate the direction in which we ought to proceed. Before this discovery, accordingly, it was impossible to undertake long voyages; the mariner durst not lose sight of the coast, for fear of mistaking his course, unless the sky was unclouded, and the stars pointed out the way.

A vessel on the wide ocean, without the knowledge of the proper course, would be precisely in the state of a man who, with a bandage over his eyes, was obliged to find his way to the great church of Magdeburg; imagining he was going one way, he might be going another. The compass, then, is the principal guide in navigation; and it was not till after

this important discovery that men ventured across the ocean, and attempted the discovery of a new world. What would a pilot do without his compass during or after a storm, when he could derive no assistance from the heavens? Take whatever course he might, he must be ignorant in what direction he was proceeding, north, south, or to any other quarter. He would presently deviate to such a degree, as infallibly to lose himself. But the compass immediately puts him right; from which you will be enabled to judge of the importance of the discovery of the magnetic needle, or mariner's compass.

6th October 1761.

Letter LV.—Declination of the Compass, and manner of observing it.

Though the magnetic needle affects the situation of being directed from south to north, there are accidental causes capable of deranging this direction, which must be carefully avoided. Such are the proximity of a loadstone, or of iron or steel. You have only to present a knife to a magnetic needle, and it will immediately quit its natural direction, and move toward the knife; and, by drawing the knife round the needle, you will make it assume every possible direction. In order to be assured, then, that the needle is in its natural direction, you must keep at a distance from it all iron or steel, as well as magnets; which is so much the more easy, that these substances influence its direction only when very near it: once removed, their effect becomes insensible, unless in the case of a very powerful magnet, which might possibly act on the needle at the distance of several feet.

But iron alone produces not this effect, as the compass may be used to advantage even in iron mines. You are perfectly sensible, that under ground, in mines, we are in the same condition as at sea when the face of heaven is overclouded, and that it is necessary to drive mines in a certain direction. Plans are accordingly constructed representing all the tracks hollowed out in the bowels of the earth, and this operation is regulated merely by the compass; this is the object of the science denominated subterraneous geometry.

To return to our compass, or magnetic needle, I have remarked that its direction is only almost northerly; it is therefore incorrect to say that the magnet has the property of always pointing north. Having employed myself in the fabrication of many magnetic needles, I constantly found that their direction at Berlin deviated about 15° from the true meridian line; now, an aberration of 15° is very considerable.

Figure 3. Plate V. represents first the true meridian line drawn from north to south; that which is drawn at right angles with it indicates the east to the right hand, and the west to the left. Now the magnetic needle AB does not fall on the meridian, but deviates from it an angle 15° BO *North*. This angle is denominated the *declination*, and sometimes the *deviation* or *variation*, of the compass or magnetic needle; and as the extremity B, nearest the north, deviates toward the west, we say the declination is 15° westerly.

Having thus determined the declination of the magnetic needle, we can make it answer the same purpose as if it pointed directly north. The needle is usually enclosed in a circle, and you have only to mark on it the due north at the exact distance from the northern extremity of the needle, so as to make

a declination of 15° westward; and the line *North South*, Fig. 3, will indicate the true meridian line, and enable us to ascertain the four cardinal points, north, east, south, and west.

The better to disguise the secret, the magnetic needle is concealed in a circle of pasteboard, as represented in the figure, only the needle is rendered invisible, the pasteboard covering it, and forming but one body with it, the centre of which is placed on a pivot,* in order to admit of a free revolution: it assumes, of course, a situation such that the point marked *North* is always directed to that point of the horizon; whereas the needle, which is not seen, in effect deviates from it 15° to the west. This construction serves only to disguise the declination, which the vulgar consider as a defect, though it be rather an object worthy of admiration, as we shall afterwards see; and the pasteboard only increasing the weight of the needle, prevents its turning so freely as if it were unencumbered.

To remedy this, and more commodiously to employ the compass, the needle is deposited in a circular box, the circumference of which, divided into 360°, exhibits the names of the principal points of the horizon. In the centre is the pivot or point which supports the needle, and this last immediately assumes a certain direction; the box is then turned till the northern extremity of the needle B exactly corresponds with 15° on the circumference, reckoning from the north-westward; and then the names marked will agree with the real quarters of the world.

At sea, however, they employ needles cased in circles of pasteboard, the circumference of which is divided into 360°, to prevent the necessity of turning

* The cap or hollow which rests on the pivot should be made of Garnet, which gives less friction than any other of the precious stones.—ED.

round the box; then the pasteboard circle, which is called the compass, indicating the real quarters of the world, we have only to refer to it the course which the ship is steering, in order to ascertain the direction, whether north or south, east or west, or any other intermediate point. By the compass likewise we distinguish the winds, or the quarters from which they blow; and from the points marked on it their names are derived. It is necessary, at any rate, to be perfectly assured of the declination or variation of the compass; we have found it to be exactly 15° westward here at Berlin; but it may be different at other places, as I shall afterwards demonstrate.

10*th October* 1761.

Letter LVI.—Difference in the Declination of the Compass at the same place.

When I say that the declination of the compass is 15° west, this is to be understood as applying only to Berlin, and the present time; for it has been remarked, that not only is this declination different at different places of the earth, but that it varies, with time, at the same place.*

The magnetic declination is accordingly much greater at Berlin now, than it was formerly. I recollect the time perfectly when it was only 10°;† and in the last century there was a period when there was no declination, so that the direction of the magnetic needle coincided exactly with the meridian line. This was about the year 1670; since then the

* In the year 1786, M. Schulze found the deviation to be 18° 28′, which seems to have been its maximum. In 1805, M. Bode found it to be 18° 3′, having been so low as 17° 5′ in 1788.—Ed.

† It was so low as 10° at Berlin in 1717.—Ed.

declination is become progressively greater toward the west, up to 15°, as at this day: and there is every appearance that it will go on diminishing, till it is again reduced to nothing. I give this, however, merely as conjecture, for we are very far from being able to predict it with certainty.

Besides, it is well known, that prior to the year 1670, the declination was in the contrary direction, that is, toward the east; and the farther back we go, the greater do we find the declination eastward. Now, it is impossible to go farther back than to the period when the compass was discovered; this happened in the fourteenth century; but it was long after the discovery before they began to observe the declination at Berlin; for it was not perceived at first that the needle deviated from the meridian line.

But at London, where this subject has been more carefully studied, the magnetic declination, in the year 1580, was observed to be 11° 15′ east; in 1622, 6° 0′ east; in 1634, 4° 5′ east; in 1657 there was no declination; but in 1672 it was 2° 30′ west; in 1692, 6° 0′ west; and at present it may probably be 18 degrees west, or more.* You see, then, that about the beginning of the last century, the declination was nearly 8 degrees east: that thenceforward it gradually diminished, till it became imperceptible in the year 1657; and that it has since become westerly, gradually increasing up to the present time.

It has preserved nearly the same order at Paris; but there it was reduced to nothing in 1666, nine years later than at London: hence you will observe a most unaccountable diversity of declination relatively to different places of the earth at the same time, and to the same place at different times.

* In January 1821, the variation of the Needle at London, was 24° 35′ west.—Ed.

At present, not only through all Europe, but through all Africa, and the greatest part of Asia, the declination is westerly, in some places greater, in others less, than with us. It is greater in certain countries of Europe than at our capital; namely, in Scotland and in Norway, where the declination considerably exceeds 20°; in Spain, Italy, and Greece, on the contrary, it is less, being about 12°; on the western coasts of Africa it is about 10°, and on the eastern 12°. But as you advance eastward into Asia it progressively diminishes, till it entirely disappears in the heart of Siberia, at Jeniseisk; it disappears too in China, at Pekin, and at Japan; but beyond these regions, to the eastward, the declination becomes easterly, and goes on increasing in this direction, along the north part of the Pacific Ocean, to the western coasts of America, from which it proceeds gradually diminishing, till it again disappears in Canada, Florida, the Antilles, and toward the coasts of Brazil. Beyond these countries, toward the east, that is, toward Europe and Africa, it again becomes westerly, as I have already remarked.

In order to attain a perfect knowledge of the present state of magnetic declination, it would be necessary to ascertain for all places, both at land and sea, the present state of magnetic declination, and whether its tendency is westward or eastward. This knowledge would be undoubtedly extremely useful, but we dare scarcely hope for it. It would require men of ability in every part of the globe, employed at the same time in observing, each on his own station, the magnetic declination, and who should communicate their observations with the utmost exactness. But the space of some years would elapse before the communications of the more remote could be received; thus the knowledge aimed at is unattainable till after the expiration of years. Now, though no

very considerable change takes place in the direction of the magnetic needle in two or three years, this change, however small, would however prevent the attainment of complete information respecting the present state of the various declinations of the magnetic needle, from observations made at the same time in the different regions of the globe.

The same thing holds with respect to times past; to every year corresponds a certain state of magnetic declination proper to itself, and which distinguishes it from every other period of time, past and future. It were, however, sincerely to be wished, that we had an exactly detailed state of the declination for one year only; the most important elucidations of the subject would certainly be derived from it.

The late *Mr. Halley*, a celebrated English astronomer, has attempted to do this for the year 1700, founding his conclusions on a great number of observations made at different places, both by land and sea; but beside that some very considerable districts, where these observations were not made, are not taken into his account, most of those which he has employed were made several years prior to 1700; so that at this era the declination might have undergone very considerable alterations. It follows, that this statement, which we find represented on a general chart of the earth, must be considered as extremely defective; and, moreover, what would it now avail us to know the state of magnetic declination for the year 1700, having since that time undergone a considerable change?

Other English geographers have produced, posterior to that period, a similar chart, intended to represent all the declinations, such as they were in the year 1744. But as it has the same defect with that of *Mr. Halley*, and as they likewise were unable to procure observations from several countries on the globe, they did not scruple to fill up the vacant places, by consulting *Halley's* chart, which certainly could not apply to 1744. You will conclude, from what I have said, that our knowledge of this important branch of physics is extremely imperfect.*

13*th October* 1761.

Letter LVII.—Chart of Declinations; Method of employing it for the Discovery of the Longitude.

It may be proper likewise to explain in what manner *Halley* proceeded to represent the magnetic declinations, in the chart which he constructed for the year 1700, that if you should happen to see it, you may comprehend its structure.

First, he marked at every place the declination of the magnetic needle, such as it had been there observed. He distinguished, among all these places, those where there was no declination, and found that they all fall in a certain line, which he calls the *line of no declination*, as every where under that line there was then none. This line was neither a meridian nor a parallel, but run in a very oblique direction over North America, and left it near the coasts of Carolina; thence it bent its course across the Atlantic Ocean, between Africa and America. Beside this line, he discovered likewise another in which the declination disappeared; it descended through the middle of China, and passed from

* Very correct and interesting charts, both of the variation and the dip of the magnetic needle, have been recently constructed by Mr. Hansteen of Christiania in Norway, and published in his very able work on the Magnetism of the Earth. Mr. Hansteen's charts will be found in the *Edinburgh Philosophical Journal*, vol. iv. p. 363.—Ed.

thence through the Philippine Isles and New Holland. It is easy to judge, from the track of these two lines, that they have a communication near both poles of the globe.

Having fixed these two lines of no declination, *Mr. Halley* remarked, that every where between the first and last, proceeding from west to east, that is, through all Europe, Africa, and almost the whole of Asia, the declination was westerly; and that on the other side, between those lines, that is, over the whole Pacific Ocean, it was easterly. After this, he observed all the places in which the declination was 5 degrees west, and found he could still conveniently draw a line through all these places, which he calls the *line of five degrees west*. He found likewise two lines of this description, the one of which accompanied, as it were, the first of no declination, and the other the last. He went on in the same manner with the places where the declination was 10°; afterwards 15°, 20°, &c., and he saw that these lines of great declination were confined to the polar regions; whereas those of small declination encompassed the whole globe, and passed through the equator.

In fact, the declination scarcely ever exceeds 15° on the equator, whether west or east; but on approaching the poles, it is possible to arrive at places where the declination exceeds 58° and 60°. There are undoubtedly some where it is still greater, exceeding even 90°, and where the northern extremity of the needle will consequently turn about and point southward.*

* This was found to be the case in the voyages of Captain Ross and Captain Parry. On the S.E. point of Byam Martin's Island, in West Long. 103° 44′½, and North Lat. 75° 9′, the variation was 165° 50′ east, having been 128° 50′ west in West Long. 91° 47′, and North Lat. 74° 40′.—Ed.

Finally, having drawn similar lines through the places where the declination was eastward 10°, 15°, 20°, and so on, *Mr. Halley* filled up the whole chart, which represented the entire surface of the earth, under each of which lines the declination is universally the same, provided the observations are not erroneous. *Mr. Halley* has accordingly scrupulously abstained from continuing such lines beyond the places where observations had actually been made: for this reason the greater part of his chart is a blank.

Had we such a chart accurate and complete, we should see at a glance what declination must have predominated at each place at the time for which the chart was constructed; and though the place in question should not be found precisely under one of the lines traced on the chart, by comparing it with the two lines between which it might be situated, we could easily calculate the intermediate declination which corresponds to it. If I found my present place to be between the lines of 10° and 15° of western declination, I should be certain that the declination there was more than 10°, and less than 15°; and according as I might be nearer the one or the other, I could easily find the means which would indicate the true declination.

From this you will readily comprehend, that if we had such a chart thus exact, it would assist us in discovering the longitude, at least for the time to which it corresponded. In order to explain this method, let us suppose that we are possessed of a chart constructed for the present year, we would see on it, first, the two lines drawn through the places where there is no declination; then the two where it is 5°, 10°, 15°, 20°, both east and west: let us farther suppose that, for the greater exactness, these lines were drawn from degree to degree, and that I found

myself at a certain place on sea, or in an unknown country, I would in the first place draw a meridian line, in order to ascertain how much my compass deviated from it, and I should find, for example, that the declination is precisely 10° east; I should then take my chart, and look for the two lines under which the declination is 10° east, fully assured that I am under the one or the other of these two lines, which must at once greatly relieve my uncertainty. Finally, I would observe the height of the pole, which being the latitude of my place, nothing more would remain but to mark, on the two lines mentioned, the points where the latitude is the same with that which I have just observed, and then all my uncertainty is reduced to two points very distant from each other; now the circumstances of my voyage would easily determine which of those two places is that where I actually am.

You will admit that if we had charts such as I have described, this method would be the most commodious and accurate of all for ascertaining the longitude; but this is precisely the thing we want; and as we are still very far from having it in our power to construct one for the time past, which would be of no use for the present time, for want of a sufficient number of observations, we are still less instructed respecting all the changes of declination which every place undergoes in the lapse of time. The observations hitherto made assure us, that certain places are subject to very considerable variations, and that others scarcely undergo any, in the same interval of time; which strips us of all hope of ever being able to profit by this method, however excellent it may be in itself.

17th October 1761.

LETTER LVIII.—WHY DOES THE MAGNETIC NEEDLE AFFECT, IN EVERY PLACE OF THE EARTH, A CERTAIN DIRECTION, DIFFERING IN DIFFERENT PLACES; AND FOR WHAT REASON DOES IT CHANGE, WITH TIME, AT THE SAME PLACE?

YOU will undoubtedly have the curiosity to be informed why magnetic needles affect, at every place on the globe, a certain direction; why this direction is not the same at different places; and why, at the same place, it changes with the course of time? I shall answer these important inquiries to the best of my ability, though, I fear, not so much to your satisfaction as I could wish.

I remark, first, that magnetic needles have this property in common with all magnets, and that it is only their form, and their being made to balance and revolve freely on a pivot, which renders it more conspicuous. The loadstone, suspended by a thread, turns toward a certain quarter, and when put in a small vessel to make it swim on water, the vessel which supports the loadstone will always affect a certain direction. Every loadstone fitted with two opposite points, the one of which is directed to the north, and the other to the south, will be subject to the same variations as the magnetic needle.

These points are very remarkable in all loadstones, as by them iron is attracted with the greatest force.

They are denominated the *poles* of a loadstone—a term borrowed from that of the poles of the earth, or of the heavens; because the one has a tendency toward the north, and the other toward the south pole of the earth: but this is to be understood as only almost, not exactly, the case; for when the name was imposed, the declination had not yet been

observed. That pole of the loadstone which is directed northward is called its north pole, and that which points southward its south pole.

I have already remarked, that a magnetic needle, as well as the loadstone itself, assumes this situation, which appears natural to it only when removed from the vicinity of another loadstone, or of iron. When a magnetic needle is placed near a loadstone, its situation is regulated by the poles of that loadstone: so that the north pole of the loadstone attracts the southern extremity of the needle; and reciprocally, the south pole of the loadstone the northern extremity of the needle. For this reason, in referring one loadstone to another, we call those the friendly poles which bear different names, and those the hostile which have the same name. This property is singularly remarkable on bringing two loadstones near each other; for then we find, that not only do the poles of different names mutually attract, but that those of the same name shun and repel each other. This is still more conspicuous when two magnetic needles are brought within the sphere of mutual influence.

In order to be sensible of this, it is of much importance to consider the situation which a magnetic needle assumes in the vicinity of a loadstone.

The bar AB (PLATE V. *Fig.* 4.) represents a loadstone, whose north pole is B, and the south pole A: you see various positions of the magnetic needle, under the figure of an arrow, whose extremity marked *b* is the north pole, and *a* the south. In all these positions, the extremity *b* of the needle is directed toward the pole A of the loadstone; and the extremity *a* to the pole B. The point *c* indicates the pivot on which the needle revolves; and you have only to consider the figure with some attention, in order to determine what situation the needle will assume, in whatever position round the loadstone the pivot *c* is fixed.

If there were, therefore, any where a very large loadstone AB, the magnetic needles placed round it would assume at every place a certain situation, as we see actually to be the case round the globe. Now if the globe itself were that loadstone, we should comprehend why the magnetic needles every where assumed a certain direction. Naturalists, accordingly, in order to explain this phenomenon, maintain that the whole globe has the property of a magnet, or that we ought to consider it as a prodigious loadstone. Some of them allege, that there is at the centre of the earth a very large loadstone, which has exercised its influence on all the magnetic needles, and even on all the loadstones, which are to be found on the surface of the earth; and that it is this influence which directs them in every place, conformably to the directions which we observe them to assume.

But there is no occasion to have recourse to a loadstone concealed in the bowels of the earth. Its surface is so replenished with mines of iron and loadstone, that their united force may well supply the want of this huge magnet. In fact, all loadstones are extracted from mines—an infallible proof that these substances are found in great abundance in the bowels of the earth, and that the union of all their powers furnishes the general force which produces all the magnetical phenomena. We are likewise enabled thereby to explain, why the magnetic declination changes, with time, at the same place; for it is well known, that mines of every kind of metal are subject to perpetual change, and particularly those of iron, to which the loadstone is to be referred. Sometimes iron is generated, and sometimes it is destroyed at one and the same place; there are

accordingly at this day mines of iron where there were none formerly; and where it was formerly found in great abundance, there are now hardly any traces of it. This is a sufficient proof that the total mass of loadstones contained in the earth is undergoing very considerable changes, and thereby undoubtedly the poles, by which the magnetic declination is regulated, likewise change with the lapse of time.

Here, then, we must look for the reason why the magnetic declination is subject to changes so considerable at the same places of the globe. But this very reason, founded on the inconstancy of what is passing in its bowels, affords no hope of our ever being able to ascertain the magnetic declination beforehand, unless we could find the means of subjecting the changes of the earth to some fixed law. A long series of observations, carried on through several ages successively, might possibly throw some light on the subject.

20*th October* 1761.

Letter LIX.—Elucidations respecting the cause and variation of the Declination of Magnetic needles.

Those who allege that the earth contains in its womb a prodigious loadstone, like a stone with a kernel in fruit, are under the necessity of admitting, in order to explain the magnetic declination, that this stone is successively shifting its situation. It must in that case be detached from the earth in all its parts; and as its motion would undoubtedly follow a certain law, we might flatter ourselves with the hope of one day discovering it. But whether there be such a magnetic stone within the earth, or whether the loadstones scattered up and down through its entrails unite their force to produce the magnetical phenomena, we may always consider the earth itself as a loadstone, in subserviency to which every particular loadstone, and all magnetic needles, assume their direction.

Certain naturalists have enclosed a very powerful magnet in a globe, and having placed a magnetic needle on its surface, observed phenomena similar to those which take place on the globe of the earth, by placing the magnet within the globe, in several different positions. Now, considering the earth as a loadstone, it will have its magnetic poles, which must be carefully distinguished from the natural poles round which it revolves. These poles have nothing in common between them but the name; but it is from the position of the magnetic poles, relatively to the natural, that the apparent irregularities in the magnetic declination proceed, and particularly of the lines traced on the globe, of which I have endeavoured to give you some account.

In order more clearly to elucidate this subject, I remark, that if the magnetic poles exactly coincided with the natural, there would be no declination all over the earth; magnetic needles would universally point to the north precisely, and their position would be exactly that of the meridian line. This would no doubt be an unspeakable advantage in navigation, as we should then know with precision the course of the vessel and the direction of the wind; whereas, at present, we must always look for the declination of the compass before we are able to determine the true quarters of the world. But then the compass could furnish no assistance toward ascertaining the longitude, an object which the declination may sooner or later render attainable.

Hence it may be concluded, that if the magnetic poles of the earth differed very greatly from the na-

tural, and that if they were directly opposite to each other—which would be the case if the magnetic axis of the earth, that is, the straight line drawn from the one magnetic pole to the other, passed through the centre of the earth—then magnetic needles would universally point toward these magnetic poles, and it would be easy to assign the magnetic direction proper to every place; we should only have to draw for every place a circle which should at the same time pass through the two magnetic poles, and the angle which this circle would make with the meridian of the same place must give the magnetic declination.

In this case, the two lines under which there is no declination, would be the meridians drawn through the magnetic poles. But as we have seen that, in reality, these two lines without declination are not meridians, but take a very unaccountable direction, it is evident that no such case actually takes place. *Halley* clearly saw this difficulty, and therefore thought himself obliged to suppose a double loadstone in the bowels of the earth, the one fixed, the other moveable; of consequence, he was obliged to admit four poles of the earth, two of them toward the north and two toward the south, at unequal distances. But this hypothesis seems to me rather a bold conjecture: it by no means follows, that because these lines of no declination are not meridians, there must be four magnetic poles on the earth; but rather, that there are only two, which are not directly opposite to each other; or, which comes to the same thing, that the magnetic axis does not pass through the centre of the earth.

It remains, therefore, that we consider the cases in which these two magnetic poles are not directly opposite, and in which the magnetic axis does not pass through the centre of the earth; for if we embrace the hypothesis of the magnetic nucleus within the earth, why should one of its poles be precisely opposite to the other? This nucleus may very probably be not exactly in the very centre of the earth, but at a considerable distance from it. Now, if the magnetic poles are not diametrically opposite to each other, the lines of no declination may actually assume a direction similar to that which, from observation, we find they do; it is even possible to assign to the two magnetic poles such places on the earth, that not only these lines should coincide with observation, but likewise, for every degree of declination, whether western or eastern, we may find lines precisely similar to those which at first seemed so unaccountable.

In order, then, to know the state of magnetic declination, all that is requisite is to fix the two magnetic poles; and then it becomes a problem in geometry to determine the direction of all the lines which I mentioned in my preceding letter, drawn for every place where the declination is the same: by such means, too, we should be enabled to rectify these lines, and to fill up the countries where no observations have been made; and were it possible to assign, for every future period, the places of the two magnetic poles on the globe, it would undoubtedly prove the most satisfactory solution of the problem of the longitude.

There is no occasion, therefore, for a double loadstone within the earth, or for four magnetic poles, in order to explain the declination of magnetic needles, as *Halley* supposed; but for a simple magnet, or two magnetic poles, provided its just place is assigned to each.* It appears to me, that, from this reflection,

* The phenomena render it absolutely necessary to admit two magnetic poles. The two northern poles, which we may call B and *b*, and

we are much more advanced in our knowledge of magnetism.

24th October 1761.

Letter LX.—Inclination or Dip of Magnetic Needles.

You will please to recollect, that on rubbing a needle against the loadstone, it acquires not only the property of pointing toward a certain point of the horizon, but that its northern extremity sinks, as if it had become heavier, which obliges us to diminish its weight somewhat, or to increase that of the other extremity, in order to restore the equilibrium. I have, without putting this in practice, made several experiments to ascertain how far the magnetic force brought down the northern extremity of the magnetized needle, and I have found that it sunk so as to make an angle of 72 degrees with the horizon, and that in this situation the needle remained at rest. It is proper to remark, that these experiments were made at Berlin about six years ago; for I shall show you afterwards, that this direction to a point below the horizon, is as variable as the magnetic declination.

Hence we see that the magnetic power produces a double effect on needles; the one directs the needle

the two southern poles, A and *a*, are thus situated, according to Hansteen, in 1823.

	North Lat.		West Long.	
B in	69° 34′	and	271° 38′	from Greenwich.
b	85 9		142 11	
A	68 48		132 11	
a	78 23		223 8	

	Years.
The pole B moves round the north pole of the globe in	1740.
——— *b*, which is weaker than B, in .	860.
——— A moves round the south pole of the globe in	4609.
——— *a*, which is weaker than A, in .	1304.

See the *Edinburgh Philosophical Journal*, vol. iv. p. 117.—Ed.

toward a certain quarter of the horizon, the deviation of which from the meridian line is what we call the magnetic declination; the other impresses on it an inclination toward the horizon, sinking the one or the other extremity under it, up to a certain angle.

Let *d e* (PLATE V. *Fig.* 5.) be the horizontal line, drawn according to the magnetic declination, and the needle will assume, at Berlin, the situation *b a*, which makes with the horizon *d e* the angle *d c b* or *e c a*, which is 72°, and consequently, with the vertical *f g*, an angle *b c g* or *a c f* of 18 degrees. This second effect of the magnetic force, by which the magnetic needle affects a certain inclination toward the horizon, is as remarkable as the first; and as the first is denominated the magnetic *declination*, the second is known by the name of magnetic *inclination* or *dip*, which deserves, as well as the declination, to be every where observed with all possible care, as we find in it a similar variation.

The inclination at Berlin has been found 72°,* at Bâsle only 70°, the northern extremity of the needle being sunk, and the opposite, of consequence, raised to that angle. This takes place in countries which are nearer to the northern magnetic pole of the earth; and in proportion as we approach it, the greater becomes the inclination of the magnetic needle, or the more it approaches the vertical line; so that if we could reach the magnetic pole itself, the needle would there actually assume a vertical situation; its northern extremity pointing perpendicularly downward, and its southern end upward.† The farther, on the contrary, you remove from the northern magnetic pole of the earth, and approach the southern, the more the inclination diminishes; it will at length disappear, and the needle will assume a horizontal position, when equally distant from both poles; but in proceeding toward the south pole of the earth, the southern extremity of the needle will sink more and more under the horizon, the northern extremity rising in proportion, till at the pole itself the needle again becomes vertical, with the southern extremity perpendicularly downward, and the northern upward.

* In 1805, it was found by Humboldt to be 69° 53′ at Berlin.—ED.

† On the 18th July 1820, the inclination of the needle was observed by Mr. Sabine to be 88° 43′ 5″ at Winter Harbour in Melville Island, in West Long. 110° 48′, and 74° 47′ of North Lat.—ED.

It were devoutly to be wished that experiments had been as carefully and as generally made, with the view of ascertaining the magnetic inclination, as of determining the declination; but this important article of experimental philosophy has hitherto been too much neglected, though certainly neither less curious nor less interesting than that of the declination. This is not, however, a matter of surprise: Experiments of this sort are subject to too many difficulties; and almost all the methods hitherto attempted of observing the magnetic inclination have failed. One artist alone, *Mr. Diterich* of Bâsle, has succeeded, having actually constructed a machine proper for the purpose, under the direction of the celebrated *Mr. Daniel Bernouilli*. He sent me two of the machines, by means of which I have observed, at Berlin, this inclination of 72 degrees; and however curious in other respects the English and French may be in prosecuting such inquiries, they have put no great value on *Mr. Diterich's* machine, though it is the only one adapted for this purpose.*

* One of the simplest machines for measuring the dip of the needle, is Capt. Scoresby's Magnetimeter. A bar of iron deprived entirely of its magnetism, either by heat, or by hammering it in the magnetic equator, is placed in the magnetic meridian, upon an inclined plane. This plane is raised or depressed by a wheel and pinion, till the iron bar exercises no action whatever upon a compass needle placed near it. When this happens, the bar

This instance demonstrates how the progress of science may be obstructed by prejudice; hence Berlin and Bâsle are the only two places on the globe where the magnetic inclination is known.

Needles prepared for the construction of compasses are by no means proper to indicate the quantity of magnetic inclination, though they may convey a rough idea of its effect, because the northern extremity in these latitudes becomes heavier. In order to render serviceable needles intended to discover the declination, we are under the necessity of destroying the effect of the inclination, by diminishing the weight of the northern extremity, or increasing that of the southern. To restore the needle to a horizontal position, the last of these methods is usually employed, and a small morsel of wax is affixed to the southern extremity of the needle. You are abundantly sensible, that this remedy applies only to these regions of the globe where the inclinatory power is so much, and no more; and that were we to travel with such a needle toward the northern magnetic pole of the earth, the inclinatory power would increase, so that to prevent the effect we should be obliged to increase the quantity of wax at the southern extremity. But were we travelling southward, and approaching the opposite pole of the earth, where the inclinatory power on the northern extremity of the needle diminishes, the quantity of wax affixed to the other extremity must then likewise be diminished; after that it must be taken away altogether, being wholly useless when we arrive at places where

is in the magnetic equator, and consequently the complement of the inclination of the plane on which it rests is the dip or inclination of the needle at the place where the observation is made. This angle of inclination was measured by a vertical graduated circle, adjusted to zero when the bar had a horizontal position.—See the *Edinburgh Transactions*, vol. ix., and the *Edinburgh Philosophical Journal*, vol. ix. p. 42., for a full account of this instrument.—Ed.

the magnetic inclination disappears. On proceeding still forward to the south pole, the southern extremity of the needle sinks; so that to remedy this, a morsel of wax must be affixed to the northern extremity of the needle. Such are the means employed, in long voyages, to preserve the compass in a horizontal position.

In order to observe the magnetic inclination, it would be necessary to have instruments made on purpose, similar to that invented by the artist of Bâsle. His instrument is called the *Inclinatory;* but there is little appearance of its coming into general use. It is still less to be expected that we should soon have charts constructed with the magnetic inclination, similar to those which represent the declination. The same method might easily be followed, by drawing lines through all the places where the magnetic inclination is the same: so that we should have lines of no inclination; afterwards other lines where the inclination would be 5°, 10°, 15°, 20°, and so on, whether northward or southward. *

27th October 1761.

Letter LXI.—True Magnetic direction; subtile matter which produces the Magnetic power.

In order to form a just idea of the effect of the earth's magnetic power, we must attend at once to the declination and inclination of the magnetic needle, at every place of the globe. At Berlin, we know the declination is 15° west, and the inclination of the northern extremity 72°. On considering this double effect, the declination and inclination, we shall have the true magnetic direction for Berlin. We draw

* See Note on Letter LVI.