brace 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.

first, on a horizontal plane, a line which shall make with the meridian an angle of 15° west, and thence descending toward the vertical line, we trace a new line, which shall make with it an angle of 72°; and this will give us the magnetic direction for Berlin: from which you will comprehend how the magnetic direction for every other place is to be ascertained, provided the inclination and declination are known.

Every magnet exhibits phenomena altogether similar. You have only to place one on a table covered with filings of steel, and you will see the filings arrange themselves round the loadstone AB, nearly as represented in *Fig.* 6. of Plate V., in which every particle of the filings may be considered as a small magnetic needle, indicating at every point round the loadstone the magnetic direction. This experiment leads us to inquire into the cause of all these phenomena.

The arrangement assumed by the steel filings leaves no room to doubt that it is a subtile and invisible matter which runs through the particles of the steel, and disposes them in the direction which we here observe. It is equally clear that this subtile matter pervades the loadstone itself, entering at one of the poles, and going out at the other, so as to form, by its continual motion round the loadstone, a vortex which reconducts the subtile matter from one pole to the other; and this motion is, without doubt, extremely rapid.

The nature of the loadstone consists, then, in a continual vortex, which distinguishes it from all other bodies; and the earth itself, in the quality of a loadstone, must be surrounded with a similar vortex, acting every where on magnetic needles, and making continual efforts to dispose them according to its own direction, which is the same I formerly denominated the magnetic direction: this subtile matter is conti-

nually issuing at one of the magnetic poles of the earth, and after having performed a circuit round to the other pole, it there enters, and pervades the globe through and through to the opposite pole, where it again escapes.

We are not yet enabled to determine by which of the two magnetic poles of the earth it enters or issues: the phenomena depending on this have such a perfect resemblance, that they are indistinguishable. It is undoubtedly, likewise, this general vortex of the globe which supplies the subtile matter of every particular loadstone to magnetic iron or steel, and which keeps up the particular vortices that surround them.

Previous to a thorough investigation of the nature of this subtile matter, and its motion, it must be remarked, that its action is confined to loadstone, iron, and steel;* all other bodies are absolutely indifferent to it: the relation which it bears to those must therefore be by no means the same which it bears to others. We are warranted to maintain, from manifold experiments, that this subtile matter freely pervades all other bodies, and even in all directions; for when a loadstone acts upon a needle, the action is perfectly the same, whether another body interposes or not, provided the interposing body is not iron, and its action is the same on the filings of iron. This subtile matter, therefore, must pervade all bodies, iron excepted, as freely as it does air, and even pure ether; for these experiments succeed equally well in a receiver exhausted by the air-pump. This matter is consequently different from ether,

* Professor Hansteen has lately found, that every vertical object, of whatever materials it is composed, has a *magnetic south pole above*, and a *magnetic north pole below*. This curious fact he has put beyond a doubt, by measuring the velocity of the oscillations of a magnetic needle on different sides of the extremities of the vertical object.—See the *Edinburgh Philosophical Journal*, vol. iv. p. 299, 300.—Ed.

and even much more subtile. And, on account of the general vortex of the earth, it may be affirmed that the globe is completely surrounded by it, and freely pervaded, as all other bodies are, excepting the loadstone and iron; for this reason iron and steel may be denominated magnetic bodies, to distinguish them from others.

But if this magnetic matter passes freely through all non-magnetic bodies, what relation can it have to those which are such? We have just observed, that the magnetic vortex enters at one of the poles of every loadstone, and goes out at the other; whence it may be concluded, that it freely pervades loadstones likewise; which would not distinguish them from other bodies. But as the magnetic matter passes through the loadstone only from pole to pole, this is a circumstance very different from what takes place in others. Here, then, we have the distinctive character. Non-magnetic bodies are freely pervaded by the magnetic matter in all directions: loadstones are pervaded by it in one direction only; one of the poles being adapted to its admission, the other to its escape. But iron and steel, when rendered magnetic, fulfil this last condition; when they are not, it may be affirmed that they do not grant a free transmission to the magnetic matter in any direction.

This may appear strange, as iron has open pores, which transmit the ether, though it is not so subtile as the magnetic matter. But we must carefully distinguish a simple passage, from one in which the magnetic matter may pervade the body, with all its rapidity, without encountering any obstacle.

31*st October* 1761.

Letter LXII.—Nature of the Magnetic Matter, and of its rapid current. Magnetic Canals.

I am very far from pretending to explain perfectly the phenomena of magnetism; it presents difficulties which I did not find in those of electricity. The cause of it undoubtedly is, that electricity consists in too great or too small a degree of compression, of a subtile fluid which occupies the pores of bodies, without supposing that subtile fluid, which is the ether, to be in actual motion; but magnetism cannot be explained, unless we suppose a vortex in rapid agitation, which penetrates magnetic bodies.

The matter which constitutes these vortices is likewise much more subtile than ether, and freely pervades the pores of loadstones, which are impervious even to ether. Now, this magnetic matter is diffused through, and mixed with the ether, as the ether is with gross air; or, just as ether occupies and fills up the pores of air, it may be affirmed that the magnetic matter occupies and fills the pores of ether.

I conceive, then, that the loadstone and iron have pores so small that the ether in a body cannot force its way into them, and that the magnetic matter alone can penetrate them; and which, on being admitted, separates itself from the ether by what may be called a kind of filtration. In the pores of the loadstone alone, therefore, is the magnetic matter to be found in perfect purity: every where else it is blended with ether, as this last is with the air.

You can easily imagine a series of fluids, one always more subtile than another, and which are perfectly blended together. Nature furnishes instances of this. Water, we know, contains in its pores particles of air, which are frequently seen discharging themselves in the form of small bubbles: air again, it is equally certain, contains in its pores a fluid incomparably more subtile, namely ether, and which on many occasions is separated from it, as in electricity. And now we see a still farther progression, and that ether contains a matter much more subtile than itself—the magnetic matter—which may perhaps contain, in its turn, others still more subtile, at least this is not impossible.

Having considered the nature of this magnetic matter, let us see how the phenomena are produced. I consider a loadstone, then, and say first, that besides a great many pores filled with ether, like all other bodies, it contains some still much more narrow, into which the magnetic matter alone can find admission. Secondly, these pores are disposed in such a manner as to have a communication with each other, and constitute tubes or canals, through which the magnetic matter passes from the one extremity to the other. Finally, this matter can be transmitted through these tubes only in one direction, without the possibility of returning in an opposite direction. This most essential circumstance requires a more particular elucidation.

First, then, I remark, that the veins and lymphatic vessels in the bodies of animals are tubes of a similar construction, containing valves, represented in *Fig.* 7. Plate V., by the strokes *m n*, which, by raising themselves, grant a free passage to the blood when it flows from A to B, and to prevent its reflux from B to A. For if the blood attempted to flow from B to A, it would press down the moveable extremity of the valve *m* on the side of the vein *o*, and totally obstruct the passage. Valves are thus employed in aqueducts, to prevent the reflux of the water. I do not consider myself, then, as supposing any thing

contrary to nature, when I say, that the canals, in loadstones, which admit the magnetic matter only, are of the same construction.

Figure 8. Plate V. represents this magnetic canal, according to my idea of it. I conceive it furnished inwardly with bristles directed from A toward B, which present no opposition to the magnetic matter in its passage from A to B, for in this case they open of themselves at *n*, to let the matter pass at *o*; but they would immediately obstruct the channel were it to attempt a retrograde course from B to A. The nature of magnetic canals consists, then, in granting admission to the magnetic matter only at A, to flow toward B, without the possibility of returning in the opposite direction from B toward A.

This construction enables us to explain how the magnetic matter enters into these tubes, and flies through them with the greatest rapidity, even when the whole ether is in a state of perfect rest, which is the most surprising; for how can a motion so rapid be produced? This will appear perfectly clear to you, if you will please to recollect that ether is a matter extremely elastic; accordingly, the magnetic matter, which is scattered about, will be pressed by it on every side. Let us suppose the magnetic canal A B still quite empty, and that a particle of magnetic matter *m* presents itself at the entrance A; and this particle pressed on every side at the opening of the canal, into which the ether cannot force admission, it will there be pressed forward with prodigious force, and enter into the canal with equal rapidity: another particle of magnetic matter will immediately present itself, and be driven forward with the same force; and in like manner all the following particles. There will thence result a continual flux of magnetic matter, which, meeting with no obstruction in this canal, will escape from it at B with the same rapidity that it enters at A.

My idea then is, that every loadstone contains a great multitude of these canals, which I denominate magnetic; and it very naturally follows, that the magnetic matter dispersed in the ether must enter into them at one extremity, and escape at the other, with great impetuosity; that is, we shall have a perpetual current of magnetic matter through the canals of the loadstone: and thus I hope I have surmounted the greatest difficulties which can occur in the theory of magnetism.

3d November 1761.

Letter XLIII.—Magnetic vortex. Action of Magnets upon each other.

You have now seen in what the distinctive character of the loadstone consists; and that each contains several canals, of which I have attempted to give a description.

Figure 9. Plate V. represents a loadstone A B, with three magnetic canals *a b*, through which the magnetic matter will flow with the utmost rapidity, entering at the extremities marked *a*, and escaping at those marked *b*: it will escape indeed with the same rapidity; but immediately meeting with the ether blended with the grosser air, great obstructions will oppose the continuation of its motion in the same direction; and not only will the motion be retarded, but its direction diverted toward the sides *c c*. The same thing will take place at the entrance, toward the extremities *a a a*; on account of the rapidity with which the particles of magnetic matter force their way into them, the circulation will quickly

overtake those which are still toward the sides *e e*, and these in their turn will be replaced by those which, escaping from the extremities *b b b*, have been already diverted toward *c c*; so that the same magnetic matter which issued from the extremities *b b b* quickly returns toward those marked *a a a*, performing the circuit *b c d e a*; and this circulation round the loadstone is what we call the *magnetic vortex*.

It must not be imagined, however, that it is always the same magnetic matter which forms these vortices: a considerable part of it will escape, no doubt, as well toward B as toward the sides, in performing the circuit; but as a compensation, fresh magnetic matter will enter by the extremities *a a a*, so that the matter which constitutes the vortex is succedaneous and very variable: a magnetic vortex, surrounding the loadstone, will, however, always be kept up, and produce the phenomena formerly observed in filings of steel scattered round the loadstone.

You will please farther to attend to this circumstance, that the motion of the magnetic matter in the vortex is incomparably slower out of the loadstone than in the magnetic tubes, where it is separated from the ether, after having been forced into them by all the elastic power of this last fluid; and that on escaping it mixes again with the ether, and thereby loses great part of its motion, so that its velocity in travelling to the extremities *a a a* is incomparably less than in the magnetic canals *a b*, though still very great with respect to us. You will easily comprehend, then, that the extremities of the magnetic canals, by which the matter enters into the loadstone and escapes from it, are what we call its poles; and that the magnetic poles of a loadstone are by no means mathematical points, the whole space in which the extremities of the magnetic canals terminate being one magnetic pole, as in the loadstone represented by *Figure* 6. PLATE V., where the whole surfaces A and B are the two poles.

Now, though these poles are distinguished by the terms *north* and *south*, yet we cannot affirm with certainty whether it is by the north or south pole that the magnetic matter enters into loadstones. You will see, in the sequel, that all the phenomena produced by the admission and escape, have such a perfect resemblance, that it appears impossible to determine the question by experiments. It is therefore a matter of indifference, whether we suppose that the magnetic matter enters or escapes by the north pole or by the south.

Be this as it may, I shall mark with the letter A the pole by which the magnetic matter enters, and with B that by which it escapes, without pretending thereby to indicate which is north or south. I proceed to the consideration of these vortices, in order to form a judgment how two loadstones act upon each other.

Let us suppose that the two loadstones A B and *a b* (PLATE V. *Fig.* 10.) are presented to each other by the poles of the same name A, *a*, and their vortices will be in a state of total opposition. The magnetic matter which is at C will enter at A and *a*, and these two vortices attempting mutually to destroy each other, the matter which proceeds by E to enter at A will meet at D that of the other loadstone returning by *e* to enter at *a*: from this must result a collision of the two vortices, in which the one will repel the other; and this effect will extend to the loadstones themselves, which thus situated, undergo mutual repulsion. The same thing would take place if the two loadstones presented to each other the other poles B and *b*: for this reason the poles of the same name are denominated *hostile*, because they actually repel each other.

But if the loadstones present to each other the poles of a different name, an opposite effect will ensue, and you will perceive that they have a mutual attraction.

In Figure 11. Plate V. where the two loadstones present to each other the poles B and *a*, the magnetic matter which issues from the pole B, finding immediately free admission into the other loadstone by its pole *a*, will not be diverted toward the sides in order to return and re-enter at A, but will pass directly by C into the other loadstone, and escape from it at *b*, and will perform the circuit by the sides *d d*, to re-enter, not by the pole *a*, but by the pole A, of the other loadstone, completing the circuit by *e f*. Thus the vortices of these two loadstones will unite, as if there were but one; and this vortex being compressed on all sides by the ether, will impel the two loadstones toward each other, so that they will exhibit a mutual attraction.

This is the reason why the poles of different names are denominated *friendly*, and those of the same name *hostile*, the principle phenomenon in magnetism, in as much as the poles of different names attract, and those of the same name repel each other.

7th November 1761.

LETTER LXIV.—NATURE OF IRON AND STEEL. METHOD OF COMMUNICATING TO THEM THE MAGNETIC FORCE.

HAVING settled the nature of the loadstone in these canals which the magnetic matter can pervade in only one direction, because the valves they contain prevent its return in the contrary direction, you can no longer doubt that they are the continuation of those pores (*Fig.* 8. PLATE V.), whose fibres point in the same direction; so that several of these particles, being joined in continuation, constitute one magnetic canal. It is not sufficient, therefore, that the matter of the loadstone should contain many similar particles; they must likewise be disposed in such a manner as to form canals continued from one extremity to the other, in order to grant an uninterrupted transmission to the magnetic matter.

Iron and steel, then, apparently contain such particles in great abundance; these are not, however, originally disposed in the manner I have been describing, but are scattered over the whole mass, and this disposition is all they want to become real magnets. In that case, they still retain all their other qualities, and are not distinguishable from other masses of iron and steel, except that now they have, besides, the properties of the loadstone; a knife and a needle answer the same purposes, whether they have or want the magnetic virtue. The change which takes place in the interior, from the arrangement of the particles in the order which magnetism requires, is not externally perceptible; and the iron or steel which has acquired the magnetic force is denominated an *artificial magnet*, to distinguish it from the natural, which resembles a stone, though the magnetic properties are the same in both. You will have a curiosity, no doubt, to be informed in what manner iron and steel may be brought to receive the magnetic force, and so become artificial magnets. Nothing can be more simple; and the vicinity of a loadstone is capable of rendering iron somewhat magnetic: it is the magnetic vortex which produces this effect, even though the iron and loadstone should not come into contact.

However hard iron may appear, the particles which contain the magnetic pores formerly represented are very pliant in substance, and the smallest

force is sufficient to change their situation. The magnetic matter of the vortex, entering into the iron, will then easily dispose the first magnetic pores which it meets following its own directions—those at least whose situation is not very different; and having run through them, it will act in the same manner on the adjacent pores, till it has forced a passage quite through the iron, and thereby formed some magnetic canals. The figure of the iron contributes greatly to facilitate this change; a lengthened figure, and placed in the same direction with the vortex, is most adapted to it, as the magnetic matter, in passing through the whole length, disposes there a great many particles in their just situation, in order to form longer magnetic canals; and it is certain, that the more there is the means of forming canals, and the longer they are without interruption, the more rapid will be the motion of the magnetic matter, and the greater the magnetic force.

It has likewise been remarked, that when the iron placed in a magnetic vortex is violently shaken or struck, it acquires a higher degree of magnetism from this, because the minute particles are by such concussion agitated and disengaged, so as to yield more easily to the action of the magnetic matter which penetrates them.

Placing accordingly a small bar of iron $a\ b$ (PLATE V. *Fig.* 12.) in the vortex of the loadstone A B, so that its direction may nearly agree with that of the current $d\ e\ f$ of the magnetic matter, it will with ease pass through the bar, and form in it magnetic canals, especially if at the same time the bar is shaken or struck to facilitate the transmission. It is likewise observable, that the magnetic matter which enters at the pole A of the loadstone, and escapes at the pole B, will enter the bar at the extremity a, and escape at the extremity b, so that the extremity *a* will become the pole of the same name A, and *b* the same with B. Then taking this bar *a b* out of the magnetic vortex, it will be an artificial magnet, though very feeble, which will supply its own vortex, and preserve its magnetic power, as long as its magnetic canals shall not be interrupted. This will take place so much the more easily that the pores of iron are pliant; thus the same circumstance which assists the production of magnetism, contributes likewise to its destruction. A natural magnet is not so easily enfeebled, because the pores are much closer, and more considerable efforts are requisite to derange them. I shall go more largely into the detail afterwards.

I here propose to explain the manner of most naturally rendering iron magnetic; though the force which it thence acquires is very small, it will assist us in comprehending this remarkable and almost universal phenomenon. It has been observed, that the tongs and other implements of iron which are usually placed in a vertical position, as well as bars of iron fixed perpendicularly on steeples, acquire in time a very sensible magnetic force. It has likewise been perceived, that a bar of iron, hammered in a vertical position, or heated red hot, on being plunged into cold water in the same position, becomes somewhat magnetic, without the application of any loadstone.

In order to account for this phenomenon, you have only to recollect that the earth itself is a loadstone, and consequently encompassed with a magnetic vortex, of which the declination and inclination of the magnetic needle every where show the true direction. If then a bar of iron remain long in that position, there is no reason to be surprised should it become magnetic. We have likewise seen, that the inclination of the magnetic needle is at Berlin 72

degrees; and as it is nearly the same all over Europe, this inclination differs only 18 degrees from the vertical position; the vertical position, accordingly, differs but little from the direction of the magnetic vortex: a bar of iron, long kept in that position, will be at last penetrated with the magnetic vortex, and must consequently acquire a magnetic force.

In other countries, where the inclination is imperceptible, which is the case near the equator, it is not the vertical, but rather the horizontal position, which renders bars of iron magnetic; for their position must correspond to the magnetic inclination, if you would have them acquire a magnetic force. I speak here only of iron; steel is too hard for the purpose, and means more efficacious must be employed to communicate the magnetic virtue to it.*

10th November 1761.

* Captain Scoresby has lately discovered a method of making artificial magnets, solely from the process of hammering soft steel. He found that a bar of soft steel, 6½ inches long, ¼ of an inch in diameter, and weighing 892 grains, when hammered in a vertical direction, on a surface of metal not ferruginous, acquired, after seventeen blows, a lifting power of 6½ grains. When a similar bar was hammered, with its lower end resting on the top of a small poker, it lifted a nail of 88 grains weight, after twenty-two blows. When the poker had been previously hammered in a vertical position, a single blow gave the bar a lifting power of 20 grains; and in one instance ten blows produced a lifting power of 188 grains. When a single blow was struck upon the bar when held with the other end up, its magnetism was almost entirely destroyed.

These curious results have a most important practical application. Captain Scoresby has shown how we may by this process convert the blade of a penknife, the limb of a pair of scissars, or even a nail, into a compass-needle, which will traverse with great facility, when suspended by a hair or a slender thread. By this means the shipwrecked mariner may guide himself in his boat as accurately as if he had been able to use his compasses.—For farther information on this subject, see the *Edinburgh Transactions*, vol. ix. p. 243; *Philosophical Transactions*, 1822, p. 241; and *Edinburgh Philosophical Journal*, vol. ix. p. 41.—Ed.

LETTER LXV.—ACTION OF LOADSTONES ON IRON: PHENOMENA OBSERVABLE ON PLACING PIECES OF IRON NEAR A LOADSTONE.

THOUGH the whole earth may be considered as a vast loadstone, and as encompassed with a magnetic vortex, which every where directs the magnetic needle, its magnetic power is, however, very feeble, and much less than that of a very small loadstone: this appears very strange, considering the enormous magnitude of the earth.

It arises undoubtedly from our very remote distance from the real magnetic poles of the earth, which, from every appearance, are buried at a great depth below the surface: now, however powerful a loadstone may be, its force is considerable only when it is very near; and as it removes, that force gradually diminishes, and at length disappears. For this reason, the magnetic force acquired in time by masses of iron suitably placed in the earth's vortex is very small, and indeed hardly perceptible, unless it is very soft, and of a figure adapted to the production of a vortex, as has been already remarked.

This effect is much more considerable near a loadstone of moderate size: small masses of iron speedily acquire from it a very perceptible magnetic force—they are likewise attracted toward the loadstone; whereas this effect is imperceptible in the earth's vortex, and consists only in directing magnetic needles, without either attracting them or increasing their weight.

A mass of iron plunged into the vortex of a loadstone likewise presents very curious phenomena, which well deserve a particular explanation. Not only is this mass at first attracted toward the loadstone, but it too attracts other pieces of iron. Let

AB (PLATE V. *Fig.* 13.) be a natural magnet, in the vicinity of which, at the pole B, is placed the mass of iron CD, and it will be found that this last is capable of supporting a bar of iron EF. Apply again to this, at F, an iron ruler GH, in any position whatever, say horizontal, supporting it at H, and it will be found that the ruler is not only attracted by the bar F, but likewise capable of supporting at H, needles as IK, and that these needles again act on filings of iron L, and attract them.

The magnetic force may thus be propagated to very considerable distances, and even made to change its direction, by the different position of these pieces of iron, though it gradually diminishes. You are perfectly sensible, that the more powerful the loadstone AB is of itself, and the nearer to it the first mass CD, the more considerable likewise is the effect. The late *Mr. de Maupertuis* had a large loadstone so powerful, that at the distance even of several feet, the mass of iron CD continued to exert a very considerable force.

In order to explain these phenomena, you have only to consider, that the magnetic matter which escapes rapidly at the pole of the loadstone B, enters into the mass of iron, and disposes the pores of it to form magnetic canals, which it afterwards freely pervades. In like manner, on entering into the bar, it will there too form magnetic canals—and so on. And as the magnetic matter, on issuing from one body, enters into another, these two bodies must undergo a mutual attraction, for the same reason, as I have before proved, that two loadstones, which present their friendly poles to each other, must be attracted; and as often as we observe an attraction between two pieces of iron, we may with certainty conclude, that the magnetic matter which issues from the one is entering into the other, from the continual motion with which it penetrates these bodies. It is thus that, in the preceding disposition of the bars of iron, the magnetic matter in its motion pervades all of them; and this is the only reason of their mutual attraction.

The same phenomena still present themselves on turning the other pole A of the loadstone, by which the magnetic matter enters, toward the mass of iron. The motion in this case becomes retrograde, and preserves the same course; for the magnetic matter contained in the mass of iron will then escape from it, to pass rapidly into the loadstone, and in making its escape will employ the same efforts to arrange the pores in the mass suitably to the current, as if it were rapidly entering into the iron. To this end, therefore, the iron must be sufficiently soft, and these pores pliant, to obey the efforts of the magnetic matter. A difficulty will no doubt here occur to you; it will be asked, How do you account for the change of direction of the magnetic matter, on entering into another bar of iron; and why is that direction regulated according to the length of the bars, as its course is represented in the figure? This is a very important article in the theory of magnetism, and it proves how much the figure of the pieces of iron contributes to the production of the magnetic phenomena.

To elucidate this, it must be recollected, that this subtile matter moves with the utmost ease in the magnetic pores, where it is separated from the ether; and that it encounters very considerable obstacles, when it escapes from them, with all its velocity, to re-enter into the ether and the air.

Let us suppose that the magnetic matter, after having pervaded the bar CD (*Fig.* 14. PLATE V.), enters into the iron ruler EF, placed perpendicularly. It would certainly, on its first admission, preserve

the same direction, in order to escape at *m*, unless it found an easier road in which to continue its motion: but meeting at *m* the greatest obstruction, it at first changes its direction, though in a very small degree, toward F, where finding pores adapted to the continuation of its motion, it will deviate more and more from its first direction, and travel through the ruler EF in all its length; and, as if the magnetic matter were loth to leave the iron, it endeavours to continue its motion there as long as possible, availing itself of the length of the ruler; but if the ruler were very short, it would undoubtedly escape at *m*. But the length of the ruler presenting it a space to run through, it follows the direction EF, till it is under the necessity of escaping at F, where all the magnetic canals, formed according to the same direction, no longer permit the subtile magnetic matter to change its direction, and return along the ruler; these canals being not only filled with succeeding matter, but, from their very nature, incapable of receiving motion in an opposite direction.

14th November 1761.

LETTER LXVI.—ARMING OF LOADSTONES.

YOU have just seen how iron may receive the magnetic current of a loadstone, convey it to considerable distances, and even change its direction. To unite a loadstone, therefore, to pieces of iron, is much the same with increasing its size, as the iron acquires the same nature with respect to the magnetic matter; and it being farther possible by such means to change the direction of the magnetic current, as the poles are the places where this matter enters the loadstone and escapes, we are enabled to conduct the poles at pleasure.

On this principle is founded the arming, or mounting, of loadstones—a subject well worthy of your attention, as loadstones are thus brought to a higher degree of strength.

Loadstones, on being taken from the mine, are usually reduced to the figure of a parallelopiped, or rectangular parallelogram, with thickness as AA, BB, (*Fig.* 15. Plate V.), of which the surface AA is the pole by which the magnetic matter enters, and BB that by which it escapes. It is filled, then, the whole length AB with canals *a b*, which the magnetic matter, impelled by the elastic power of the ether, freely pervades with the utmost rapidity, and without any mixture of that fluid. Let us now see in what manner such a loadstone is usually armed.

To each surface, AA and BB (Plate V. *Fig.* 16.), the two poles of the loadstone, are applied plates of iron *a a* and *b b*, terminating below in the knobs 𝔄 and 𝔅, called the feet; this is what we denominate the *armour* of the loadstone, and when this is done, the loadstone is said to be armed. In this state, the magnetic matter which would have escaped at the surface BB, passes into the iron plate *b b*, where the difficulty of flying off into the air, in its own direction, obliges it to take a different one, and to flow along the plate *b b* into the foot 𝔅, and there it is under the necessity of escaping, as it no longer finds iron to assist the continuation of its motion. The same thing takes place on the other side; the subtile matter will be there conducted through the foot 𝔄, from which it will pass into the plate *a a*, changing its direction to enter into the loadstone, and to fly through its magnetic canals. For the subtile matter contained in the plate enters first into the loadstone; it is followed by that which is the foot 𝔄, replaced in its turn by the external magnetic matter,

which being there impelled by the elasticity of the ether, penetrates the foot 𝔄 and the plate *a a* with a rapidity whose vehemence is capable of arranging the poles, and of forming magnetic canals.

Hence it is evident that the motion must be the same on both sides, with this difference, that the magnetic matter will enter by the foot 𝔄, and escape by the foot 𝔅, so that in these two feet we now find the poles of the armed loadstone; and as the poles formerly diffused over the surfaces AA and BB are now collected on the bases of the feet 𝔄 and 𝔅, it is naturally to be supposed that the magnetic force must be considerably greater in these new poles.

In this state, accordingly, the vortex will be more easily formed. The matter escaping from the foot 𝔅 will, with the utmost facility, return to the foot 𝔄, passing through C; and the rest of the body of the loadstone will not be encompassed by any vortex, unless perhaps a small quantity of magnetic matter should escape from the plate *b b*, from its not being able to change the direction so suddenly; and unless a small quantity should find admission by the plate *a a*, which in that case might produce a feeble vortex, whereby the subtile matter would be immediately conducted from the plate *b b* to *a a*; however, if the armour be well fitted, this second vortex will be almost imperceptible, and consequently the current between the feet is so much the stronger.

The principal direction for arming loadstones, is carefully to polish both surfaces of the loadstone A A and B B, as well as the plates of iron, so that on applying them to the loadstone, they may exactly touch it in every point, the subtile matter passing easily from the loadstone to the iron, when unobstructed by any intervening matter; but if there be a vacuum, or a body of air, between the loadstone and the plates, the magnetic matter will lose almost all its motion, its current will be interrupted, and rendered incapable of forcing its passage through the iron, by forming magnetic canals in it.

The softest and most ductile iron is to be preferred for the construction of such armour, because its pores are pliant, and easily arrange themselves in conformity to the current of the magnetic matter. Iron of this description, accordingly, appears well adapted to the production of a sudden change in the direction of the current: the magnetic matter, too, seems to affect a progress in that direction as long as possible, and does not quit it till the continuance of its motion through that medium is no longer practicable: it prefers making a circuit to a premature departure—a thing that does not take place in the loadstone itself, in which the magnetic canals are already formed, nor in steel, whose pores do not so easily yield to the efforts of a magnetic current. But when these canals are once formed in steel, they are not so easily deranged, and much longer retain their magnetic force; whereas soft iron, whatever force it may have exerted during its junction with a loadstone, loses it almost entirely on being disjoined.

Experience must be consulted as to the other circumstances of arming loadstones. Respecting the plates, it has been found, that a thickness either too great or too small is injurious; but for the most part, the best adapted plates are very thin, which would appear strange, did we not know that the magnetic matter is much more subtile than ether, and that consequently the thinnest plate is sufficient to receive a very great quantity of it.

17th November 1761.

Letter LXVII.—Action and force of armed Loadstones.

At the feet of its armour, then, a loadstone exerts its greatest force, because there its poles are collected; and each foot is capable of supporting a weight of iron, greater or less in proportion to the excellency of the loadstone.

Thus a loadstone AA, BB (Plate V. *Fig.* 17.), armed with plates of iron *a a* and *b b*, terminating in the feet 𝔄 and 𝔅, will support by the foot 𝔄 not only the iron ruler CD, but this last will support another of smaller size EF, this again another still smaller GH, which will in its turn support a needle IK, which, finally, will attract filings of iron L; because the magnetic matter runs through all these pieces to enter at the pole 𝔄; or if it were the other pole, by which the magnetic matter issues from the loadstone, it would in like manner run through the pieces CD, EF, GH, IK. Now, as often as the matter is transmitted from one piece to another, an attraction between the two pieces is observable; or rather they are impelled toward each other by the surrounding ether, because the current of the magnetic matter between them diminishes the pressure of that fluid.

When one of the poles of the loadstone is thus loaded, its vortex undergoes a very remarkable change of direction; for as, without this weight, the magnetic matter which issues from the pole 𝔅, directing around its course, would flow toward the other pole 𝔄; and as now the entrance into this pole is sufficiently supplied by the pieces which it supports, the matter issuing from the pole 𝔅 must take quite a different road, which will at length conduct it to the last piece IK. A portion of it will undoubtedly be likewise conveyed toward the last but one GH, and toward those which precede it, as those which follow, being smaller, do not supply in sufficient abundance those which go before; but the vortex will always extend to the last piece. By these means, if the pieces are well proportioned to each other in length and thickness, the loadstone is capable of supporting much more than if it were loaded with a single piece, in which the figure likewise enters principally into consideration. But in order to make it sustain the greatest possible weight, we must contrive to unite the force of both poles.

For this purpose, there is applied to the two poles 𝔄 and 𝔅 (Plate V. *Fig.* 20.), a piece of soft iron CD, touching the base of the feet in all points, and whose figure is such, that the magnetic matter which issues from 𝔅 shall find in it the most commodious passage to re-enter at the other extremity 𝔄. Such a piece of iron is called the supporter of the loadstone; and as the magnetic matter enters into it on issuing from the loadstone at 𝔅, and enters into the other pole 𝔄 on issuing from the supporter, the iron will be attracted to both poles at once, and consequently adhere to them with great force. In order to know how much power the loadstone exerts, there is affixed to the supporter, at the middle F, a weight P, which is increased till the loadstone is no longer capable of sustaining it; and then that weight is said to counterbalance the magnetic power of the loadstone: this is what you are to understand when told that such a loadstone carries ten pounds weight, such another thirty, and so on. Mahomet's coffin, they pretend, is supported by the force of a loadstone—a thing by no means impossible, as artificial magnets have already been constructed which carry more than 100 pounds weight.

A loadstone armed with its supporter loses nothing of the magnetic matter, which performs its complete vortex within the loadstone and the iron, so that

none of it escapes into the air. Since, then, magnetism exerts its power only in so far as the matter escapes from one body to enter into another, a loadstone whose vortex is shut up should no where exert the magnetic power; nevertheless, when it is touched on the plate at *a* with the point of a needle, a very powerful attraction is perceptible, because the magnetic matter being obliged suddenly to change its direction, in order to enter into the canals of the loadstone, finds a more commodious passage by running through the needle, which will consequently be attracted to the plate *a a*. But by that very thing the vortex will be deranged inwardly; it will not flow so copiously into the feet; and if you were to apply several needles to the plate, or iron rulers still more powerful, the current toward the feet would be entirely diverted, and the force which attracts the supporter would altogether disappear, so that it would drop off without effort. Hence it is evident that the feet lose their magnetic power in proportion as the loadstone exercises its force in other places; and thus we are enabled to account for a variety of very surprising phenomena, which, without the theory, would be absolutely inexplicable.

This is the proper place for introducing the experiment which demonstrates, that after having applied its supporter to an armed loadstone, you may go on from day to day increasing the weight which it is able to sustain, till it at length shall exceed the double of what it carried at first. It is necessary to show, therefore, how the magnetic force may in time be increased in the feet of the armour. The case above described, of the derangement of the vortex, assures us, that at the moment when the supporter is applied, the current of the magnetic matter is still abundantly irregular, that a considerable part of it is still escaping by the plate *b b*, and that it will require time to form magnetic canals in the iron: it is likewise probable that, when the current shall have become more free, new canals may be formed in the loadstone itself, considering that it contains, beside these fixed canals, moveable poles, as iron does. But on violently separating the supporter from the loadstone, the current being disturbed, and these new canals in a great measure destroyed, the force is suddenly rendered as small as at the beginning; and some time must intervene before these canals, with the vortex, can recover their preceding state. I once constructed an artificial magnet, which at first could support only ten pounds weight; and, after some time, I was surprised to find that it could support more than thirty. It is remarked, chiefly in artificial magnets, that time alone strengthens them considerably; but that this increase of force lasts only till the supporter is separated from it.

21st November 1761.

LETTER LXVIII.—THE METHOD OF COMMUNICATING TO STEEL THE MAGNETIC FORCE, AND OF MAGNETIZING NEEDLES FOR THE COMPASS: THE SIMPLE TOUCH, ITS DEFECTS; MEANS OF REMEDYING THESE.

HAVING explained the nature of magnets in general, an article as curious as interesting still remains, namely, the manner of communicating to iron, but especially to steel, the magnetic power, and even the highest degree possible of that power.

You have seen that, by placing iron in the vortex of a loadstone, it acquires a magnetic force, but which almost totally disappears as soon as it is removed out of the vortex; and that the vortex of the earth alone is capable, in time, of impressing a slight magnetic power upon iron; now, steel being harder than

iron, and almost entirely insensible to this action of the magnetic vortex, more powerful operations must be employed to magnetize it; but then it retains the magnetic force much longer.

For this purpose we must have recourse to touching, and even to friction. I begin, therefore, with explaining the method formerly employed for magnetizing the needles of compasses; the whole operation consisted in rubbing them at the pole with a a good loadstone, whether naked or armed.

The needle *a b c* (PLATE V. *Fig.* 18.) was laid on a table; the pole B of the loadstone was drawn over it, from *b* toward *a*, and, being arrived at the extremity *a*, the loadstone was raised aloft, and brought back through the air to *b*; this operation was repeated several times together, particular care being taken that the other pole of the loadstone should not come near the needle, as this would have disturbed the whole process. Having several times drawn the pole B of the loadstone over the needle, from *b* to *a*, the needle had become magnetic, and the extremity *b* of the same name with that of the loadstone with which it had been rubbed. In order to render the extremity *b* the north pole, it would have been necessary to rub with the pole of this name in the loadstone, proceeding from *b* to *a*; but in rubbing with the south pole, the progress must be from *a* to *b*.

This method of rubbing, or touching, is denominated *the simple touch*, because the operation is performed by touching with one pole only; but it is extremely defective, and communicates but very little power to the needle, let the loadstone be ever so excellent; accordingly, it does not succeed when the steel is carried to the highest degree of hardness, though this be the state best adapted to the retention of magnetism. You will yourself readily discern the defects of this method by *the simple touch*.

Let us suppose that B is the pole of the loadstone from which the magnetic matter issues, as the effect of the two poles is so similar that it is impossible to perceive the slightest difference: having rested the pole on the extremity *b* of the needle, the magnetic matter enters into it with all the rapidity with which it moves in the loadstone, incomparably greater than that of the vortex which is in the external air. But what will become of this matter in the needle? It cannot get out at the extremity *b*, it will therefore make an effort to force its way through the needle toward *a*, and the pole B moving in the same direction, will assist this effort; but as soon as the pole B shall arrive at *a*, the difficulty of escaping at the extremity *a* will occasion a contrary effort, by which the magnetic matter will be impelled from *a* toward *b*; and before the first effect is entirely destroyed, this last cannot take place. Afterwards, when the pole B is again brought back to the extremity *b*, this last effect is again destroyed, but without producing, however, a current in the contrary direction from *b* toward *a*; and consequently, when the pole B shall have got beyond *c* in its progress toward *a*, it will more easily produce a current from *a* to *b*, especially if you press more hard on the half *c a*: hence it is clear, that the needle can have acquired only a small degree of the magnetic power.

Some, accordingly, rub only the half *c a* (Plate V. *Fig.* 18.), proceeding from *c* to *a*, and others touch only the extremity *a* of the needle with the pole B of the loadstone, and with nearly the same success. But it is evident that the magnetic matter which enters by the extremity *a* only, is incapable of acting with sufficient vigour on the pores of the needle, for arranging them conformably to the laws of magnetism; and that the force impressed by this method must be extremely small, if any thing, when the steel is very much hardened.

It appears to me, then, that these defects of *the simple touch* might be remedied in the following manner; of the success of which I entertain no doubt, though I have not yet tried it; but am confirmed in my opinion by experiments which I have made.

I would case the extremity *b* of the needle (Plate V. *Fig.* 19.) in a ruler of soft iron E F; and I should think it proper to make that ruler very thin, and as straight as possible; but the extremity must be exactly applied in all points, and even fitted to a groove perfectly adjusted for its reception. On resting the pole B of the loadstone upon the extremity *b* of the needle, the magnetic matter which enters into it, meeting scarcely any difficulty in its progress through the iron ruler, will at once pursue its course in the direction *b d*; and in proportion as the pole advances toward *a*, the magnetic matter, in order to continue this course, has only to arrange the pores on which it immediately acts; and having reached *a*, all these pores, or at least by far the greater number of them, will be already disposed conformably to that direction. When you afterwards recommence the friction at the extremity *b*, nothing is destroyed; but you continue to perfect the current of the magnetic matter, following the same direction *b d*, by likewise arranging the pores which resisted the first operation; and thus the magnetic canals in the needle will always become more perfect. A few strokes of the pole B will be sufficient for the purpose, provided the loadstone is not too weak; and I have no doubt that the best tempered steel, that is, rendered as hard as possible, would yield to this method of operating; an unspeakable advantage in the construction of compasses, as it has been found that ordinary needles frequently lose, by a slight accident, all their magnetic power; by which ships at sea would be exposed to the greatest dangers, if they had not others in reserve.

But when needles are made of well tempered steel, accidents of this kind are not so much to be apprehended; for if a greater force is requisite to render them magnetic, in return they preserve the power more tenaciously.

24th November 1761.

Letter LXIX.—On the Double Touch. Means of preserving the Magnetic Matter in Magnetized Bars.

Instead of this method of magnetizing iron or steel by *the simple touch*, by rubbing with one pole only of the loadstone, we now employ *the double touch*, in which we rub with both poles at once, which is easily done by means of an armed loadstone.

Let E F (Plate V. *Fig.* 23.) be a bar of iron or steel, which you wish to render magnetic. Having fixed it steadily on a table, you press upon it the two feet A and B of an armed loadstone. In this state, you will easily see that the magnetic matter which issues from the loadstone by the foot B, must penetrate into the bar, and would diffuse itself in all directions, did not the foot A, on its side, attract the magnetic matter contained in the pores of the bar. This evacuation, therefore, at *d*, will determine the matter which enters by the pole B to take its course from *c* toward *d*, provided the poles A and B are not too remote from each other. Then the magnetic current will force its way in the bar, in order to pass from the pole B to the pole A, disposing its pores to form magnetic canals; and it is very easy to discover whether this is taking place; you have only to observe if the loadstone is powerfully attracted to the bar, which never fails if the

bar is of soft iron, as the magnetic matter easily penetrates it. But if the bar is of steel, the attraction is frequently very small—a proof that the magnetic matter is incapable of opening for itself a passage from *c* to *d*; hence it is to be concluded that the loadstone is too feeble, or that the distance between its two poles is too great: in this case it would be necessary to employ a loadstone more powerful, or whose feet are nearer; or finally, the armour of the loadstone ought to be changed into the form represented in Plate V. *Fig.* 22.

But the following is a method of remedying this inconvenience.

Having fixed the bar as in *c d* (Plate V. *Fig.* 23.), the loadstone must be several times drawn backward and forward over it, from one extremity to the other, without taking it off, till you perceive that the attraction no longer increases; for it is undoubtedly certain, that attraction is increased in proportion to the increase of the magnetic force. The bar E F will be magnetized by this operation in such a manner, that the extremity E, toward which the pole A was turned, will be the friendly pole of A, and consequently of the same name with the other pole B. Again, on removing the loadstone, as magnetic canals are formed the whole length of the bar, the magnetic matter diffused through the air will force a passage through these canals, and will make the bar a real magnet. It will enter by the extremity *a*, and escape by the extremity *b*, from whence a part, at least, will return to *a*, and will form a vortex such as the nature of the bar permits.

I take this occasion to remark, that the formation of a vortex is absolutely necessary to the increase of magnetism; for if all the magnetic matter which goes out at the extremity *b* were to fly off, and be entirely dispersed, without returning to *a*, the air would not supply a sufficient quantity to the other extremity *a*, which must occasion a diminution of the magnetic force. But if a considerable part of that which escapes at the extremity *b* returns to *a*, the air is abundantly able to supply the remainder, and perhaps still more, if the magnetic canals of the bar are capable of receiving it; the bar will therefore in that case acquire a much greater magnetic force.

This consideration leads me to explain how it is possible to keep up the magnetic matter in magnetized bars. The object being to prevent the magnetic matter which pervades them from dispersing in the air, these bars are always disposed in *pairs* of exactly the same size. They are placed on a table, in a parallel situation, so that the friendly poles, or those of different names, should be turned to the same side as in Fig. 24, where M M and N N represent the two bars, whose friendly poles *a*, *b*, *b*, *a*, are turned the same way. To prevent mistake, a mark × is made on each bar, at the extremity where the north pole is, and to both ends is applied a piece of soft iron E E and F F, for receiving the magnetic current. In this manner, the whole magnetic matter which pervades the bar M M, and which issues at the extremity *b*, passes into the piece of iron E E, where it easily makes its way, to enter at the extremity *a* of the other bar N N, from which it will escape at the extremity *b*, into the other piece of iron F F, which reconveys it into the first bar M M by the extremity *a*. Thus the magnetic matter will continue to circulate, and no part of it escape; and even in case there should not be at first a sufficient quantity to supply the vortex, the air will supply the deficiency, and the vortex will preserve all its force in the two bars.

This disposition of the two bars may likewise be employed for magnetizing both of them at once.

The two poles of a loadstone must be drawn over the two bars, passing from the one to the other by the pieces of iron; and the circuit must be several times performed, carefully observing that the two poles of the loadstone A and B be turned as the figure directs.

This method of magnetizing two bars at once must be much more efficacious than the preceding, as from the very first circuit performed by the loadstone, the magnetic matter will begin to flow through the two bars by means of the two pieces of iron. Afterwards, by repeated circuitous applications of the loadstone to the bars, a greater quantity of pores will be arranged in them conformably to magnetism, and more magnetic canals will be opened, by which the vortex will be more and more strengthened, without undergoing any diminution. If the bars are thick, it would be proper to turn and rub them in the same manner on the other surfaces, in order that the magnetic action may penetrate them thoroughly.

Having obtained these magnetic bars M M, N N, (Plate V. *Fig.* 26.) they may be employed in place of the natural loadstone, for magnetizing others. They are joined together at the top, so that the two friendly poles *a*, *b* may touch each other; and the other two poles below, *b* and *a*, are separated as far as it is thought proper. Then we rub with the two under extremities, which supply the place of the two poles of a loadstone, two other bars E F, in the manner which I have above explained.

As these two bars are joined in the form of compasses, we have the advantage of opening the lower extremities as much or as little as we please, which cannot be done with a loadstone; and the magnetic current will easily pass at top, where the bars touch each other, from the one to the other. A small piece of soft iron P might likewise be applied there, the better to keep up the current; and in this manner you may easily and speedily magnetize as many double bars as you please.

28th November 1761.

Letter LXX.—The method of communicating to bars of Steel a very great magnetic force, by means of other bars which have it in a very inferior degree.

Though this method of magnetizing by *the double touch* be preferable to the preceding, the magnetic power, however, cannot be carried beyond a certain degree. Whether we employ a natural loadstone, or two magnetic bars, for rubbing other bars, these last will never acquire so much force as the first; it being impossible that the effect should be greater than the cause.

If the bars with which we rub have little force, those which are rubbed will have still less: the reason is evident; for as bars destitute of magnetic force never could produce it in others, so a moderate degree of force is incapable of producing one greater than itself, at least by the method which I have been describing.

But this rule is not to be taken in the strict interpretation of the words, as if it were literally impossible to produce a greater magnetic force by the assistance of a smaller. I am going to point out a method by which the magnetic power may be increased almost as far as you please, beginning with the smallest degree possible. This is a late discovery, which merits so much the more attention that it throws much light on a very difficult subject—the nature of magnetism.

Supposing that I am possessed of a very feeble loadstone, or, for want of a natural magnet, of bars of iron rendered somewhat magnetic merely by the vortex of the earth, as I explained it in a preceding letter, I then provide myself with eight bars of steel, very small, and not hardened, in order the more easily to receive the small degree of magnetic power which the feeble loadstone, or slightly magnetized bars, are capable of communicating, by rubbing each pair or couple in the manner I formerly described. Having then eight bars, magnetic, but in a very small degree, I take two pair, which I join together in the manner represented in *Fig.* 26.

By uniting the two bars by the poles of the same name, I form but one of double the thickness, and with which I form the compass A C and B D; the better to keep up the magnetic current, a piece of soft iron P may be applied at the top C D. The legs of the compass may be separated as far as is judged proper, and I rub with them, one after the other, the remaining bars, which will thereby acquire more power than they had before, because the powers of the first are now united. I have now only to join these two pair newly rubbed in the same manner, and by rubbing with them, one after the other, the two pair first employed, and the power of these will be considerably increased. I afterwards join these two pair together, and go on rubbing others, in order to augment their magnetic force, and still two pair with two pair alternately; and by repeating this operation, the magnetic power may be carried to such a degree as to become insusceptible of farther increase, even by continuing the operation. When we have more than four pair of such bars, instead of two pair, three may be joined together for the purpose of rubbing others; they will thereby be sooner carried to the highest degree possible.