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 it's 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 it's 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 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.

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.

roneous. 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 correſponded 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 juſt medium, 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 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

ſelf 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

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 enquiries 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, contrived 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 needles.

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 it's north pole, and that which points ſouthward it's 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, it's 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.

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 II. 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

exerciſed it's 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. It's 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, wherefore 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 is ſometimes 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 decli-

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nation 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 it's 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.

20th October, 1761.

LETTER LIX.

Elucidations reſpecting the Cauſe and Variation of the Declination of Magnetic Needles.

THOSE who allege that the earth contains in it's 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 it's ſituation. It muſt in that caſe be detached from the earth in all it's parts; and as it's 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 it's 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 it's 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 it's 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 were no doubt 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 natural, 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.

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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 nut within the earth, why ſhould one of it's poles be preciſely oppoſite to the other? This nut 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

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 ſatisfying 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 it's juſt place is aſſigned to each. It appears to me that, from this reflection, we are much more advanced in our knowledge of magnetiſm.

24th October, 1761.

LETTER LX.

Inclination 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 it's northern extremity ſinks, as if it had become heavier, which obliges us to diminiſh it's 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 ſhew you afterwards, that this direction to 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 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 de (*plate II. fig.* 5.) be the horizontal line, drawn according to the magnetic declination, and the needle will aſſume, at Berlin, the ſituation ba, which makes with the horizon de the angle dcb or eca, which is 72°, and conſequently, with the vertical fg, an angle bcg or acf 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*, which deſerves, as well as the declination, to be every where obſerved with all poſſible care, as we find in it a ſimilar variety.

The inclination at Berlin has been found 72°, at Bâle 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 pole itſelf, the needle would there actually aſſume a vertical ſituation, it's 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.

It were devoutly to be wiſhed that experiments had been as carefully, and as generally made, in 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.

It is not however a matter of ſurprize; 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 Bâle, 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 theſe 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 enquiries, they have put no great value on Mr. *Diterich*'s machine, though the only one adapted to the deſign. This inſtance demonſtrates how the progreſs of ſcience may be obſtructed by prejudice; hence Berlin and Bâle 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 it's 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

dantly 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 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 Bâle. His inſtrument is called the *inclinatory*, but there is little appearance of it's coming into general uſe.* It is ſtill leſs to be expected that we ſhould ſoon have charts conſtructed on 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 at 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 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

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* Since this was written, on occaſion of the late tranſit of Venus over the ſun's diſk, Meſſrs. Mallet and Pictet of Geneva, employed to obſerve that tranſit in Lapland, made uſe of the *inclinatory*, and found, in the month of May, 1769, the magnetic inclination firſt at Peterſburg to be 73° 40′; afterwards at Kola in Lapland 77° 45′; at Oumba 75° 10′; and at Panoi 76° 30′.

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, *plate II.* 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 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 it's continual motion round the loadſtone, a vortex which re-conducts 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 quality of 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 continually iſſuing, then, 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.

In order to a thorough inveſtigation of the nature of this ſubtile matter, and it's motion, it muſt be remarked, that it's 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 on a needle, the action is perfectly the ſame whether another body interpoſes or not, provided the interpoſing body is not iron, and it's 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, 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 it's admiſſion, the other to it's 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 it's rapidity, without encountering any obſtacle.

31ſt October, 1761.

LETTER LXII.

Nature of the Magnetic Matter, and of it's 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 a too great, or too ſmall, 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 loadſtone and iron have pores ſo ſmall that the ether in a body connot force it's 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 it's pores particles of air, which are frequently ſeen diſcharging themſelves in the form of ſmall bubbles: air again, it is equally certain, contains in it's 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 it's turn, others ſtill more ſubtile, at leaſt this is not impoſſible.

Having ſettled this magnetic matter, let us ſee how it's 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

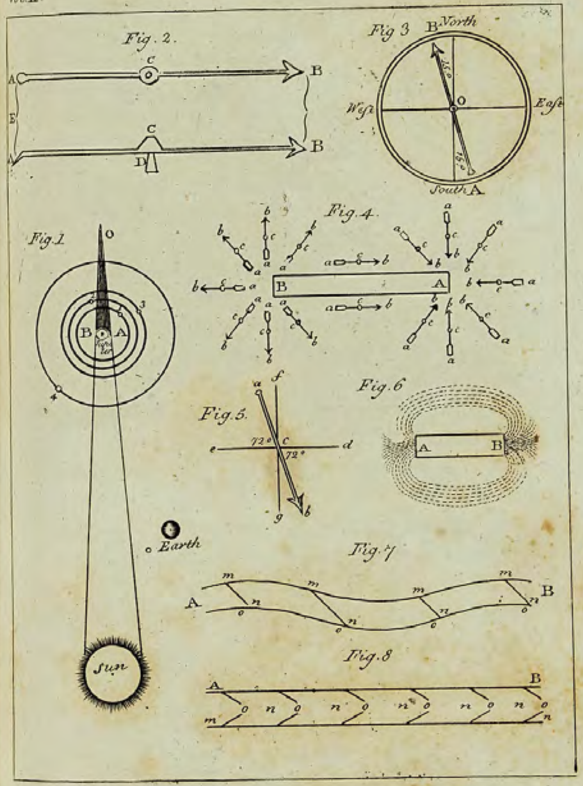
only in one direction, without the poſſibility of returning in an oppoſite direction. This moſt eſſential circumſtance requires a more particular elucidation.

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 II.* by the ſtrokes *m n*, whoſe office it is to grant, by raiſing themſelves, a free paſſage to the blood when it flows from A to B, and to prevent it's 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 II.* 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 it's 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



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 LXIII.

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 a deſcription.

Figure 1. *plate III.* 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 it's motion in the ſame direction; and not only will the motion be retarded, but it's 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, eſcaped 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 it's motion, ſo that it's 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 it's poles; and that the magnetic poles of a loadſtone

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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 *figure* 6, *plate II.* where the whole ſurfaces A and B are the two poles.

Now, as 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 it 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 (*plate III. fig.* 2.) that the two loadſtones A B and *a b* 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

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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* 3, *plate III.* 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 it's 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 principal phenomenon in magnetiſm, in

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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. Manner 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 it's return in the contrary direction, you can no longer doubt that they are the continuation of thoſe pores, (*fig.* 8, *plate II.*) 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,

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 it's own direction; 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, there diſpoſes 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, the longer they will be 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 III. fig.* 4.) in the vortex of the loadſtone A B, ſo that it's 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 it's own vortex,

tex, and preſerve it's magnetic power, as long as it's 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 it's 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 afterward.

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 ſhew the true direction. If then a bar of iron remain long in that poſition, there is no reaſon to be ſurprized, 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.

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, it's 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

tance 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, it's 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 III. fig.* 5.) 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 at 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 it's 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 afterward 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 it's 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 it's 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 it's 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

and that it encounters very conſiderable obſtacles, when it eſcapes from them, with all it's velocity, to re-enter into the ether and the air.

Let us ſuppoſe that the magnetic matter, after having pervaded the bar CD, (*fig. 6. plate III.*) enters into the iron ruler EF, placed perpendicularly. It would certainly, on it's firſt admiſſion, preſerve the ſame direction, in order to eſcape at *m*, unleſs it found an eaſier road in which to continue it's motion: but meeting at *m* the greateſt obſtruction, it at firſt changes it's direction, though in a very ſmall degree, toward F, where finding pores adapted to the continuation of it's motion, it will deviate more and more from it's firſt direction, and travel through the ruler EF in all it's length; and, as if the magnetic matter were loth to leave the iron, it endeavours to continue it's 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 it's 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 it's direction. To unite a loadſtone, therefore, to pieces of iron, is much the ſame with increaſing it's 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 thereby carried 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. 7. plate III.*) 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 *ab*, which the magnetic matter, impelled by the elaſtic power of the ether, freely pervades in the utmoſt rapidity, without any mixture of that fluid. Let us now ſee in what manner ſuch a loadſtone is uſually armed.

To

To each ſurface AA and BB, (*plate III. fig. 8.*) the two poles of the loadſtone, are applied plates of iron *aa* and *bb*, 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 *bb*, where the difficulty of flying off into the air, in it's own direction, obliges it to take a different one, and to flow along the plate *bb* into the foot 𝔅, and there it is under the neceſſity of eſcaping, as it no longer finds iron to aſſiſt the continuation of it's 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 *aa*, changing it's direction to enter into the loadſtone, and to fly through it's 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 it's turn by the external magnetic matter, which being there impelled by the elaſticity of the ether, penetrates the foot 𝔄 and the plate *aa* 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

now collected in 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 it's 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 AA and BB, 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 intervenient 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 it's motion, it's current will be interrupted, and rendered incapable of forcing it's 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 it's pores are pliant, and eaſily arrange themſelves in conformity to the current of the magnetic matter: iron of this deſcription, accordingly, appears much 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 quits it not, till the continuance of it's 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 it's 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 it's armour, then, a loadſtone exerts it's greateſt force, becauſe there it's 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 III. fig.* 9.) 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 it's 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, it's vortex undergoes a very remarkable change of direction; for as, without this weight, the magnetic

matter which iſſues from the pole 𝔅, directing around it's 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 IV. fig.* 1.) a piece of ſoft iron CD, touching the baſes 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

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 it's ſupporter loſes nothing of the magnetic matter, which performs it's complete vortex within the loadſtone and the iron, ſo that none of it eſcapes into the air. Since, then, magnetiſm exerts it's 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 it's 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 it's force in other places, and thus we are enabled to account for a variety of very ſurprizing phenomena, which, without the theory, would be abſolutely inexplicable.

This is the proper place for introducing the experiment which demonſtrates, that after having applied it's 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 ſhew, 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 force 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 thoſe 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,

nals, with the vortex, can recover their preceding ſtate. I once conſtructed an artificial magnet, which at firſt could ſupport only ten pound weight, and, after ſome time, I was ſurprized 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 Manner of communicating to Steel the Magnetic Force, and of magnetizing Needles for the Compaſs: the Simple Touch, *it's 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 good loadſtone, whether naked or armed.

The needle *a b c (plate IV. fig.* 2.) 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

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 it's 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 it's 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 III. fig.* 10.) 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 vigor 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.

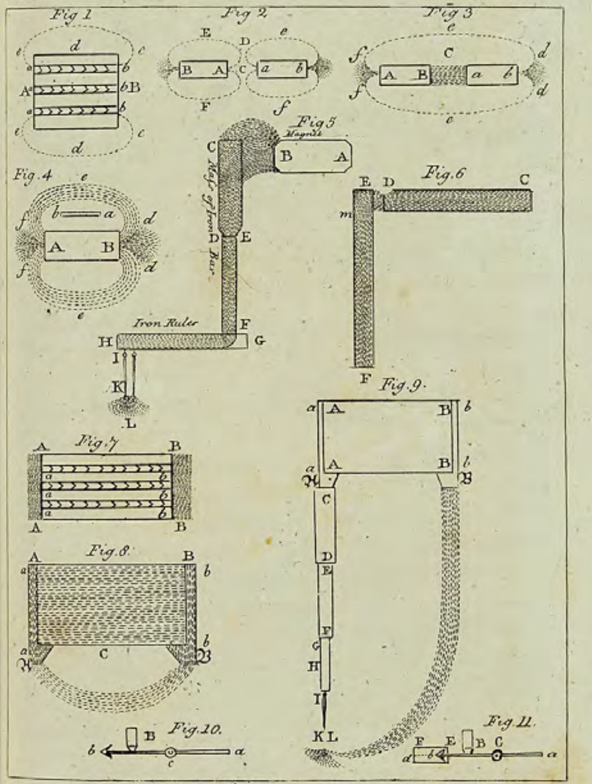
It appears to me, then, that theſe defects of *the ſimple touch* might be remedied in the following manner; of the ſucceſs of which I entertain no doubt, though I have not yet tried it, but am confirmed in my opinion by experiments which I have made.

I would caſe the extremity *b* of the needle, (*plate III. fig.* 11.) 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 it's 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 it's progreſs through the iron ruler, will at once purſue it's courſe in the direction *b d*; and in proportion as the pole advances toward *a*, the magnetic matter, in order to continue this

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 part of them, will be already diſpoſed conformably to that direction. When you afterwards re-commence 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



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 IV. fig.* 4.*)* 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 it's 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 it's courſe from *c* toward *d*, provided the poles A and B are not too remote from each other. Then the magnetic current will force it's way in the bar, in order to paſs from the pole B to the pole A, diſpoſing it's 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 it's 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 IV. fig.* 3,

But here is a method for remedying this inconvenience.

Having diſpoſed, at ſmall intervals *c d (plate IV. fig.* 4.) the powers conformably to magnetiſm, the loadſtone muſt be ſeveral times drawn backward and forward over the bar, 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.* 5.

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 it's 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 re-conveys 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 it's 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 IV. fig.* 6.) they may be employed, in place of the natural loadſtone, for magnetizing others. They are joined together a-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 a-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 me 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, *plate IV. fig.* 7.

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.

The greateſt obſtacles are, therefore, ſurmounted, and, by means of ſuch bars joined together by two or more pairs, we may rub others of ſteel properly hardened, and which may be either of the ſame ſize, or ſtill greater than the firſt, to which the greateſt power of which they are ſuſceptible may be thus communicated.

Beginning with ſmall bars ſuch as I have deſcribed, theſe operations may be ſucceſſively applied to bars of an enormous ſize, and made of the hardeſt ſteel, which is leſs liable to loſe the magnetic power. Only it is to be obſerved, that for the purpoſe of rubbing large bars, ſeveral pairs ought to be joined together, whoſe united weight ſhould be at leaſt double that of the large one. But it would always be better to proceed by degrees, and to rub each ſpecies of bars with bars not much ſmaller than themſelves, or it may be ſufficient to join at moſt two pair: for when we are obliged to join more than two pair, the extremities with which the friction is performed will extend too far, and the magnetic matter, which paſſes that way, will itſelf prevent it's being directed conformably to the direction of the bar that is rubbed; and the rather, that it enters the bar perpendicularly, whereas it neceſſarily ſhould take a horizontal direction.

In

In order to facilitate this change of direction, it is proper that the magnetic matter ſhould be led to it in a ſmall ſpace, and in a direction already approaching to that which it ought to take within the bar which we are going to rub. The following method, I think, might be effectual for this purpoſe.

Plate IV. fig. 8. repreſents five pair of bars M M, N N, joined together, but not in the form of a compaſs. There is at top a bar of ſoft iron C D, to keep up the vortex; below, I do not rub immediately with the extremities of the bars, but I caſe theſe extremities on each ſide in a foot of ſoft iron, faſtening them to it with ſcrews marked O. Each foot is bent at A and B, ſo that the direction of the magnetic matter, which freely pervades theſe feet, already has a conſiderable approximation to the horizontal, ſo that in the bar to be rubbed E F it has no need greatly to change it's direction. I have no doubt that, by means of theſe feet, the bar E F will receive a much greater magnetic power, than if we rubbed immediately by the extremities of the bars, the depth of whoſe vertical direction naturally oppoſes the formation of horizontal magnetic canals in the bar E F. It is likewiſe poſſible, in practiſing this method, to contract or extend the diſtance of the feet A and B, at pleaſure.

I muſt farther obſerve, that when theſe bars loſe, in time, their magnetic power, it is eaſily reſtored by the ſame operation.

1ſt December, 1761.

LETTER

LETTER LXXI.

Conſtruction of artificial Magnets in Form of a Horſe Shoe.

WHOEVER wiſhes to make experiments on the properties of the loadſtone, ought to be provided with a great number of magnetic bars, from a very ſmall, up to a very large ſize. Each may be conſidered as a particular magnet, having it's two poles, the one north and the other ſouth.

You muſt have conſidered it as extremely remarkable, that by the interpoſition of the magnetic power, the feebleſt which can be ſupplied by a wretched natural loadſtone, or by a pair of tongs in the chimney corner, which have acquired by length of time a ſmall portion of magnetiſm, we ſhould be enabled to increaſe that power to ſuch a degree, as to communicate to the largeſt bars of ſteel, the higheſt degree of magnetic force of which they are ſuſceptible. It would be needleſs to add that, by this method, we are enabled to conſtruct the beſt magnetic needles, not only much larger than the common, but made of a ſteel hardened to the higheſt degree, which renders them more durable. I have only a few words to add on the conſtruction of artificial magnets, which have uſually the form of a horſe-ſhoe, as you muſt no doubt have ſeen.

Theſe artificial magnets anſwer the ſame purpoſes, on every occaſion, as the natural, with this advantage in their favour, that we can have them much more

powerful, by giving them a ſufficient magnitude. They are made of well-tempered ſteel, and the figure of a horſe-ſhoe ſeems the moſt proper for keeping up the vortex. When the mechanic has finiſhed his work, we communicate to it the greateſt degree of magnetic power of which it is ſuſceptible, by means of the magnetic bars of which I have given a deſcription. It is evident that the greater this magnet is, the larger muſt be the bars we employ; and this is the reaſon why we ſhould be provided with bars of all ſizes.

In order to magnetize a horſe-ſhoe H I G, (*plate IV. fig.* 9.) which ought to be of ſteel well tempered, we place on the table a pair of magnetic bars A C and B D, with their ſupporters of ſoft iron applied on both ſides, but of which the figure repreſents only one E F, the other having been removed to make way gradually for the application of the feet of the horſe-ſhoe, as you ſee. In this ſtate, the magnetic matter, which pervades the bars, will make ſtrong efforts to paſs through the horſe-ſhoe, the poles of the bars being adapted magnetically to thoſe of the horſe-ſhoe; but conſidering the hardneſs of tempered ſteel, it will not be ſufficient to arrange the pores and open for itſelf a paſſage. The ſame means, therefore, muſt be employed to this effect, which were preſcribed for the magnetizing of bars. We take a compaſs formed of another pair of magnetic bars, and rub them in the ſame manner over the horſe-ſhoe; magnetic canals will thereby be opened, and the ſubtile matter of the bars, by pervading it, will form the vortex of that

that fluid. Particular care muſt be taken, in this operation, that the legs of the compaſs, in paſſing over the horſe-ſhoe, do not touch the extremities A and B of the bars; for this would diſturb the current of the magnetic matter, which would paſs immediately from the bars into the legs of the compaſs; or, the vortices of the bars and of the compaſs would mutually derange each other.

The horſe-ſhoe will thereby acquire very great power, being pervaded by an impetuous magnetic current. All that remains to be done, is to detach the bars, without deranging the current. If they are ſeparated violently, the magnetic vortex will be deſtroyed, and the artificial magnet will retain very little power.

The canals being kept up no longer than the magnetic matter pervades them, it muſt be concluded, that the particles which form theſe canals are in a forced ſtate, and that this ſtate ſubſiſts only while the vortex acts; and that as ſoon as it ceaſes, theſe particles, by their elaſticity, will deviate from their forced ſituation, and the magnetic canals will be interrupted and deſtroyed. This we clearly ſee in the caſe of ſoft iron, whoſe pores are quickly arranged, on the approach of a magnetic vortex, but retain ſcarcely any magnetic power, when removed out of the vortex. This proves that the pores of iron are moveable, but endowed with an elaſticity which changes their ſituation, as ſoon as force ceaſes. It requires length of time to fix certain pores in the poſition impreſſed on them by the magnetic force, which takes place chiefly in bars of iron long expoſed to the vortex of the earth. The pores of ſteel are much leſs flexible, and better ſupport the ſtate into which they have been forced; they are, however, liable to ſome derangement, as ſoon as force ceaſes to act on them, but this derangement is leſs in proportion to the hardneſs of the ſteel. For this reaſon, artificial magnets ought to be made of the hardeſt ſteel: were they to be made of iron, they would immediately acquire, on being applied to magnetic bars, a very great degree of power; but the moment you detach them, all that power would diſappear. Great precaution muſt, therefore, be employed, in ſeparating from the bars magnets compoſed of well-tempered ſteel. For this purpoſe, before the ſeparation, you preſs the ſupporter, which is of very ſoft iron, in the direction of the line M N, (*plate IV. fig.* 10.) taking particular care not to touch the bars with it, for this would mar the whole proceſs, and oblige you to repeat the operation. On the application of the ſupporter, a conſiderable portion of the magnetic matter which is circulating in the magnet G H I, will make its way through the ſupporter, and form a ſeparate vortex, which will continue after the magnet is detached from the bars.

Afterwards you preſs the ſupporter ſlowly forward over the legs of the magnet to the extremities, as repreſented in the figure, and in this ſtate permit it to reſt for ſome time, that the vortex may be allowed to ſettle. The ſupporter is likewiſe furniſhed with a weight P, which may be increaſed every day; it being always underſtood, that the ſupporter is to be ſo perfectly adjuſted to the feet of the magnet, as to touch them in all points.

5th December, 1761.

LETTER LXXI.

On Dioptricks; Inſtruments which that Science ſupplies: of Teleſcopes and Microſcopes. Different Figures given to Glaſſes or Lenſes.

THE wonders of dioptricks will now, I think, furniſh a ſubject worthy of your attention. This ſcience provides us with two kinds of inſtruments compoſed of glaſs, which ſerve to extend our ſphere of viſion, by diſcovering objects which would eſcape the naked eye.

There are two caſes in which the eye needs aſſiſtance: the firſt is, when objects are too diſtant to admit of our ſeeing them diſtinctly; ſuch are the heavenly bodies, reſpecting which the moſt important diſcoveries have been made by means of dioptrical inſtruments. You will pleaſe to recollect what I have ſaid, concerning the ſatellites of Jupiter, which aſſiſt us in the diſcovery of the longitude: they are viſible only with the aid of good teleſcopes, and thoſe of Saturn require teleſcopes of a ſtill better conſtruction.

There are, beſides, on the ſurface of the earth objects very diſtant, which it is impoſſible for us to ſee, and to examine in detail, without the aſſiſtance of teleſcopes, which repreſent them to us in the ſame manner, as if they were near. Theſe dioptrical glaſſes or inſtruments, for viewing diſtant bodies, are denominated by the term we have already employed, *teleſcopes* or perſpectives.

The other caſe, in which the eye needs aſſiſtance, is when the object, though ſufficiently near, is too ſmall to admit of a diſtinct examination of it's parts. If we wiſhed, for example, to diſcover all the parts of the leg of a fly, or of any inſect ſtill ſmaller: if we were diſpoſed to examine the minuter particles of the human body, ſuch as the ſmalleſt fibres of the muſcles, of the nerves, it would be impoſſible to ſucceed without the help of certain inſtruments called *microſcopes*, which repreſent ſmall objects in the ſame manner as if they were a hundred or a thouſand times greater.

Here then are two kinds of inſtruments, teleſcopes and microſcopes, furniſhed by dioptricks for aſſiſting the weakneſs of our ſight. A few ages only have elapſed ſince theſe inſtruments were invented; and from the era of that invention muſt be dated the moſt important diſcoveries in aſtronomy, by means of the teleſcope, and in phyſics by the microſcope.

Theſe wonderful effects are produced merely by the figure given to bits of glaſs, and the happy combination of two or more glaſſes, which we denominate *lenſes*. Dioptricks is the ſcience that unfolds the principles on which ſuch inſtruments are conſtructed, and the uſes to which they are applied, and you will pleaſe

pleaſe to recollect that it turns chiefly on the direction which rays of light take on paſſing through tranſparent mediums of a different quality; on paſſing, for example, from air into glaſs or water, and reciprocally from glaſs or water into air.

As long as the rays are propagated through the ſame medium, ſay air, they preſerve the ſame direction, in the ſtraight lines L A, L B, L C, L D, (*plate IV. fig.* 2.) drawn from the luminous point L, whence theſe rays proceed, and when they any where meet an eye, as at ſea, they enter into it, and there paint an image of the object from which they proceeded. In this caſe the viſion is denominated ſimple, or natural; and repreſents to us the objects as they really are. The ſcience, which explains to us the principles of this viſion, is termed *optics*.

But when the rays, before they enter into the eye, are reflected on a finely poliſhed ſurface, ſuch as a mirror, the viſion is no longer natural; as in this caſe we ſee the objects differently, and in a different place, from what they really are. The ſcience which explains the phenomena preſented to us by this viſion from reflected rays, is termed *catoptricks*. It too ſupplies us with inſtruments calculated to extend the ſphere of our viſion, and you are acquainted with ſuch ſorts of inſtruments, which, by means of one or two mirrors, render us the ſame ſervices as thoſe conſtructed with lenſes. Theſe are what we properly denominate *teleſcopes*: but in order to diſtinguiſh them from the common perſpectives, which are compoſed only of glaſſes, it would be better to call them catoptrick reflecting teleſcopes. This mode of expreſſion would at leaſt be more accurate; for the word teleſcope was in uſe before the diſcovery of reflecting inſtruments, and then meant the ſame thing with perſpective.

I propoſe, at preſent, to confine myſelf entirely to dioptrical inſtruments, of which we have two ſorts, teleſcopes or perſpectives, and microſcopes. In the conſtruction of both we employ glaſſes formed after different manners, the various ſorts of which I am going to explain. They are principally three, according to the figure given to the ſurface of the glaſs.

The firſt is the *plane*, when the ſurface of a glaſs is plane on both ſides, as that of a common mirror. If you were to take, for example, a piece of looking-glaſs, and to ſeparate from it the quick-ſilver which adheres to it's farther ſurface, you would have a glaſs both of whoſe ſurfaces are *plane*, and of the ſame thickneſs throughout.

The ſecond is the *convex*: a glaſs of this denomination is more raiſed in the middle than toward the edge.

The third is the *concave*: ſuch a glaſs is hollow toward the middle, and riſes toward the edge.

Of theſe three different figures, which may be given to the ſurface of a glaſs, are produced the ſix ſpecies of glaſſes repreſented in *fig.* 12.

I. The *plano-plane* glaſs has both it's ſurfaces plane.

II. The *plano-convex* glaſs has one ſurface plane and the other convex.

III. The *plano-concave* has one ſurface plane and the other concave.

IV. The *convexo-convex*, or *double convex*, has both ſurfaces convex.

V. The *convexo-concave*, or *meniſcus*, has one ſurface convex and the other concave.

VI. Finally, the *concavo-concave*, or *double concave*, has both ſurfaces concave.

It is proper to remark that the figure repreſents the cut of theſe glaſſes or lenſes.

8th December, 1761.

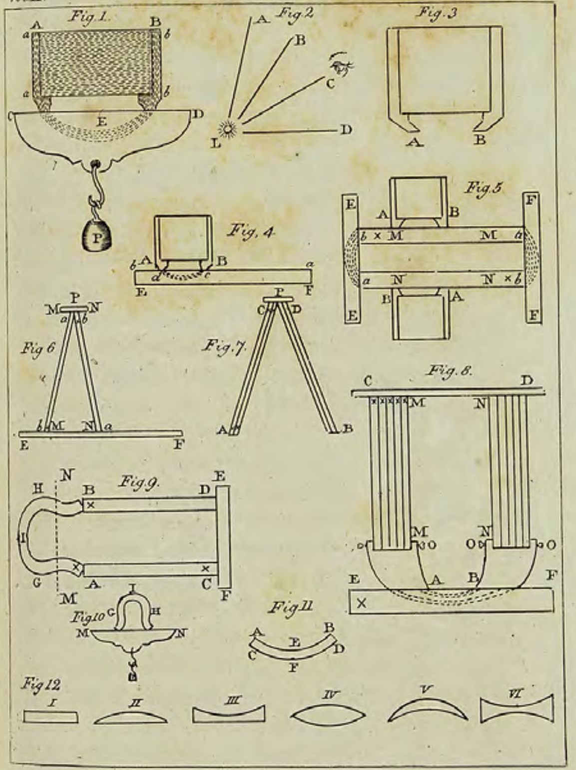
LETTER LXXIII.

Difference of Lenſes with reſpect to the Curve of their Surfaces. Diſtribution of Lenſes into Three Claſſes.

FROM what I have ſaid reſpecting the convex and concave ſurfaces of lenſes, you will eaſily comprehend that their form may be varied without end, according as the convexity and concavity are greater or leſs. There is only one ſpecies of plane ſurfaces; becauſe a ſurface can be plane in one manner only; but a convex ſurface may be conſidered as making part of a ſphere, and, according as the radius or diameter of that ſphere is greater or leſs, the convexity will differ; and as we repreſent lenſes on paper by ſegments of a circle, according as theſe circles are greater or leſs, the form of lenſes muſt be

infinite

Vol. II. Plate IV



infinite with reſpect both to the convexity and concavity of their ſurfaces.

As to the manner of forming and poliſhing glaſſes, all poſſible care is taken to render their figure exactly circular or ſpherical; for this purpoſe we employ baſons of metal formed by the turning machine, on a ſpherical ſurface, both inwardly and outwardly.

Let AEBDFC (*plate IV. fig.* 13.) be the form of ſuch a baſon, which ſhall have two ſurfaces AEB and CFD, each of which may have it's ſeparate radius; when a piece of glaſs is rubbed on the concave ſide of the baſon AEB, it will become convex; but if it is rubbed on the convex ſide CFD, it will become concave. Sand is, at firſt, uſed in rubbing the glaſs on the baſon, till it has acquired the form, and after that, a fine ſpecies of earth, to give it the laſt poliſh.

In order to know the real figure of the ſurfaces of a lens, you have only to meaſure the radius of the ſurface of the baſon, on which that lens was formed; for the true meaſure of the convexity and concavity of ſurfaces, is the radius of the circle or ſphere which correſponds to them, and of which they make a part.

Thus, when it is ſaid, that the radius of the convex ſurface AEB (*plate V. fig.* 1.) is three inches, the meaning is, that AEB is an arch of a circle deſcribed with a radius of three inches, the other ſurface AB being plane.

That I may convey a ſtill clearer idea of the difference of convexities, when their radii are greater or leſs, I ſhall here preſent you with ſeveral figures of different convexity; (ſee *plate V. fig.* 1.)

From this you ſee, that the ſmaller the radius is, the greater is the curve of the ſurface, or the greater it's difference from the plane; on the contrary, the greater the radius is, the more the ſurface approaches to a plane, or the arch of the circle to a ſtraight line. If the radius were made ſtill greater, the curve would at length become hardly perceptible. You ſcarcely perceive it in the arch MN, (*fig.* 2.) the radius of which is ſix inches, or half a foot; and if the radius were ſtill extended to ten or a hundred times the magnitude, the curve would become altogether imperceptible to the eye.

But this is by no means the caſe as to dioptricks; and I ſhall afterwards demonſtrate, that though the radius were a hundred or a thouſand feet, and the curve of the lens abſolutely imperceptible, the effect would nevertheleſs be abundantly apparent. The radius muſt indeed be inconceivably great, to produce a ſurface perfectly plane: from which you may conclude, that a plane ſurface might be conſidered as a convex ſurface whoſe radius is infinitely great, or as a concave of a radius infinitely great. Here it is that convexity and concavity are confounded, ſo that the plane ſurface is the medium which ſeparates convexity from concavity. But the ſmaller the radii are, the greater and more perceptible do the convexities and concavities become; and hence, we ſay reciprocally, that a convexity or concavity is greater

in proportion as it's radius, which is the meaſure of it, is ſmaller.

However great, in other reſpects, may be the variety we meet with in lenſes or glaſſes, according as their ſurfaces are plane, convex, or concave, and this in an infinity of different manners; nevertheleſs, with reſpect to the effect reſulting from them in dioptricks, they may be reduced to the three following claſſes:

The firſt comprehends glaſſes which are every where of an equal thickneſs; whether their two ſurfaces be plane and parallel to each other, (*fig.* 3.) or the one convex and the other concave, but concentric, or deſcribed round the ſame centre (*fig.* 4.) ſo that the thickneſs ſhall remain every where the ſame. It is to be remarked reſpecting glaſſes of this claſs, that they produce no change in the appearance of the objects which we view through them; the objects appear exactly the ſame as if nothing interpoſed; accordingly, they are of no manner of uſe in dioptricks. This is not becauſe the rays which enter into theſe glaſſes undergo no refraction, but becauſe the refraction at the entrance is perfectly ſtraightened on going off, ſo that the rays, after having paſſed through the glaſs, reſume the ſame direction which they had purſued before they reached it. Glaſſes, therefore, of the other two claſſes, on account of the effect which they produce, conſtitute the principal object of dioptricks.

The ſecond claſs of lenſes contains thoſe which are thicker at the middle than at the edge, (*fig.* 5.)

Their effect is the ſame, as long as the exceſs of the thickneſs of the middle over that of the edge has the ſame relation to the magnitude of the lens. All lenſes of this claſs are commonly denominated *convex*, as convexity predominates, though otherways one of their ſurfaces may be plain, and even concave.

The third claſs contains all thoſe lenſes which are thicker at the edge than in the middle *(plate V. fig. 6.)* which all produce a ſimilar effect, depending on the exceſs of thickneſs toward the edge, over that in the middle. As concavity prevails in all ſuch lenſes, they are ſimply denominated *concave*. They muſt be carefully diſtinguiſhed from thoſe of the ſecond claſs, which are the convex.

Lenſes of theſe two laſt claſſes are to be the ſubject of my following letters, in which I ſhall endeavour to explain their effects in dioptricks.

12th December, 1761.

LETTER LXXIV.

Effect of Convex Lenſes.

IN order to explain the effect produced by both convex and concave lenſes, in the appearance of objects, two caſes muſt be diſtinguiſhed, the one when the object is very far diſtant from the lens, and the other when it is nearer.

But before I enter on the explanation of this, I muſt ſay a few words on what is called the axis of the lens. As the two ſurfaces are repreſented by

ſegments of a circle, you have only to draw a ſtraight line through the centres of the two circles; this line is named the axis of the lens. In *fig. 7. plate V.* the centre of the arch A E B being at C, and that of the arch A F B at D, the ſtraight line C D is denominated the axis of the lens A B, and it is eaſy to ſee that this axis paſſes through the middle of it. The ſame thing would apply, if the ſurfaces of the lens were concave. But, if one is plane, the axis will be perpendicular to it, paſſing through the centre of the other ſurface.

Hence it is obvious, that the axis paſſes through the two ſurfaces perpendicularly, and that accordingly, a ray of light coming in the direction of the axis, will ſuffer no refraction, becauſe rays paſſing from one medium into another are not broken or refracted, except when they do not enter in a perpendicular direction.

It may likewiſe be proved that all other rays paſſing through the middle of the lens O, undergo no refraction, or rather that they again become parallel to themſelves.

It muſt be conſidered, in order to comprehend the reaſon of this, that at the points E and F the two ſurfaces of the lens are parallel to each other, for the angle M E B, which the ray M E makes with the arch of the circle E B, or it's tangent at E, is perfectly equal to the angle P F A, which this ſame ray produced, F P, makes with the arch of the circle A F, or it's tangent at F; you recollect that two ſuch angles are denominated alternate, and that it is demonſtrated, when the alternate angles are equal, that the ſtraight lines are parallel to each other: conſequently the two tangents at E and at F will be paparallel, and it will be the ſame thing as if the ray M E F P paſſed through a lens whoſe two ſurfaces were parallel to each other. Now, we have already ſeen that rays do not change their direction in paſſing through ſuch a lens.

Having made theſe remarks, let us now conſider a convex lens A B (*plate V. fig.* 8.) whoſe axis ſhall be the ſtraight line O E F P, and let us ſuppoſe that there is in this line, at a great diſtance from the lens, an object or luminous point O, which diffuſes rays in all directions; ſome of theſe will paſs through our lens A B, ſuch as O M, O E, and O N; of which that in the middle O E will undergo no refraction, but will continue it's direction through the lens in the ſame produced ſtraight line F I P. The other two rays O M and O N, in paſſing through the lens toward the edge, will be refracted, both at entering and departing, ſo that they will ſomewhere meet the axis, ſay at I, and afterwards continue their progreſs in the directions I Q and I R. It might likewiſe be demonſtrated that all the rays which fall between M and N will be refracted, ſo as to meet with the axis in the ſame point I. Therefore the rays which, had no lens interpoſed, would have purſued their rectilineal direction O M and O N, will, after the refraction, purſue other directions, as if they had taken

their

their departure from the point I; and if there were an eye ſomewhere at P, it would be affected juſt as if the luminous point were actually at I, though there be no reality in this. You have only to ſuppoſe for a moment, that there is at I a real object, which, diffuſing it's rays, would be equally ſeen by an eye placed at P, as it now ſees the object at O by means of the rays refracted by the lens, becauſe there is at I an image of the object O, and the lens A B there repreſents the object O, or tranſports it nearly to I. The point O is therefore no longer the object of viſion, but rather it's image, repreſented at I; for this is now it's immediate object.

This lens, then, produces a very conſiderable change: an object very remote O is ſuddenly tranſported to I, from which the eye muſt undoubtedly receive a very different impreſſion from what it would do, if, withdrawing the lens, it were to view the object O immediately. Let O be conſidered as a ſtar, the point O being ſuppoſed extremely diſtant, the lens will repreſent at I the image of that ſtar, but an image which it is impoſſible to touch, and which has no reality, as nothing exiſts at I, unleſs it be that the rays proceeding from the point O are collected there by the refraction of the lens. Neither is it to be imagined, that the ſtar would appear to us in the ſame manner as if it really exiſted at I. How could a body, many thouſands of times bigger than the earth, exiſt at a point I? Our ſenſes would be very differently ſtruck by it: We muſt carefully remark, then, that an image only is repreſented at I, like that

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of a ſtar repreſented in the bottom of the eye, or that which we ſee in a mirror, the effect of which has nothing to ſurprize.

15th December, 1761.

LETTER LXXV.

The ſame Subject: Diſtance of the Focus of Convex Lenſes.

I MEAN to employ this letter in exploring the effect produced by convex lenſes, that is, ſuch as are thicker at the middle than at the edge. The whole conſiſts in determining the change which rays undergo in their progreſs, on paſſing through ſuch a glaſs. In order to place this ſubject in it's cleareſt light, two caſes muſt be carefully diſtinguiſhed, the one, when the object is very diſtant from the lens; and the other when it is at no great diſtance. I begin with conſidering the firſt caſe, that is, when the object is extremely remote from the lens.

In *fig.* 9. of *plate V.* M N is the convex lens, and the ſtraight line O A B I S it's axis, paſſing perpendicularly through the middle. I remark, by the way, that this property of the axis of every lens, that of paſſing perpendicularly through it's middle, conveys the juſteſt idea of it that we are capable of forming. Let us now conceive that on this axis there is ſomewhere at O an object O P, which I here repreſent as a ſtraight line, whatever figure it may really have; and as every point of this object emits it's rays in all directions, we confine our attention to thoſe which fall on the lens.

My remarks ſhall be at preſent farther limited to the rays iſſuing from the point O, ſituated in the very axis of the lens. The figure repreſents three of theſe rays, O A, O M and O N, the firſt of which, O A, paſſing through the middle of the lens, undergoes no change of direction, but proceeds, after having paſſed through the lens, in the ſame ſtraight line B I S, that is in the axis of the lens; but the other two rays, O M and O N, undergo a refraction both on entering into the glaſs, and leaving it, by which they are turned aſide from their firſt direction, ſo as to meet ſomewhere at I with the axis, from which they will proceed in their new direction, in the ſtraight lines M I Q and N I R; ſo that afterwards, when they ſhall meet an eye, they will produce in it the ſame effect as if the point O exiſted at I, as they preſerve the ſame direction. For this reaſon, the convex lens is ſaid to tranſport the object O to I; but in order to diſtinguiſh this point I from the real point O, the former is called the image of the latter, which in it's turn is denominated the object.

This point I is very remarkable, and when the object O is extremely diſtant, the image of it is likewiſe denominated the focus of the lens, of which I ſhall explain the reaſon. If the ſun be the object at O, the rays which fall on the lens are all collected at I, and being endowed with the quality of heating, it is natural that the concourſe of ſo many rays at I, ſhould produce a degree of heat, capable of ſetting

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on fire any combuſtible matter that may be placed there. Now, the place where ſo much heat is collected we call the *focus*; the reaſon of this denomination with reſpect to convex lenſes is evident. Hence, too, a convex lens is denominated a *burning-glaſs*, the effects of which you are undoubtedly well acquainted with. I only remark that this property of collecting the rays of the ſun, in a certain point called their focus, is common to all convex lenſes; they likewiſe collect the rays of the moon, of the ſtars, and of all very diſtant bodies; though their force is too ſmall to produce any heat, we nevertheleſs employ the ſame term, focus; the focus of a glaſs, accordingly, is nothing elſe but the ſpot where the image of very diſtant objects is repreſented: to which this condition muſt ſtill be added, that the object ought to be ſituated in the very axis of the lens; for if it be out of the axis, it's image will likewiſe be repreſented out of the axis: I ſhall have occaſion to ſpeak of this afterward.

It may be proper, ſtill farther, to ſubjoin the following remarks reſpecting the focus:

1. As the point O, or the object, is infinitely diſtant, the rays O M, O A, and O N, may be conſidered as parallel to each other, and, for the ſame reaſon, parallel to the axis of the lens.

2. The focus I, therefore, is the point behind the glaſs, where the rays parallel to the axis, which falls on the lens, are collected by the refraction of the lens.

3. The focus of a lens, and the ſpot where the image of an object, infinitely diſtant, and ſituated in the axis of the lens, is repreſented, are the ſame thing.

4. The diſtance of the point I behind the lens, that is the length of the line B I, is called the diſtance of the focus of the lens. Some authors call it the focal diſtance.

5. Every convex lens has it's particular diſtance of focus, one greater, another leſs, which is eaſily aſcertained by expoſing the lens to the ſun, and obſerving where the rays meet.

6. Lenſes formed by arches of ſmall circles, have their focuſes very near behind them; but thoſe whoſe ſurfaces are arches of great circles, have more diſtant focuſes.

7. It is of importance to know the focal diſtance of every convex lens employed in dioptricks; and it is ſufficient to know the focus in order to form a judgment of all the effects to be expected from it, whether in the conſtruction of teleſcopes or microſcopes.

8. If we employ lenſes equally convex on both ſides, ſo that each ſurface ſhall correſpond to the ſame circle; then the radius of that circle gives nearly the focal diſtance of that lens: thus, to make a burning-glaſs which ſhall burn at the diſtance of a foot, you have only to form the two ſurfaces arches of a circle whoſe radius is one foot.

9. But when the lens is plano-convex, it's focal diſtance is nearly equal to the diameter of the circle, which correſponds to the convex ſurface.

Acquaintance

Acquaintance with theſe terms will facilitate the knowledge of what I have farther to advance on this ſubject.

19th December, 1761.

LETTER LXXVI.

Diſtance of the Image of Objects.

HAVING remarked that an object infinitely diſtant, is repreſented by a convex lens in the very focus, provided ſuch object be in the axis of the lens, I proceed to nearer objects, but always ſituated in the axis of the glaſs; and I obſerve, firſt, that the nearer the object approaches to the lens, the farther the image retires.

Let us accordingly ſuppoſe that F (*plate V. fig.* 10.) is the focus of the lens M M, ſo that an object infinitely diſtant before the glaſs, or at the top of the figure, the image ſhall be repreſented at F; on bringing the object nearer to the glaſs, and placing it ſucceſſively at P Q R, the image will be repreſented at the point *p q r*, more diſtant from the lens than the focus: in other words, if A P is the diſtance of the object, B *p* will be the diſtance of the image, and if A Q is the diſtance of the object, B *q* will be that of the image, and the diſtance B *r* of the image will correſpond to the diſtance A R of the object.

There is a rule by which it is eaſy to calculate the diſtance of the image behind the lens, for every diſtance of the object before it, but I will not tire you with a dry expoſition of this rule; it will be ſufficient to remark, in general, that the more the diſtance of the object before the glaſs is diminiſhed, the more is the diſtance of the image behind it increaſed. I ſhall to this ſubjoin the inſtance of a convex lens, whoſe focal diſtance is 6 inches, or of a lens ſo formed, that if the diſtance of the object is infinitely great, the diſtance of the image behind the lens ſhall be preciſely ſix inches; now, on bringing the object nearer to the lens, the image will retire, according to the gradations marked in the following table:

Diſtance of the Object.	Diſtance of the Image.
Infinity	6
42	7
24	8
18	9
15	10
12	12
10	15
9	18
8	24
7	42
6	Infinity.

Thus the object being 42 inches diſtant from the lens, the image will fall at the diſtance of 7 inches, that is one inch beyond the focus. If the object is at the diſtance of 24 inches, the image will be removed to the diſtance of 8 inches from the lens, that is two inches beyond the focus, and ſo of the reſt.

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Though theſe numbers are applicable only to a lens, whoſe focal diſtance is 6 inches, ſome general conſequences may, however, be deduced from them.

1. If the diſtance of the object is infinitely great, the image falls exactly in the focus.

2. If the diſtance of the object is double the diſtance of the focus, the diſtance of the image will likewiſe be double the diſtance of the focus; in other words, the object and the image will be equally diſtant from the lens. In the example above exhibited, the diſtance of the object being 12 inches, that of the image is likewiſe 12 inches.

3. When the object is brought ſo near the lens, that the diſtance is preciſely equal to that of the focus, ſay 6 inches, as in the preceding example, then the image retires to an infinite diſtance behind the lens.

4. It is likewiſe obſervable in general, that the diſtance of the object and that of the image reciprocally correſpond, or, if you put the object in the place of the image, it will fall in the place of the object.

5. If, therefore, the lens M M (*plate V. fig.* 11.) collects at I the rays which iſſue from the point O, that ſame lens will likewiſe there collect rays iſſuing from the point I.

6. It is the conſequence of a great principle in dioptricks, in virtue of which it may be maintained, that whatever are the refractions which rays have undergone in paſſing through ſeveral refringent mediums, they may always return in the ſame direction.

This truth is of much importance in the knowledge of lenſes: thus when I know, for example, that a lens has repreſented, at the diſtance of 8 inches, the image of an object 24 inches diſtant, I may confidently infer, that if the object were 8 inches diſtant, the ſame lens would repreſent it's image at the diſtance of 24 inches.

It is farther eſſential to remark, that when the diſtance of the object is equal to that of the focus, the image will ſuddenly retire to an infinite diſtance; which perfectly harmonizes with the relation exiſting between the object and the image.

You will no doubt be curious to know in what place the image will be repreſented when the object is brought ſtill nearer to the lens, ſo that it's diſtance ſhall become leſs than that of the focus. This queſtion is the more embarraſſing, that the anſwer muſt be, the diſtance of the image will, in this caſe, be greater than infinity, ſince the nearer the object approaches the lens, the farther does the image retire. But the image being already infinitely diſtant, how is it poſſible that diſtance ſhould be increaſed? The queſtion might undoubtedly puzzle philoſophers, but is of eaſy ſolution to the mathematician. The image will paſs from an infinite diſtance, to the other ſide of the lens, and conſequently will be on the ſame ſide with the object. However ſtrange this anſwer may appear, it is confirmed, not only by reaſoning, but by experience, ſo that it is impoſſible to doubt of it's ſolidity; to increaſe beyond infinity is the ſame thing with paſſing to the other ſide: this is unqueſtionably a real paradox.

22d December, 1761.

LETTER LXXVII.

Magnitude of Images.

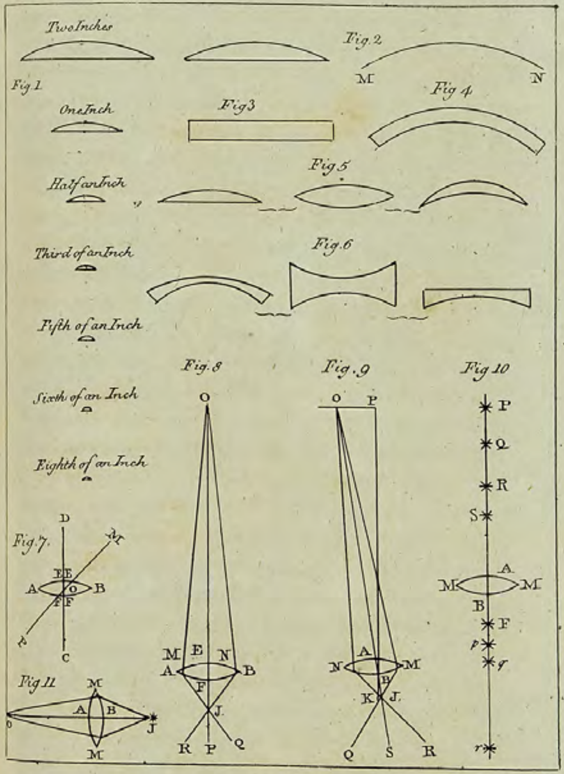
YOU can no longer doubt that every convex lens muſt repreſent ſomewhere the image of an object preſented to it; and that, in every caſe, the place of the image varies as much, according to the diſtance of the object, as according to the focal diſtance of the lens: but a very important article remains yet to be explained, I mean the magnitude of the image.

When ſuch a lens repreſents to us the image of the ſun, of the moon, or of a ſtar, at the diſtance of a foot, you are abundantly ſenſible that theſe images muſt be incomparably ſmaller than the objects themſelves. A ſtar being much greater than the whole earth, how is it poſſible that an image of ſuch magnitude ſhould be repreſented to us at the diſtance of a foot? But the ſtar appearing to us only as a point, the image, repreſented by the lens, likewiſe reſembles a point, and, conſequently, is infinitely ſmaller than the object itſelf.

There are then, in every repreſentation made by lenſes, two things to be conſidered; the one reſpects the place where the image is repreſented, and the other, the real magnitude of the image, which may be very different from that of the object. The firſt being ſufficiently elucidated, I proceed to furniſh you with a very ſimple rule, by which you will be enabled, in every caſe, to determine what muſt be the magnitude of the image repreſented by the lens.

Let

Vol. II. *Plate V.*



Let O P *(plate VI. fig. 1.)* be any object whatever, ſituated on the axis of the convex lens M N; we muſt firſt look for the place of the image, which is at I, ſo that the point I ſhall be the repreſentation of the extremity O of the object, as the rays iſſuing from the point O are there collected by the refraction of the lens. Let us now ſee in what place will be repreſented the other extremity P of the object; for this purpoſe, let us conſider the rays P M, P A, P N, which, iſſuing from the point P, fall on the lens; I obſerve that the ray P A, which paſſes through the middle of the lens, does not change it's direction, but continues it's progreſs in the ſtraight line A K S; it will be, therefore, ſomewhere in this line at K, that the other rays P M and P N will meet: in other words, the point K will be the image of the other extremity P of the object, the point I being that of the extremity O: hence it is eaſy to conclude that I K will be the image of the object O P, repreſented by the lens.

In order then, to determine the magnitude of this image, having found the place I, you have only to draw from the extremity P of the object, through A, the middle of the lens, the ſtraight line P A K S, and to raiſe from I the line I K perpendicular to the axis, and this line I K will be the image in queſtion; it is evident from this that the image is reverſed, ſo that if the line O R were horizontal, and the object O P a man, the image would have the head K undermoſt, and the feet I upward.

On this I ſubjoin the following remarks:

1. The nearer the image (*plate VI. fig.* 2.) is to the lens, the ſmaller it is; and, the more remote it is, the greater it's magnitude. Thus O P being the object placed on the axis before the lens M N, if the image fell at Q it would be ſmaller than if it fell at R, S, or T. For, as the ſtraight line P A *t*, drawn from the ſummit of the object P, through the middle of the lens, always terminates the image at whatever diſtance it may be, it is evident, that among the lines Q *q*, R *r*, S *s*, T *t*, the firſt Q *q* is the ſmalleſt, and that the others increaſe in proportion as they remove from the lens.

2. There is one caſe in which the image is preciſely equal to the object: it is when the diſtance of the image is equal to that of the object; and this takes place, as I have already remarked, when the diſtance of the object A O is double that of the focus of the lens; the image will then be T *t*, ſo that the diſtance B *t* is equal to A O. You have only then to conſider the two triangles O A P and T A *t*, which having the oppoſite angles at the point A, as well as the ſides A O and A T equal each to each, as likewiſe the angles at O and T, which are both right angles: theſe two triangles will be every way equal, and conſequently the ſide T *t*, which is the image, will be equal to the ſide O P, which is the object.

3. If the image were twice farther from the lens than the object, it would be double the object; and, in general, as many times as the image is farther from the lens than the object, ſo many times will it be greater than the object. For the nearer you bring the object to the glaſs, the farther the image retires, and conſequently the greater it becomes.

4. The contrary takes place when the image is nearer the lens than the object; it is then as many times ſmaller than the object, as it is nearer the lens than the object is. If then the diſtance of the image were one thouſand times leſs than that of the object, it would likewiſe be one thouſand times ſmaller.

5. Let us apply this to burning-glaſſes, which, being expoſed to the ſun, repreſent it's image in the focus, or rather repreſent the focus, that is, the luminous and brilliant circle which burns, and which is nothing elſe but the image of the ſun repreſented by the lens. You will no longer be ſurprized, then, at the ſmallneſs of the image, notwithſtanding the prodigious magnitude of the ſun, it being as many times ſmaller in the focus than the real ſun, as the diſtance of the ſun from the lens is greater than that of the image.

6. Hence likewiſe it is evident, that the greater is the diſtance of the focus of a burning-glaſs, the more brilliant alſo is the circle in the focus, that is, the greater will be the image of the ſun: and the diameter of the focus is always about one hundred times ſmaller than the diſtance of the focus from the lens.

I ſhall afterwards explain the different uſes which may be made of convex lenſes; they are all ſufficiently curious to merit attention.

26th December, 1761.

LETTER

LETTER LXXVIII.

Burning Glaſſes.

THE firſt uſe of convex lenſes, is their employment as burning-glaſſes, the effect of which muſt appear altogether aſtoniſhing, even to thoſe who already have ſome acquaintance with natural philoſophy. In fact, who could believe, that the image of the ſun, ſimply, ſhould be capable of exciting ſuch a prodigious degree of heat? But your ſurprize will ceaſe, if you pleaſe to pay ſome attention to the following reflections.

1. Let M N, (*plate VI. fig.* 3.) be a burning-glaſs, which receives on it's ſurface the rays of the ſun R, R, R, refracted in ſuch a manner as to preſent at F a ſmall luminous circle, which is the image of the ſun, and ſo much ſmaller as it is nearer to the glaſs.

2. All the rays of the ſun, which fall on the ſurface of the glaſs, are collected in the ſmall ſpace of the focus F; their effect, accordingly, muſt, in that ſpace, be as many times greater as the ſurface of the glaſs exceeds the magnitude of the focus, or of the ſun's image. We ſay that the rays, which were diſperſed over the whole ſurface of the glaſs, are concentrated in the ſmall ſpace F.

3. The rays of the ſun having a certain degree of heat, they exert their power, in a very ſenſible manner, at the focus; it is poſſible even to calculate how many times the heat at the focus muſt exceed the

natural heat of the ſun's rays: we have only to obſerve how many times the ſurface of the glaſs is greater than the focus.

4. If the glaſs were not greater than the focus, the heat would not be ſtronger at the focus than any where elſe; hence we muſt conclude, that in order to the production of a ſtrong heat by a burning-glaſs, it is not ſufficient that it ſhould be convex, or that it ſhould repreſent the image of the ſun, it muſt, beſides, have a ſurface which ſeveral times exceeds the magnitude of the focus, which is ſmaller in proportion as it is nearer to the glaſs.

5. France is in poſſeſſion of the moſt excellent burning-glaſs; it is three feet in diameter, and it's ſurface is calculated to be nearly two thouſand times greater than the focus, or the image of the ſun which it repreſents. It muſt produce, therefore, in the focus, a heat two thouſand times greater than that which we feel from the ſun. It's effects are, accordingly, prodigious: wood of every kind is, in a moment, ſet on fire; metals are melted in a few minutes; and, in general, the moſt ardent fire which we are capable of producing, is not once to be compared with the vehement heat of this focus.

6. The heat of boiling water is calculated to be about thrice greater than what we feel from the rays of the ſun in ſummer, or, which amounts to the ſame thing, the heat of boiling water is thrice greater than the natural heat of the blood in the human body. But in order to melt lead, we muſt have a heat thrice greater than is requiſite to make water boil; and to

melt copper a heat ſtill thrice greater is neceſſary. To melt gold requires a much higher degree of heat. Heat, then, one hundred times greater than that of our blood is capable of melting gold; how far then muſt a heat two thouſand times greater exceed the force of our ordinary fires?

7. But how are theſe prodigious effects produced by the rays of the ſun collected in the focus of a burning-glaſs? This is a very difficult queſtion, with reſpect to which philoſophers are very much divided. Thoſe who maintain that the rays are an emanation from the ſun, darted with the amazing velocity which I formerly deſcribed, are not greatly embarraſſed for a ſolution; they have only to ſay that the matter of the rays, ſtriking bodies with violence, muſt totally break and deſtroy their minute particles. But this opinion is no longer admitted in ſound philoſophy.

8. The other ſyſtem, which makes the nature of light to conſiſt in the agitation of the ether, appears little adapted to explain theſe ſurprizing effects of burning-glaſſes. On carefully examining, however, all the circumſtances, we ſhall ſoon be convinced of the poſſibility of this. The natural rays of the ſun, as they fall on bodies, excite the minute particles of the ſurface to a concuſſion, or motion of vibration, which, in it's turn, is capable of exciting new rays, and by theſe the body in queſtion is rendered viſible. And a body is illuminated only ſo far as theſe proper particles are put into a motion of vibration ſo rapid as to be capable of producing new rays in the ether.

9. It is clear, then, that if the natural rays of the ſun have ſufficient force to agitate the minute particles of bodies, thoſe which are collected in the focus muſt put the particles which they meet there into an agitation ſo violent, that their mutual adheſion is entirely diſſolved, and the body itſelf completely deſtroyed, which is the effect of fire. For if the body is combuſtible, as wood, the diſſolution of theſe minute particles, joined to the moſt rapid agitation, makes a conſiderable part of it to fly off into air, in the form of ſmoke, and the groſſer particles remain in form of aſhes. Fuſible bodies, as metals, become liquid by the diſſolution of their particles, whence we may comprehend how fire acts on bodies; it is only the adheſion of their minuteſt particles which is attacked, and the particles themſelves are thereby afterwards put into the moſt violent agitation. Here, then, is a very ſtriking effect of burning-glaſſes, which derives its origin from the nature of convex lenſes. There are beſides many other wonderful effects to be deſcribed.

28th December, 1761.

LETTER LXXIX.

The Camera Obſcura.

WE likewiſe employ convex lenſes in the *camera obſcura*, and by means of them, all external objects are preſented in the darkened room on a white ſurface, in their natural colours, in ſuch a manner that landſcapes and public buildings, or objects

jects in general, are repreſented in much greater perfection than the power of the pencil is capable of producing. Painters accordingly avail themſelves of this method, in order to draw, with exactneſs, landſcapes and other objects which are viewed at a diſtance. The camera obſcura, then, is to be the ſubject of this letter.

E F G H, (*plate VI. fig.* 4.) repreſents the form of a camera obſcura, cloſely ſhut up on all ſides, except one little round aperture made in one of the window ſhutters, in which is fixed a convex lens, of ſuch a focus as to throw the image of external objects, ſay the tree O P, exactly on the oppoſite wall F G, at *o p*. A white and moveable table is likewiſe employed, which is put in the place of the images repreſented.

The rays of light, therefore, can be admitted into the chamber only through the aperture M N, in which the lens is fixed, without which total darkneſs would prevail.

Let us now conſider the point P of any object, ſay the ſtem of our tree O P. It's rays P M, P A, P N will fall, then, on the lens M N, and be refracted by it, ſo as to meet again at the point *p* on the wall, or on a white table placed there for the purpoſe. This point *p* will conſequently receive no other rays but ſuch as proceed from the point P; and in like manner every other point of the table will receive only the rays which proceed from the correſponding point of the object; and reciprocally, to every point of the external object will correſpond a point on the table, which receives thoſe rays and no other. If the

lens were to be removed from the aperture M N, the table would be illuminated in quite a different manner, for in that caſe every point of the object would diffuſe it's rays over the whole table, ſo that every point of the table would be illuminated at once by all the external objects, whereas at preſent it is ſo by one only, that whoſe rays it receives; from this you will eaſily comprehend that the effect muſt be quite different from what it would be if the rays entered ſimply by the aperture MN into the chamber.

Let us now examine, ſomewhat more cloſely, wherein this difference conſiſts; and let us firſt ſuppoſe that the point P of the object is green, the point of the table *p* will, therefore, receive only thoſe green rays of the object P, and theſe, re-uniting on the wall or table, will make a certain impreſſion, which here merits conſideration. For this purpoſe you will pleaſe to recollect the following propoſitions which I had formerly the honour of explaining to you.

1. Colours differ from each other in the ſame manner as muſical ſounds: each colour is produced by a determinate number of vibrations, which, in a given time, are excited in the ether. The green colour of our point P is accordingly appropriated to a certain number of vibrations, and would no longer be green were theſe vibrations more or leſs rapid. Though we do not know the number of vibrations which produce ſuch or ſuch a colour, we may, however, be permitted to ſuppoſe here that green requires twelve thouſand vibrations in a ſecond, and what we affirm of this number, twelve thouſand,

thouſand, may likewiſe be eaſily underſtood of the real number, whatever it be.

2. This being laid down, the point *p* on the white table will be ſtruck by a motion of vibration, of which twelve thouſand will be completed in a ſecond. Now, I have remarked that the particles of a white ſurface are all of ſuch a nature as to receive every ſort of agitation, more or leſs rapid, whereas thoſe of a coloured ſurface are adapted to receive only that degree of rapidity which correſponds to their colour. And as our table is white, the point *p* in it will be excited to a motion of vibration correſponding to the colour of green; in other words it will be agitated twelve thouſand times in a ſecond.

3. As long as the point *p*, or the particle of the white ſurface which exiſts there, is agitated with a ſimilar motion, this will be communicated to the particles of the ether which ſurround it; and this motion diffuſing itſelf in all directions, will generate rays of the ſame nature, that is to ſay, green; juſt as in muſic, the ſound of a certain note, ſay C, agitates a ſtring wound up to the ſame tone, and makes it emit a ſound without being touched.

4. The point *p* of the white table will accordingly produce green rays, as if it were dyed or painted that colour: and what I affirm of the point *p*, will equally take place with reſpect to all the points of the illuminated table, which will produce all the rays, each of the ſame colour with that of the object whoſe image it repreſents. Every point of the table will, therefore, become viſible, under a certain colour, as if it were actually painted that colour.

5. You will perceive, then, on the table, all the colours of the external objects, the rays of which will be admitted into the chamber through the lens: each point in particular will appear of the colour of that point of the object which correſponds to it, and you will ſee on the table a combination of various colours, diſpoſed in the ſame order as you ſee them in the objects themſelves, that is to ſay, a repreſentation, or rather the perfect picture of all the objects on the outſide of the dark chamber which are before the lens NN.

6. All theſe objects will, however, appear reverſed on the table, as you will conclude from what I have ſaid in my foregoing letters. The under part of the tree O will be repreſented at *o*, and the ſummit P at *p*: for, in general, each object muſt be repreſented on the white table, in the place which is the termination of the ſtraight line drawn from the object P through the middle of the lens A: that which is upward will, conſequently, be repreſented downward, and that which is to the left will be to the right; in a word, every thing will be reverſed in the picture; the repreſentation will, nevertheleſs, be more exact and more perfect than the moſt accurate painter is capable of producing.

7. You will further remark, that this picture will be ſo much ſmaller than the objects themſelves, in proportion as the focus of the lens is ſhorter. Lenſes of a ſhort focus will accordingly give the objects in miniature;

miniature; and if you would wiſh to have them magnified, you muſt employ lenſes of a longer focus, or which repreſent the images at a greater diſtance.

8. In order to contemplate theſe repreſentations more at eaſe, the rays may be intercepted by a mirror, from which they are refracted, ſo as to repreſent the whole picture on a horizontal table; and this is of peculiar advantage when we wiſh to copy the images.

2d January, 1762.

LETTER LXXX.

Reflections on the Repreſentation in the Camera Obſcura.

THOUGH you can no longer entertain any doubt reſpecting the repreſentations made in a dark chamber, by means of a convex lens, I hope the following reflections will not appear ſuperfluous, as they ſerve to place this ſubject in a clearer light.

1. The chamber muſt be completely darkened, for, were the light admitted, the white table would be viſible, and the particles of it's ſurface, already agitated, would be incapable of receiving the impreſſion of the rays which unite to form the images of external objects. Though, however, the chamber were a little illuminated, ſtill ſomething of the repreſentation would appear on the table, but by no means ſo vivid as if the chamber were entirely dark.

2. We muſt carefully diſtinguiſh the picture repreſented on the white table, from the image which the lens, in virtue of it's own nature, repreſents, as I have formerly explained. It is very true, that placing the table in the very place where the image of the objects is formed by the lens, this image will be confounded by the picture we perceive on the table; theſe two things are, nevertheleſs, of a nature entirely different: the image is only a ſpectre or ſhade floating in the air, which is viſible but in certain places, whereas the repreſentation is a real picture, which every one in the chamber may ſee, and to which duration alone is wanting.

3. In order the more clearly to elucidate this difference, you have only to conſider carefully the nature of the image *o*, (*plate VI. fig.* 5.) repreſented by the convex lens MN, the object being at O. This image is nothing elſe but the place in which the rays OM, OC, ON of the object, after having paſſed through the lens, meet by refraction, and thence continue their direction as if they proceeded from the point *o*, though they really originated from O, and by no means from *o*.

4. Hence the image is viſible only to eyes ſituated ſomewhere within the angle R *o* Q, as at S, where an eye will actually receive the rays which come to it from the point *o*. But an eye ſituated out of this angle, as at F or V, will ſee nothing at all of it, becauſe no one of the rays collected at *o* is directed toward it: the image at *o*, therefore, differs very eſſentially from a real object, and is viſible only in certain places.

5. But

5. But if a white table is placed at *o*, and it's ſurface at this point *o* is really excited to an agitation ſimilar to that which takes place in the object O, this ſpot *o* of the ſurface itſelf generates rays which render it viſible every where. Here, then, is the difference between the image of an object, and it's repreſentation made in a camera obſcura: the image is viſible only in certain places, namely, thoſe through which are tranſmitted the rays that originally proceed from the object; whereas the picture, or repreſentation formed on the white table, is ſeen by it's own rays, excited by the agitation of the particles of it's ſurface, and conſequently viſible in every place of the camera obſcura.

6. It is likewiſe evident, that the white table muſt abſolutely be placed exactly in the place of the image formed by the lens, in order that every point of the table may receive no other rays except ſuch as proceed from a ſingle point of the object: for if other rays were likewiſe to fall upon it, they would diſturb the effect of the former, or render the repreſentation confuſed.

7. Were the lens to be entirely removed, and free admiſſion given to the rays into the dark chamber, the white table would be illuminated by it, but no picture would be viſible. The rays of the different objects would fall on every point of the table, without expreſſing any one determinate image. The picture, accordingly, which we ſee in a camera obſcura, on a white ſurface, is the effect of the convex

lens fixed in the ſhutter: this it is which collects anew, in a ſingle point, all the rays that proceed from one point of the object.

8. A very ſingular phenomenon is here, however, obſervable, when the aperture, made in the window-ſhutter of the dark chamber, is very ſmall: for though no lens be applied, you may, nevertheleſs, perceive on the oppoſite partition the images of external objects, and even with their natural colours: but the repreſentation is very faint and confuſed, and if the aperture is enlarged this repreſentation entirely diſappears. I ſhall explain this phenomenon.

In *fig.* 6. *plate VI.* MN is the ſmall aperture through which the rays of external objects are admitted into the dark chamber EFGH. The wall FG oppoſite to the aperture is white, the better to receive the impreſſion of rays of all ſorts.

Let the point O be an object, of which the rays OM, ON alone, with thoſe which fall between them, can enter into the chamber. Theſe rays will be confined to the ſmall ſpace *o o* of the wall, and will illuminate it. This ſpace *o o* will be ſo much ſmaller, or approach the nearer to a point, in proportion as the aperture MN is ſmall: if then this aperture were very ſmall, we ſhould have the effect already deſcribed, according to which every point of the white table receives only the rays proceeding from a ſingle point of the object: there would be produced, of conſequence, a repreſentation ſimilar to that which is produced by the application of a convex lens to an aperture in the window-ſhutter. But in the preſent caſe, the aperture being of a certain extent, every point O of the object will illuminate a certain ſmall ſpace *o o* on the wall, and agitate it by it's rays. The ſame thing then, nearly, would take place, as if a painter, inſtead of making points with a fine pencil, ſhould with a coarſe one make ſpots of a certain magnitude, attending, however, to deſign and colouring, the repreſentation made on the wall will have a reſemblance to this ſort of daubing; but it will be clearer in proportion to the ſmallneſs of the aperture by which the rays are admitted.

5th January, 1762.

LETTER LXXXI.

Of the Magic Lantern, and Solar Microſcope.

THE camera obſcura has properly no effect except on very diſtant objects, but you will eaſily comprehend, that it's application may be equally extended to nearer objects; for this purpoſe the white table muſt be removed further from the lens, conformably to this general rule, that the nearer the object is brought to the convex lens, the farther does the image, where the white table ought to be placed, retire from it; and if the chamber is not of ſufficient depth, a different lens, of a ſhorter focus, muſt be employed.

You may place then, out of the chamber, before the aperture to which the convex lens is fitted, any object or picture whatever, and you will ſee a copy of it on the white table within the dark chamber, greater or ſmaller than the original, according as the diſtance of the image is greater or ſmaller; but it would be more commodious, undoubtedly, if the object could be expoſed within-ſide the dark chamber, in order to it's being moved and changed at pleaſure. But here a great difficulty occurs; the object itſelf would, in this caſe, be darkened, and conſequently rendered incapable of producing the effect we wiſh.

The thing wanted, then, is, to illuminate the object as much as poſſible, within-ſide the dark chamber, and at the ſame time to exclude the light. I have found out the means of doing this. You will recollect that I conſtructed a machine to the effect I am mentioning, which I had the honour of preſenting to you ſix years ago; and now you will eaſily comprehend the ſtructure, and the principles on which it is founded.

This machine conſiſts of a box very cloſe on all ſides, nearly of a figure ſimilar to *fig. 7. plate VII.* The farther ſide of which EG has an opening IK, in which are to be fitted the objects, portraits or other pictures OP which you mean to repreſent; on the other ſide, directly oppoſite, is a tube MNQR, containing a convex lens MN; this tube is moveable, for the purpoſe of bringing the lens nearer to the object, or of removing it at pleaſure. Then, provided the object OP be well illuminated, the lens will throw ſomewhere the image of it *o p*, and if you there place a white tablet, you will ſee upon it a perfect copy of the object, ſo much the clearer as the object itſelf is more illuminated.

For this purpoſe I have contrived in this box two ſide wings for the reception of lamps with large wicks, and in each wing is placed a mirror to reflect the light of the lamps on the objects OP; above, at EF, is a chimney by which the ſmoke of the lamps paſſes off. Such is the conſtruction of this machine, within which the object OP may be very ſtrongly illuminated, while the darkneſs of the chamber ſuffers no diminution. In order to the proper uſe of this machine, attention muſt be paid to the following remarks.

I. On ſliding inward the tube MNQR, that is bringing the lens MN nearer to the object OP, the image *op* will retire; the white tablet muſt therefore be removed backward, to receive the image at the juſt diſtance; the image will thereby be likewiſe magnified, and you may go on to enlarge it at pleaſure by preſſing the lens MN nearer and nearer to the object OP.

II. On removing the lens from the object, the diſtance of the image will be diminiſhed: the white tablet muſt in this caſe be moved nearer to the lens, in order to have a clear and diſtinct repreſentation, but the image will be reduced.

III. It is obvious that the image will be always reverſed; but this inconveniency is eaſily remedied; you have only to reverſe the object OP itſelf, turning it upſide down, and the image will be repreſented upright on the white tablet.

IV. It is a farther general remark, that the more the image is magnified on the white tablet, the leſs luminous and diſtinct it will be; but on reducing the image, it is rendered more diſtinct and brilliant. The reaſon is plain, the light proceeds wholly from the illumination of the object; the greater that the ſpace is, over which it is diffuſed, the more it muſt be weakened, and the more contracted it is, the more brilliant.

V. Accordingly, the more you wiſh to magnify the repreſentation, the more you muſt ſtrengthen the illumination of the object, by increaſing the light of the lamps in the wings of the machine: but for ſmall repreſentations a moderate illumination is ſufficient.

The machine which I have been deſcribing is called the *magic-lantern*, to diſtinguiſh it from the common camera obſcura, employed for repreſenting diſtant objects: its figure, undoubtedly, has procured it the name of lantern, eſpecially as it is deſigned to contain light; but the epithet *magic* muſt have been an invention of it's firſt proprietors, who wiſhed to impreſs the vulgar with the idea of magic or witchcraft. The ordinary magic-lanterns, however, are not conſtructed in this manner, and ſerve to repreſent no other objects but figures painted on glaſs, whereas this machine may be applied to objects of all ſorts.

It may even be employed for repreſenting the ſmalleſt objects, and for magnifying the repreſentation to a prodigious ſize, ſo as that the ſmalleſt fly ſhall appear as large as an elephant: but, for this purpoſe, the ſtrongeſt light that lamps can give is far from being ſufficient; the machine muſt be diſpoſed in ſuch a manner that the objects may be illuminated by the rays of the ſun, ſtrengthened by a burning-glaſs: the machine, in this caſe, changes it's name, and is called the *ſolar-microſcope:* I ſhall have occaſion to ſpeak of it more at large in the ſequel.

8th January, 1762.

LETTER LXXXII.

Uſe and Effect of a ſimple Convex Lens.

WE likewiſe employ convex lenſes for immediately looking through: but in order to explain their different uſes, we muſt go into a cloſer inveſtigation of their nature.

Having obſerved the focal diſtance of ſuch a glaſs, I have already remarked, that when the object is very remote, it's image is repreſented in the focus itſelf, but on bringing the object nearer to the lens, the image retires farther and farther from it; ſo that if the diſtance of the object be equal to that of the focus of the lens, the image is removed to an infinite diſtance, and, conſequently, becomes infinitely great.

The reaſon is, that the rays OM, OM, *(plate VI. fig. 7.)* which come from the point O, are refracted by the lens, ſo as to become parallel to each other,

as NF, NF; and as parallel lines are ſuppoſed to proceed forward to infinity, and as the image is always in the place where the rays, iſſuing from one point of the object, are collected again after the refraction; in the caſe when the object OA is equal to that of the focus of the lens, the place of the image removes to an infinite diſtance; and as it is indifferent whether we conceive the parallel lines NF and NF to meet at an infinite diſtance to the left or to the right, it may be ſaid indifferently, that the image is to the right or to the left, infinitely diſtant, the effect being always the ſame.

Having made this remark, you will eaſily judge what muſt be the place of the image, when the object is brought ſtill nearer to the lens.

Let OP, *(plate VI. fig.* 8.) be the object, and as it's diſtance OA from the convex lens is leſs than the diſtance of the focus, the rays OM, OM, which fall upon it from the point O, are too divergent to admit of the poſſibility of their being rendered parallel to each other by the refractive power of the lens; they will, therefore, be ſtill divergent after the refraction, as marked by the lines NF, NF, though much leſs ſo than before, therefore if theſe lines are produced backward, they will meet ſomewhere at *o*, as you may ſee in the dotted lines N *o*, N *o*. The rays NF, NF, will, of conſequence, after having paſſed through the lens, preſerve the ſame direction as if they had proceeded from the point *o*, though they have not actually paſſed through that point, as it is only in the lens that they have taken this new direction. An eye which receives theſe refracted rays NF, NF, will be, therefore, affected as if they really came from the point *o*, and will imagine that the object of it's viſion exiſts at *o*. There will, however, be no image at that point, as in the preceding caſe: to no purpoſe would you put a white tablet at *o*, it would preſent no picture there, for want of rays; for this reaſon we ſay that there is an imaginary image at *o*, and not a real one: the term *imaginary* being oppoſed to that of *real*.

Nevertheleſs, an eye placed at E receives the ſame impreſſion as if the object OP, from which the rays originally proceed, exiſted at *o*. It is of great importance, then, to know, as in the preceding caſes, the place and the magnitude of this imaginary image *o p*. As to the place, it is ſufficient to remark, that if the diſtance of the object AO be equal to the diſtance of the focus of the lens, the image will be at an infinite diſtance from it, and this is what the preſent caſe has in common with the preceding; but the nearer the object is brought to the lens, or the leſs that the diſtance AO becomes than that of the focus of the lens, the nearer does the imaginary image approach to the lens, though, at the ſame time, it remains always at a greater diſtance from the lens than the object itſelf.

To elucidate this by an example, let us ſuppoſe that the focal diſtance of the lens is 6 inches, and for the different diſtances of the object, the annexed table indicates the diſtance of the imaginary image *o p*.

Diſtance of the Object A O.	Diſtance of the imaginary Image A *o*.
6	Infinity
5	30
4	12
3	6
2	3
1	1 and a fifth.

The rule for aſcertaining the magnitude of this imaginary image *o p* is eaſy and general, you have only to draw through the middle of the lens, marked C, and through the extremity of the object P, the ſtraight line C P *p*; and where it meets with the line *o p* drawn from *o* at right angles with the axis of the lens, you will have found the magnitude of the imaginary image *o p*; from which it is evident, that this image is always greater than the object O P itſelf, as many times as it is farther from the lens than the object O P. It is likewiſe evident, that this image is not reverſed, as in the preceding caſe, but upright as the object.

You will eaſily comprehend, from what I have ſaid, the benefit that may be derived from lenſes of this ſort, by perſons whoſe ſight is not adapted to the view of near objects, but who can ſee them to more advantage at a conſiderable diſtance. They have only to look at objects through a convex lens, in order to ſee them as if they were very diſtant. The defect of ſight with reſpect to near objects occurs uſually in aged people, who conſequently make uſe of ſpectacles with convex glaſſes, which, expoſed to the ſun, produce the effect of a burning-glaſs, and this aſcertains the focal diſtance of every glaſs. Some perſons have occaſion for ſpectacles of a very near focus, others of one more diſtant, according to the ſtate of their ſight; but it is ſufficient, for my preſent purpoſe, to have given a general idea of the uſe of ſuch ſpectacles.

12th January, 1762.

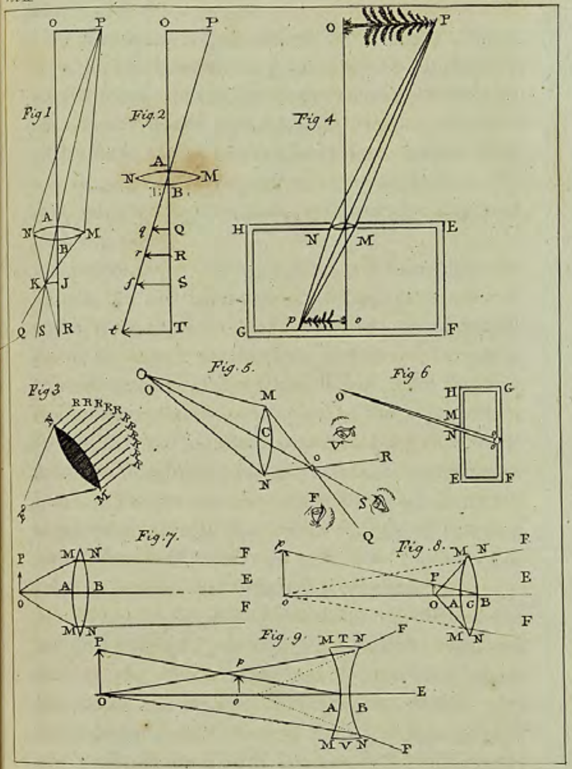
LETTER LXXXIII.

Uſe and Effect of a Concave Lens.

YOU have ſeen how convex glaſſes aſſiſt the ſight of old people, by repreſenting to them objects as at a greater diſtance than they really are: there are eyes, on the contrary, which, in order to diſtinct viſion, require the objects to be repreſented as nearer; and concave glaſſes procure them this advantage: which leads me to the explanation of the effect of concave lenſes, which is directly the contrary of that of the convex.

When the object O P, *(plate VI. fig. 9.)* is very diſtant, and it's rays O M, O M, fall almoſt parallel on the concave lens T V, in this caſe, inſtead of becoming convergent by the refraction of the lens, they, on the contrary, become more divergent, purſuing the direction N F, N F, which, produced backward, meet at the point *o*; ſo that an eye placed, for example, at E, receives theſe refracted rays in the ſame

Vol II. Plate VI.



ſame manner as if they proceeded from the point *o*, though they really proceed from the point O; for this reaſon I have, in the figure, dotted the ſtraight lines N *o*, N *o*.

As the object is ſuppoſed to be infinitely diſtant, were the lens convex the point *o* would be what we call the focus; but as, in the preſent caſe, there is no real concurrence of rays, we call this point, the imaginary focus of the concave lens; ſome authors likewiſe denominate it *the point of diſperſion*, becauſe the rays, refracted by the glaſs, appear to be diſperſed from this point.

Concave lenſes, then, have no real focus, like the convex, but only an imaginary focus, the diſtance of which from the lens A *o* is, however, denominated the focal diſtance of this lens, and ſerves, by means of a rule ſimilar to that which is laid down for convex lenſes, to determine the place of the image, when the object is not infinitely diſtant. Now this image is always imaginary, whereas in the caſe of convex lenſes, it becomes ſo only when the object is nearer than the diſtance of the focus. Without entering into the explication of this rule, which reſpects calculation merely, it is ſufficient to remark:

I. When the object O P is infinitely diſtant, the imaginary image *o p* is repreſented at the focal diſtance of the concave lens, and this too on the ſame ſide with the object. Neverthleſs, though this image be imaginary, the eye placed at E is quite as much affected by it as if it were real, conformably to the explanation given on the ſubject of convex lenſes,

lenſes, when the object is nearer the lens than it's focal diſtance.

II. On bringing the object O P nearer to the lens, it's image *o p* will likewiſe approach nearer, but in ſuch a manner, that the image will always be nearer to the lens than the object is; whereas, in the caſe of convex lenſes, the image is more diſtant from the lens than the object. In order to elucidate this more clearly, let us ſuppoſe the focal diſtance of the concave lens to be 6 inches.

If the Diſtance of the Object O A is	The Diſtance of the Image *o* A will be
Infinite	6
30	5
12	4
6	3
3	2
2	1 and a half.

III. By the ſame rule you may always determine the magnitude of the imaginary image *o p*. You draw from the middle of the lens a ſtraight line, to the extremity of the object P, which will paſs through the extremity *p* of the image. For, ſince the line P A repreſents a ray coming from the extremity of the object, this ſame ray muſt, after the refraction, paſs through the extremity of the image; but, as this ray P A paſſes through the middle of the lens, it undergoes no refraction; therefore it muſt itſelf paſs through the extremity of the image, at the point *p*.

IV. This

IV. This image is not reverſed, but in the ſame poſition with the object; and it may be laid down as a general rule, that whenever the image falls on the ſame ſide of the lens that the object is, it is always repreſented upright, whether the lens be convex or concave; but when repreſented on the other ſide of the lens, it is always reverſed; and this can take place only in convex lenſes.

V. It is evident, therefore, that the images repreſented by concave lenſes are always ſmaller than the objects; the reaſon is obvious, the image is always nearer than the object; you have only to look at the figure to be ſatisfied of this truth. Theſe are the principal properties to be remarked reſpecting the nature of concave lenſes, and the manner in which objects are repreſented by them.

It is now eaſy to comprehend how concave glaſſes may be rendered eſſentially ſerviceable to perſons whoſe ſight is ſhort. You are acquainted with ſome who can neither read nor write without bringing the paper almoſt cloſe to their noſe. In order, therefore, to their ſeeing diſtinctly, the object muſt be brought very near to the organ of viſion; I think I have formerly remarked that ſuch perſons are denominated *Miopes*. Concave lenſes, then, may be made of great uſe to them, for they repreſent the moſt diſtant objects as very near: the image not being farther from ſuch glaſſes than their focal distance, which, for the moſt part, is only a few inches.

Theſe images, it is true, are much ſmaller than the objects themſelves: but this by no means prevents

diſtinctneſs

diſtinctneſs of viſion. A ſmall object near, may appear greater than a very large body at a diſtance. In fact, a *two-dreyer* piece[*] appears to the eye greater than a ſtar in the heavens, though that ſtar far exceed the earth in magnitude.

Perſons whoſe ſight is ſhort, or *Miopes*, have occaſion, then, for glaſſes which repreſent objects as nearer; ſuch are concave lenſes. And thoſe whoſe ſight is long, or *Preſbites*, need convex glaſſes, which repreſent to them objects at a greater diſtance.

16th January, 1762.

LETTER LXXXIV.

Of apparent Magnitude, of the Viſual Angle, and of Microſcopes in general

I HAVE been remarking, that *Miopes* are obliged to make uſe of concave glaſſes to aſſiſt their viſion of diſtant objects, and that *Preſbites* employ convex glaſſes in order to a more diſtinct viſion of ſuch as are near: each ſight has a certain extent, and each requires a glaſs which ſhall repreſent objects perfectly. This diſtance in the *Miopes* is very ſmall, and in the *Preſbites* very great: but there are eyes ſo happily conformed, as to ſee nearer and more diſtant objects equally well.

Nevertheleſs, of whatever nature any perſon's ſight may be, this diſtance is never very ſmall: there is no *Miope* capable of ſeeing diſtinctly at the diſtance of leſs than an inch; you muſt have obſerved, that when the object is brought too cloſe to the eye, it has a very confuſed appearance; this depends on the ſtructure of the organ, which is ſuch in the human ſpecies, as not to admit of their ſeeing objects very near. To inſects, on the contrary, very diſtant objects are inviſible, while they eaſily ſee ſuch as are nearer. I do not believe that a fly is capable of ſeeing the ſtars, becauſe it can ſee extremely well at the diſtance of the tenth part of an inch, a diſtance at which the human eye can diſtinguiſh abſolutely nothing. This leads me to an explanation of the microſcope, which repreſents to us the ſmalleſt object as if it were very great.

In order to convey a juſt idea of it, I muſt entreat you carefully to diſtinguiſh between the apparent and the real magnitude of every object. Real magnitude conſtitutes the object of geometry, and is invariable as long as the body remains in the ſame ſtate. But apparent magnitude admits of infinite variety, though the body may remain always the ſame. The ſtars, accordingly, appear to us extremely ſmall, though their real magnitude is prodigious, becauſe we are at an immenſe diſtance from them. Were it poſſible to approach them, they would appear greater, from which you will conclude, that the apparent magnitude depends on the angle formed in our eyes, by the rays which proceed from the extremities of the object.

Let P O Q *(plate VII. fig. 1.)* be the object of viſion,

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[*] A ſmall ſilver coin, ſomewhat bigger than the pupil of the eye, in value the forty-eighth part of a crown.

ſion, which, if the eye were placed at A, would appear under the angle P A Q, called the viſual angle, and which indicates to us the apparent magnitude of the object; it is evident, on inſpecting the figure, that the farther the eye withdraws from the object, the ſmaller this angle becomes, and that it is poſſible for the greateſt bodies to appear to us under a very ſmall viſual angle, provided our diſtance from them be very great, as is the caſe with the ſtars. But when the eye approaches nearer to the object, and looks at it from B, it will appear under the viſual angle P B Q, which is evidently greater than P A Q. Let the eye advance ſtill forward to C, and the viſual angle P C Q is ſtill greater. Farther, the eye being placed at D, the viſual angle will be P D Q; and on advancing forward to E, the viſual angle will be P E Q, always greater and greater. The nearer, therefore, the eye approaches to the object, the more the viſual angle increaſes, and conſequently likewiſe the apparent magnitude. However ſmall the object may be, it is poſſible, therefore, to increaſe it's apparent magnitude at pleaſure, you have only to bring it ſo near the eye as is neceſſary to form ſuch a viſual angle. A fly near enough to the eye may, of conſequence, appear under an angle as great as an elephant at the diſtance of ten feet. In a compariſon of this ſort, we muſt take into the account the diſtance at which we ſuppoſe the elephant to be viewed: unleſs this is done, we affirm abſolutely nothing; for an elephant appears great only when we are not very far from it; at the diſtance of a mile, it would be

impoſſible, perhaps, to diſtinguiſh an elephant from a pig; and, tranſported to the moon, he would become abſolutely inviſible; and I might affirm with truth, that a fly appeared to me greater than an elephant, if the latter was removed to a very conſiderable diſtance. Accordingly, if we would expreſs ourſelves with preciſion, we muſt not ſpeak of the apparent magnitude of a body, without taking diſtance likewiſe into the account, as the ſame body may appear very great or very ſmall, according as it's diſtance is greater or leſs. It is very eaſy, then, to ſee the ſmalleſt bodies under very great viſual angles; they need only to be placed very cloſe to the eye.

This expedient may be well enough adapted to a fly, but the human eye could ſee nothing at too ſmall a diſtance, however ſhort it's ſight may be; beſides, perſons of the beſt ſight would wiſh to ſee likewiſe the ſmalleſt objects extremely magnified. The thing required, then, is to find the means of enabling us to view an object diſtinctly, notwithſtanding it's great proximity to the eye. Convex lenſes render us this ſervice, by removing the image of objects which are too near.

Let a very ſmall convex lens M N be employed, *(plate VII. fig. 2.)* the focal diſtance of which ſhall be half an inch; if you place before it a ſmall object O P, at a diſtance ſomewhat leſs than half an inch, the lens will repreſent the image of it *o p*, as far off as could be wiſhed. On placing the eye, then, behind the lens, the object will be ſeen as if it were at *o*, and at a ſufficient diſtance, as if it's magnitude were *o p*: as the eye is ſuppoſed very near the lens, the viſual angle will be *p t o*, that is the ſame as P *t* O, under which the naked eye would ſee the object O P in that proximity; but the viſion is become diſtinct by means of the lens: ſuch is the principle on which microſcopes are conſtructed.

19th January, 1762.

LETTER LXXXV.

Eſtimation of the Magnitude of Objects viewed through the Microſcope.

WHEN ſeveral perſons view the ſame object through a microſcope, the foot of a fly, for example, they all agree that they ſee it greatly magnified, but their judgment reſpecting the real magnitude will vary: one will ſay, it appears to him as large as that of a horſe; another, as that of a goat; a third, as that of a cat. No one, then, advances any thing poſitive on the ſubject, unleſs he adds, at what diſtance he views the feet of the horſe, the goat, or the cat. They all mean, therefore, without expreſſing it, a certain diſtance which is undoubtedly different; conſequently there is no reaſon to be ſurprized at the variety of the judgments which they pronounce, as the foot of a horſe, viewed at a diſtance, may very well appear no bigger than that of a cat, viewed near to the eye. Accordingly, when the queſtion is to be decided, How much does the microſcope magnify an object? we muſt accuſtom ourſelves to a more accurate mode of expreſſion, and particularly to ſpecify the diſtance, in the compariſon which we mean to inſtitute.

It is improper, therefore, to compare the appearances preſented to us by the microſcope, with objects of another nature, which we are accuſtomed to view ſometimes near, and ſometimes at a diſtance. The moſt certain method of regulating this eſtimation ſeems to be that which is actually employed by authors who treat of the microſcope. They compare a ſmall object viewed through the microſcope with the appearance which it would preſent to the naked eye, on being removed to a certain diſtance; and they have determined, that, in order to contemplate ſuch ſmall object to advantage by the naked eye, it ought to be placed at the diſtance of eight inches, which is the ſtandard for good eyes, for a ſhort-ſighted perſon would bring it cloſer to the eye, and one far-ſighted would remove it. But this difference does not affect the reaſoning, provided the regulating diſtance be ſettled; and no reaſon can be aſſigned for fixing on any other diſtance than that of eight inches, the diſtance received by all authors who have treated of the ſubject. Thus, when it is ſaid that a microſcope magnifies the object a hundred times, you are to underſtand that, with the aſſiſtance of ſuch microſcope, objects appear a hundred times greater than if viewed at the diſtance of eight inches, and thus you will form a juſt idea of the effect of a microſcope.

In general, a microſcope magnifies as many times as an object appears larger than if it were viewed without the aid of the glaſs, at the diſtance of eight inches. You will readily admit that the effect is ſurprizing, if an object is made to appear even a hundred times greater than it would to the naked eye, at the diſtance of eight inches: but it has been carried much farther, and microſcopes have been conſtructed, which magnify five hundred times, a thing almoſt incredible. In ſuch a caſe it might be with truth affirmed, that the leg of a fly appears greater than that of an elephant. Nay I have full conviction, that it is poſſible to conſtruct microſcopes capable of magnifying one thouſand, or even two thouſand times, which would undoubtedly lead to the diſcovery of many things hitherto unknown.

But when it is affirmed, that an object appears, through the microſcope, a hundred times greater than when viewed at the diſtance of eight inches, it is to be underſtood that the object is magnified as much in length, as in breadth and depth, ſo that each of theſe dimenſions appears a hundred times greater. You have only, then, to conceive, at the diſtance of eight inches, another object ſimilar to the firſt, but whoſe length is a hundred times greater, as well at it's breadth and depth, and ſuch will be the image viewed through the microſcope. Now, if the length, the breadth and depth of an object, be a hundred times greater than thoſe of another, you will eaſily perceive that the whole extent will be much more than a hundred times greater. In order to put this in the cleareſt light, let us conceive two parallelograms A B C D, and E F G H, (*plate VII. fig.* 3.) of the

ſame breadth, but that the length of the firſt A B, ſhall be five times greater than the length of the other E F; it is evident that the area, or ſpace contained in the firſt, is five times greater than that contained in the other, as in fact this laſt is contained five times in the firſt. To render, then, the parallelogram A D, five times greater than the parallelogram E H, it is ſufficient that it's length A B be five times greater, the breadth being the ſame; and if, beſides, the breadth were likewiſe five times greater, it would become five times greater ſtill, that is five times five times, or twenty-five times greater. Thus, of two ſurfaces, if the one be five times longer and five times broader than the other, it is, in fact, twenty-five times greater.

If we take, farther, the height or depth into the account, the increaſe will be ſtill greater. Conceive two apartments, the one of which is five times longer, five times broader and five times higher than the other; it's contents will be five times 25 times, that is 125 times greater. When, therefore, it is ſaid that a microſcope magnifies 100 times, as this is to be underſtood not only of length, but of breadth and depth, or thickneſs, that is of three dimenſions, the whole extent of the object will be increaſed 100 times 100 times 100 times; now 100 times 100 make 10,000, which taken again 100 times make 1,000,000; thus when a microſcope magnifies 100 times, the whole extent of the object is repreſented 1,000,000 times greater. We ſatiſfy ourſelves, however, with ſaying that the microſcope magnifies 100 times; but it is to be underſtood that all the three dimenſions, namely, length, breadth, and depth are repreſented 100 times greater. If then a microſcope ſhould magnify 1000 times, the whole extent of the object would become 1000 times 1000 times 1000 times greater, which makes 1000,000,000, or a thouſand millions: a moſt aſtoniſhing effect! This remark is neceſſary to the formation of a juſt idea of what is ſaid reſpecting the power of microſcopes.

23d January, 1762.

LETTER LXXXVI.

Fundamental Propoſition for the Conſtruction of Simple Microſcopes. Plan of ſome Simple Microſcopes.

HAVING explained in what manner we are enabled to judge of the power of microſcopes, it will be eaſy to unfold the fundamental principle for the conſtruction of ſimple microſcopes. And here it may be neceſſary to remark, that there are two kinds of microſcopes; ſome conſiſting of a ſingle lens, others of two or more, named, accordingly, ſimple or compound microſcopes, and which require particular elucidations. I ſhall confine myſelf, at preſent, to the ſimple microſcope, which conſiſts of a ſingle convex lens, the effect of which is determined by the following propoſition: *A ſimple microſcope magnifies as many times as it's focal diſtance is nearer than eight inches*. The demonſtration follows.

Let M N, *(plate VII. fig.* 4.*)* be a convex lens, whoſe focal diſtance, at which the object O P muſt

be

be placed nearly, in order that the eye may ſee it diſtinctly, ſhall be C O; this object will be perceived under the angle O C P. But if it be viewed at the diſtance of eight inches, it would appear under an angle as many times ſmaller as the diſtance of eight inches ſurpaſſes the diſtance C O: the object will appear, therefore, as many times greater than if it were viewed at the diſtance of eight inches. Now, in conformity to the rule already eſtabliſhed, a microſcope magnifies as many times as it preſents the object greater than if we viewed it at the diſtance of eight inches. Conſequently a microſcope magnifies as many times as it's focal diſtance is leſs than eight inches. A lens, therefore, whoſe focal diſtance is an inch, will magnify preciſely eight times; and a lens whoſe focal diſtance is only half an inch, will magnify ſixteen times. The inch is divided into twelve parts, called *lines;* half an inch, accordingly, contains ſix lines; hence it would be eaſy to determine how many times every lens, whoſe focal diſtance is given in lines, muſt magnify; according to the following table:

Focal diſtance of the lens in lines.

	12.	8.	6.	4.	3.	2.	1.	½	lines
magnifies	8.	12.	16.	24.	32.	48.	96.	192	times

Thus a convex lens, whoſe focal diſtance is one line, magnifies ninety-ſix times, and if the diſtance be half a line, the microſcope will magnify one hundred and ninety-two, that is near two hundred times. Were greater effect ſtill to be deſired, lenſes muſt be conſtructed of a ſtill ſmaller focus. Now, it has been

already

already remarked that, in order to conſtruct a lens of any certain given focus, it is only neceſſary to make the radius of each face equal to that focal diſtance, ſo that the lens may become equally convex on both ſides. I now proceed, then, to place before you *(plate VII. fig. 5.)* the form of ſome of theſe lenſes or microſcopes.

I. The focal diſtance of this lens A O is one inch or twelve lines. This microſcope, therefore, magnifies eight times.

II. The focal diſtance of the lens M N is eight lines. This microſcope magnifies twelve times.

III. The focal diſtance of the lens M N is ſix lines. This microſcope magnifies ſixteen times.

IV. The focal diſtance of this lens is four lines; and ſuch a microſcope magnifies twenty-four times.

V. The focal diſtance here is three lines. This microſcope magnifies thirty-two times.

VI. The focal diſtance here is two lines. This microſcope magnifies forty-eight times.

VII. The focal diſtance of this lens is only one line; and ſuch a microſcope magnifies ninety-ſix times.

It is poſſible to conſtruct microſcopes ſtill much ſmaller. They are actually executed, and much more conſiderable effects are produced; whence it muſt be carefully remarked, that the diſtance of the object from the glaſs becomes ſmaller and ſmaller, as it muſt be nearly equal to the focal diſtance of the lens. I ſay *nearly*, as every eye brings the glaſs cloſer to it, ſomewhat more or leſs, according to it's formation; the ſhort-ſighted apply it cloſer, the far-ſighted leſs ſo. You perceive then, that the effect is greater, as the

microſcope or lens become ſmaller, and the cloſer likewiſe the object muſt be applied; this is a very great inconvenience, for, on the one hand, it is troubleſome to look through a glaſs ſo very ſmall, and, on the other, becauſe the object muſt be placed ſo near the eye. Attempts have been made to remedy this inconvenience, by a proper mounting, which may facilitate the uſe of it; but the viſion of the object is conſiderably diſturbed, as ſoon as the diſtance of it undergoes the ſlighteſt change: and as in the caſe of a very ſmall lens, the object muſt almoſt touch it, whenever the ſurface of the object is in the leaſt degree unequal, it is ſeen but confuſedly. For, while the eminences are viewed at the juſt diſtance, the cavities being too far removed, muſt be ſeen very confuſedly. This renders it neceſſary to lay aſide ſimple microſcopes, when we wiſh to magnify very conſiderably, and to have recourſe to the compound microſcope.

26th January, 1762.

LETTER LXXXVII.

Bounds, and Defects of the Simple Microſcope.

YOU have now ſeen how ſimple microſcopes may be conſtructed, which ſhall magnify as many times as may be deſired; you have only to meaſure off a ſtraight line of eight inches, like that which I have marked A B,* *(plate VII. fig. 6.)* which contains

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* It being impoſſible here to preſent a ſtraight line of eight inches, one of four is employed for the purpoſe of demonſtration.

preciſely

preciſely eight inches of the Rheniſh foot, which is the ſtandard all over Germany. This line A B muſt then be ſubdivided into as many equal parts as correſpond to the number of times you wiſh to magnify the object propoſed, and one of theſe parts will give the focal diſtance of the lens that is requiſite. Thus, if you wiſh to magnify a hundred times, you muſt take the hundredth part of the line A B, conſequently, you muſt conſtruct a lens whoſe focal diſtance ſhall be preciſely equal to that part A 1, which will give, at the ſame time, the radius of the ſurfaces of the lens repreſented in article VII, of the preceding figure. Hence it is evident, that the greater the effect we mean to produce, the ſmaller muſt be the lens, as well as the focal diſtance at which the object O P muſt be placed before the lens, while the eye is applied behind it: and if the lens were to be made twice ſmaller than what I have now deſcribed, in order to magnify two hundred times, it would become ſo minute, as almoſt to require a microſcope to ſee the lens itſelf; beſides it would be neceſſary to approach ſo cloſe, as almoſt to touch the lens, which, as I have already obſerved, would be very inconvenient. The effect of the microſcope, therefore, could hardly be carried beyond two hundred times; which is by no means ſufficient for the inveſtigation of many of the minuter productions of nature. The pureſt water contains ſmall animalcules, which, though magnified two hundred times, ſtill appear no bigger than fleas; and a microſcope which ſhould magnify 20,000 times, would be neceſſary to magnify their appearance to the ſize of a rat, and we are far from reaching

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ing this degree, even with the aſſiſtance of the compound microſcope.

But beſides the inconveniences attending the uſe of ſimple microſcopes which have been already pointed out, all thoſe who employ them, with a view to very great effect, complain of another conſiderable defect; it is this, the more that objects are magnified, the more obſcure they appear; they ſeem as if viewed in a very faint light, or by moon-light, ſo that you can hardly diſtinguiſh any thing clearly. You will not be ſurprized at this, when you recollect, that the light of the full moon is more than two hundred thouſand times fainter than that of the ſun.

It is of much importance, therefore, to explain whence this diminution of light proceeds. We can eaſily comprehend, that if the rays which proceed from a very ſmall object muſt repreſent it to us, as if it were much larger, this ſmall quantity of light would not be ſufficient. But, however well founded this reaſoning may appear, it wants ſolidity, and throws only a falſe light on the queſtion. For if the lens, as it proceeded in magnifying, neceſſarily produced a diminution of clearneſs, this muſt likewiſe be perceptible in the ſmalleſt effects; even ſuppoſing it were not to ſo high a degree; but you may magnify up to fifty times without perceiving the leaſt apparent diminution of light, which, however, ought to be fifty times fainter, if the reaſon adduced were juſt. We muſt look elſewhere, then, for the cauſe of this phenomenon, and even reſort to the firſt principles of viſion.

I muſt

I muſt entreat you, then, to recollect what I have already ſuggeſted reſpecting the uſe of the pupil, or that black aperture which we ſee in the eye at the middle of the iris. It is through this aperture that the rays of light are admitted into the eye; accordingly, the larger this aperture is, the more rays are admitted. We muſt here conſider two caſes, in which objects are very luminous and brilliant, and in which they are illuminated by only a very faint light. In the firſt, the pupil contracts of itſelf, without any act of the will, and the Creator has beſtowed on it this faculty, in order to preſerve the interior of the eye from the too dazzling effect of light, which would infallibly injure the nerves. Whenever, therefore, we are expoſed to a very powerful light, we obſerve that the pupil of every eye contracts, to prevent the admiſſion of any more rays into the eye than are neceſſary to paint in it an image ſufficiently luminous. But the contrary takes place when we are in the dark; the pupil, in that caſe, expands to admit the light in a greater quantity. This change is eaſily perceptible every time we paſs from a dark to a luminous ſituation. With reſpect to the ſubject before us, I confine myſelf to this circumſtance, that the more rays of light are admitted into the eye, the more luminous will be the image tranſmitted to the retina, and reciprocally, the ſmaller the quantity of rays which enter the eye, the fainter does the image become, and conſequently the more obſcure does it appear. It may happen, that though the pupil is abundantly expanded, a few rays only ſhall be admitted into the eye. You have only to prick a little hole in a card with a pin, and look at an object through it; and then, however ſtrongly illuminated by the ſun, the object will appear dark in proportion as the aperture is ſmall, nay, it is poſſible to look at the ſun itſelf, employing this precaution. The reaſon is obvious, a few rays only are admitted into the eye: however expanded the pupil may be, the pin-hole in the card determines the quantity of light which enters the eye, and not the pupil, which uſually performs that function.

The ſame thing takes place in the microſcopes which magnify very much; for when the lens is extremely ſmall, a very few rays only are tranſmitted, as *m n* (*plate VII. fig.* 8.) which being ſmaller than the aperture of the pupil, make the object appear ſo much more obſcure; hence, it is evident, that this diminution of light takes place only when the lens MN, or rather it's open part, is ſmaller than the pupil. If it were poſſible to produce a great magnifying effect by means of a greater lens, this obſcurity would not take place; and this is the true ſolution of the queſtion. In order to remedy this inconvenience, in the great effects of the microſcope, care is taken to illuminate the object as ſtrongly as poſſible, to give greater force to the few rays which are conveyed into the eye. To this effect objects are illuminated by the ſun itſelf, mirrors likewiſe are employed, which reflect on them the light of the ſun. Theſe are, nearly, all the circumſtances to be conſidered reſpecting the ſimple microſcope, and by theſe

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you will eaſily form a judgment of the effect of all thoſe which you may have occaſion to inſpect.

30th January, 1762.

LETTER LXXXVIII.

On Teleſcopes, and their Effect.

BEFORE I proceed to explain the conſtruction of compound microſcopes, a digreſſion reſpecting the teleſcope may perhaps be acceptable. Theſe two inſtruments have a very intimate connection: the one greatly aſſiſts the elucidation of the other. As microſcopes ſerve to aid us in contemplating nearer objects, by repreſenting them under a much greater angle than when viewed at a certain diſtance, ſay eight inches; ſo the teleſcope is employed to aſſiſt our obſervation of very diſtant objects, by repreſenting them under a greater angle than that which they preſent to the naked eye. Inſtruments of this ſort are known by ſeveral names, according to their ſize and uſe; but they muſt be carefully diſtinguiſhed from the glaſſes uſed by aged perſons to relieve the decay of ſight.

A teleſcope magnifies as many times as it repreſents objects under an angle greater than is preſented to the naked eye. The moon, for example, appears to the naked eye under an angle of half a degree, conſequently, a teleſcope magnifies one hundred times, when it repreſents the moon under an angle of fifty degrees, which is one hundred times greater than

half a degree. If it magnified two hundred times, it would repreſent the moon under an angle of one hundred degrees: and the moon would, in that caſe, appear to fill more than half of the viſible heavens, whoſe whole extent is only one hundred and eighty degrees.

In common language, we ſay that the teleſcope brings the object nearer to us. This is a very equivocal mode of expreſſion, and admits of two different ſignifications. The one, that on looking through a teleſcope, we conſider the object as many times nearer as it is magnified. But I have already remarked, that it is impoſſible to know the diſtance of objects but by actual meaſurement, and that ſuch meaſurement can be applied only to objects not greatly remote; when, therefore, they are ſo remote as is here ſuppoſed, the eſtimation of diſtance might greatly miſlead us. The other ſignification, which conveys the idea, that teleſcopes repreſent objects as great as they would appear, if we approached nearer to them, is more conformable to truth. You know that the nearer we come to any object, the greater becomes the angle under which it appears; this explanation, accordingly, reverts to that with which I ſet out. When, however, we look at well-known objects, ſay men, at a great diſtance, and view them through a teleſcope under a much greater angle, we are led to imagine ſuch men to be a great deal nearer, as, in that caſe, we would, in effect, ſee them under an angle ſo much greater. But in examining objects leſs approachable, ſuch as the ſun and moon, no meaſurement of diſtance can take place. This caſe is entirely different from that which I have formerly ſubmitted to you, that of a concave lens, employed by near-ſighted perſons, which repreſents the images of objects at a very ſmall diſtance. The concave lens which I uſe, for example, repreſents to me the images of all remote objects, at the diſtance of four inches; it is impoſſible for me, however, to imagine that the ſun, moon, and ſtars are ſo near; accordingly we do not conclude that objects are where their images are found repreſented by glaſſes: we believe this as little as we do the exiſtence of objects in our eyes, though their images are painted there. You will pleaſe to recollect that the eſtimation of the real diſtance, and real magnitude of objects, depends on particular circumſtances.

The principal end of teleſcopes, then, is to increaſe, or multiply, the angle under which objects appear to the naked eye; and the principal diviſion of teleſcopes is eſtimated by the effect which they procure. Accordingly we ſay ſuch a teleſcope magnifies five, another ten, another twenty, another thirty times, and ſo on. And here I remark that pocket-glaſſes rarely magnify beyond ten times; but the uſual teleſcopes employed for examining very diſtant terreſtrial objects magnify from twenty to thirty times; and their length amounts to ſix feet or more. A ſimilar effect, though very conſiderable with regard to terreſtrial objects, is a mere nothing with reſpect to the heavenly bodies, which require an effect inconceivably greater. We have, accordingly, aſtronomical teleſcopes, which magnify from fifty to two hundred times; and it would be difficult to go farther, as according to the uſual mode of conſtructing them, the greater the effect is, the longer they become. A teleſcope that ſhall magnify one hundred times muſt be at leaſt thirty feet long; and one of a hundred feet in length could ſcarcely magnify two hundred times. You muſt be ſenſible, therefore, that the difficulty of pointing and managing ſuch an unwieldy machine, muſt oppoſe inſurmountable obſtacles to puſhing the experiment farther. The famous Hevelius, the aſtronomer at Dantzick, employed teleſcopes two hundred feet long; but ſuch inſtruments muſt, undoubtedly, have been very defective, as the ſame things are now diſcovered by inſtruments much ſhorter.

This is a brief general deſcription of teleſcopes, and of the different kinds of them, which it is of importance carefully to remark, before we enter into a detail of their conſtruction, and of the manner in which two or more lenſes are united, in order to produce all the different effects.

2d February, 1762.

LETTER LXXXIX.

Of Pocket-Glaſſes.

WE have no certain information reſpecting the perſon to whom we are indebted for the diſcovery of the teleſcope; whether he were a Dutch artiſt, or an Italian of the name of Porta. Whoever he was, it is almoſt one hundred and fifty years ſince ſmall pocket glaſſes were firſt conſtructed, compoſed of two lenſes, of which the one was convex, and the other concave. To pure chance, perhaps, a diſcovery of ſo much utility is to be aſcribed. It was poſſible, without deſign, to place two lenſes nearer to, or farther from each other, till the object appeared diſtinctly.

The convex lens PAP *(plate VII. fig. 9.)* is directed toward the object, and the eye is applied to the concave lens QBQ: for which reaſon the lens PAP is named the objective, and QBQ the ocular lens. Theſe two lenſes are diſpoſed on the ſame axis AB, perpendicular to both, and paſſing through their centres. The focal diſtance of the convex lens PAP muſt be greater than that of the concave; and the lenſes muſt be diſpoſed in ſuch a manner, that if AF be the focal diſtance of the objective PAP, the focus of the ocular QBQ muſt fall at the ſame point F; accordingly, the interval between the lenſes A and B, is the difference between the focal diſtances of the two lenſes, AF being the focal diſtance of the objective, and BF that of the ocular. When the lenſes are arranged, a perſon with good eyes will clearly ſee diſtant objects, which will appear as many times greater as the line AF is greater than BF. Thus, ſuppoſing the focal diſtance of the objective to be ſix inches, and that of the ocular one inch, the object will be magnified ſix times, or will appear under an angle ſix times greater than when viewed with the naked eye, and, in this caſe, the interval between the

lenſes A and B will be five inches, which is, at the ſame time, the length of the inſtrument. There is no need to inform you that theſe two lenſes are caſed in a tube of the ſame length, though not thus repreſented in the figure.

Having ſhewn in what manner the two lenſes are to be joined together in order to produce a good inſtrument, two things muſt be explained to you: the one, How theſe lenſes come to repreſent objects diſtinctly; and the other, Why they appear magnified as many times as the line AF exceeds the line BF. With reſpect to the firſt, it muſt be remarked, that a good eye ſees objects beſt, when they are ſo diſtant that the rays which fall on the eye may be conſidered as parallel to each other.

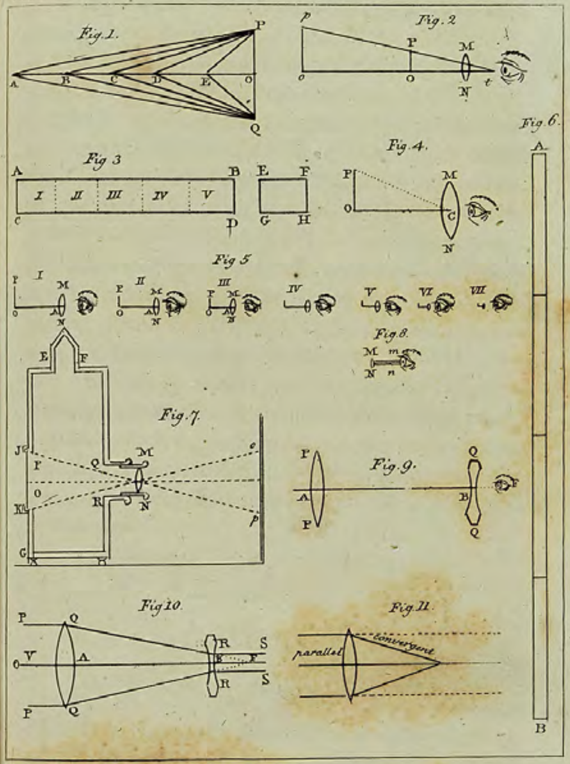
Let us conſider, then, a point V *(plate VII. fig. 10.)* in the object toward which the inſtrument is directed, and on the ſuppoſition of it's being very diſtant, the rays which fall on the objective PQ, OA, PQ, will be almoſt parallel to each other; accordingly, the objective QAQ, being a convex lens, will collect them in it's focus F, ſo that theſe rays, being convergent, will not ſuit a good eye. But the concave lens at B, having the power of rendering the rays more divergent, or of diminiſhing their convergency, will refract the rays QR, QR, ſo that they ſhall become parallel to each other; that is, inſtead of meeting in the point F, they will aſſume the direction RS, RS, parallel to the axis BF. Thus a good eye, according to which the conſtruction of theſe is always regulated, on receiving theſe parallel rays RS, BF, RS, will ſee the object diſtinctly. The rays RS, RS, become exactly parallel to each other, becauſe the concave lens has it's focus, or rather it's point of diſperſion, at F.

You have only to recollect that, when parallel rays fall on a concave lens, they become divergent by refraction, ſo that being produced backward, they meet in the focus. This being laid down, we have only to reverſe the caſe, and to conſider the rays SR, SR, as falling on the concave lens; in this caſe it is certain they would aſſume the directions RQ, RQ, which, produced backward, would meet in the point F, which is the common focus of the convex and concave lenſes. Now it is a general law, that in whatever manner rays are refracted in their paſſage from one place to another, they muſt always undergo the ſame refractions in returning from the laſt to the firſt. If, therefore, the refracted rays RQ, RQ, correſpond to the incident rays SR, SR; then, reciprocally, the rays QR, QR, being the incident, the refracted rays will be RS and RS.

The matter will, perhaps, appear in a clearer light ſtill, when I ſay, that concave lenſes have the power of rendering parallel thoſe rays which, without the refraction, would proceed to their focus. You will pleaſe carefully to attend to the following laws of refraction, which apply to both convex and concave lenſes.

I. By a convex lens (*plate VII. fig.* 11.) parallel rays are rendered convergent.

Convergent



Convergent rays become ſtill more ſo, (*plate VIII. fig.* 1.) and divergent leſs divergent.

II. By a concave lens parallel rays are rendered divergent. (*Plate VIII. fig.* 2.)

Divergent rays become ſtill more divergent, *fig.* 3. and convergent rays leſs convergent.

All this is founded on the nature of refraction, and the figure of the lenſes, the diſcuſſion of which would require a very long detail; but the two rules which I have now laid down, contain all that is eſſential. It is abundantly evident, then, that when the convex and the concave lenſes are ſo combined, that they acquire a common focus at F, they will diſtinctly repreſent diſtant objects, becauſe the paralleliſm of the rays is reſtored by the concave lens, after the convex lens had rendered them convergent. In other words, the rays of very diſtant objects, being nearly parallel to each other, become convergent by a convex lens, and afterwards, the concave lens deſtroys this convergency, and again renders the rays parallel to each other.

6th February, 1762.

LETTER XC.

On the magnifying Power of Pocket Glaſſes

THE principal article reſpecting teleſcopical inſtruments, remains ſtill to be explained, namely, their effect in magnifying objects. I hope to place this in ſo clear a light, as to remove every difficulty in which the ſubject may be involved; and for this purpoſe I ſhall comprize what I have to ſay, in the following propoſitions.

I. Let E *e* (*plate VIII. fig.* 4.) be the object, ſituated on the axis of the inſtrument which paſſes perpendicularly through both lenſes in their centres. This object E *e* muſt be conſidered as at an infinite diſtance.

II. If then the eye, placed at A, looks at this object, it will appear under the angle E A *e*, called it's viſual angle. It will, accordingly, be neceſſary to prove, that on looking at the ſame object through the glaſs, it will appear under a greater angle, and exactly as many times greater as the focal diſtance of the objective lens P A P exceeds that of the ocular Q B Q.

III. As the effect of all lenſes conſiſts in repreſenting the objects in another place, and with a certain magnitude, we have only to examine the images which ſhall be ſucceſſively repreſented by the two lenſes, the laſt of which is the immediate object of the ſight of the perſon who looks through the inſtrument.

IV. Now, the object E *e* being infinitely diſtant from the convex lens P A P, it's image will be repreſented behind the lens at F *f*, ſo that A F ſhall be equal to the focal diſtance of the lens; and the magnitude of this image F *f* is determined by the ſtraight line *f* A *e* drawn from the extremity of the object *e* through the centre of the lens A, by which we ſee that this image is inverted, and as many times ſmaller than

the object, as the diſtance A F is ſmaller than the diſtance A E.

V. Again, this image F *f* holds the place of the object, relatively to the ocular lens Q B Q: as the rays which fall on this lens are preciſely thoſe which would almoſt form the image F *f*, but are intercepted in their progreſs by the concave lens Q B Q; ſo that this image is only imaginary; the effect, however, is the ſame as if it were real.

VI. This image F *f*, which we are now conſidering as an object, being at the focal diſtance of the lens Q B Q, will be tranſported, almoſt to infinity, by the refraction of this lens. The preceding figure marks this new image at G *g*, whoſe diſtance A G muſt be conceived as infinite, and the rays, refracted a ſecond time by the lens Q B Q, will purſue the ſame direction as if they actually proceeded from the image G *g*.

VII. This ſecond image G *g* being, then, the object of the perſon who looks through the inſtrument, it's magnitude falls to be conſidered. To this effect, as it is produced by the firſt image F *f* from the refraction of the lens Q B Q, following the general rule, we have only to draw through the centre of the lens B a ſtraight line, which ſhall paſs through the point *f* of the firſt image, and that line will mark, at *g*, the extremity of the ſecond image.

VIII. Let the ſpectator now apply his eye to B; and as the rays which it receives purſue the ſame direction as if they actually proceeded from the image G *g*, it will appear to him under the angle G B *g*, which

which is greater than the angle EAe, under which the object Ee appears to the naked eye.

IX. In order the better to compare theſe two angles, it is evident, firſt, that the angle EAe is equal to the angle FAf, being vertical angles; for the ſame reaſon the angle GBg is equal to the angle FBf, being vertical and oppoſite at the point B. It remains to be proved, therefore, that the angle FBf exceeds the angle FAf as many times as the line AF exceeds the line Bf; the former of which, AF, is the focal diſtance of the objective, and the other, BF, the focal diſtance of the ocular.

X. In order to demonſtrate this, we muſt have recourſe to certain geometrical propoſitions reſpecting the nature of ſectors. You will recollect that the ſector is part of a circle contained between two radii CM and CN, and an arch or portion of the circumference MN. In a ſector, then, there are three things to be conſidered; 1. The radius of the circle, CM or CN: 2. The quantity of the arch MN: 3. The angle MCN.

XI. Let us now conſider two ſectors, MCN and mcn (*plate VIII. fig.* 5.) whoſe radii CM and cm are equal to each other: now it is demonſtrated in the elements of geometry, that the angles C and c have the ſame proportion to each other, that the arches MN and mn have; in other words, the angle C is as many times greater than the angle c, as the arch MN is greater than the arch mn: but, inſtead of this aukward mode of expreſſion, we ſay, that

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the angles C and c are proportional to the arches MN and mn, the radii being equal.

XII. Let us likewiſe conſider two ſectors, MCN and mcn (*fig.* 6.) whoſe angles C and c are equal to each other, but the radii unequal: and it is demonſtrated in geometry, that the arch MN is as many times greater than the arch mn, as the radius CM is greater than the radius cm: or, in geometrical language, the arches are in proportion to the radii, the angles being equal. The reaſon is obvious; for every arch contains as many degrees as it's angle; and the degrees of a great circle exceed thoſe of a ſmall one as many times as the greater radius exceeds the ſmaller.

XIII. Finally, let us conſider likewiſe the caſe when, as in the two ſectors MCN and mcn (*fig.* 7.) the arches MN and mn are equal, but the radii CM and cm unequal.

In this caſe, the angle C, which correſponds to the greater radius CM, is the ſmaller, and the angle c, which correſponds to the ſmaller radius cm, is the greater, and this in the ſame proportion as the radii. That is, the angle c is as many times greater than the angle C, as the radius CM is greater than the radius cm: or, to ſpeak geometrically, the angles are reciprocally proportional to the radii, the arches being equal.

XIV. This laſt propoſition carries me forward to my concluſion, after I have ſubjoined this remark, that when the angles are very ſmall, as in the caſe of pocket-glaſſes, there is no ſenſible difference in the

chords

chords of the arches MN and *m n*, that is of the ſtraight lines MN, and *m n*.

XV. Having made this remark, we return to *fig.* 4. The triangles FA*f* and FB*f* may be conſidered as ſectors, in which the arch F*f* is the ſame in both. Conſequently the angle FB*f* exceeds the angle FA*f* as often as the diſtance AF exceeds the diſtance BF. That is, the object E*e* will appear through the inſtrument, under an angle as many times greater as the focal diſtance of the objective AF exceeds the focal diſtance of the ocular BF: which was the thing to be demonſtrated.

9th February, 1762.

LETTER XCI.

Defects of Pocket Glaſſes. Of the apparent Field.

YOU muſt be ſenſible that no great advantage is to be expected from ſuch ſmall inſtruments; and it has already been remarked that they do not magnify objects above ten times. Were the effect to be carried farther, not only would the length become too great to admit of their being carried about in the pocket, but they would become ſubject to other and more eſſential defects. This has induced artiſts entirely to lay aſide glaſſes of this ſort, when ſuperior effect is required.

The principal of theſe defects is the ſmallneſs of the apparent field; and this leads me forward to explain an important article relating to teleſcopes of every

deſcription. When a teleſcope is directed toward the heavens, or to very diſtant objects on the earth, the ſpace diſcovered appears in the figure of a circle, and we ſee thoſe objects only which are included in that ſpace; ſo that if you wiſhed to examine other objects, the poſition of the inſtrument muſt be altered. This circular ſpace, preſented to the eye of the ſpectator, is denominated the *apparent field*, or, in one word, *the field* of the inſtrument: and it is abundantly obvious, that it muſt be a great advantage to have a very large field, and that, on the contrary, a ſmall field is a very great inconvenience, in inſtruments of this ſort. Let us ſuppoſe two teleſcopes directed toward the moon, by the one of which we can diſcover only the half of that luminary, whereas by the other we ſee her whole body, together with the neighbouring ſtars; the field of this laſt is, therefore, much greater than that of the other. That which preſents the greater field relieves us not only from the trouble of frequently changing the poſition, but procures another very great advantage; that of enabling us to compare, by viewing them at the ſame time, ſeveral parts of the object, one with another.

It is, therefore, one of the greateſt perfections of a teleſcope to preſent a very ample field; and it is, accordingly, a matter of much importance to meaſure the field of every inſtrument. In this view, we are regulated by the heavens, and we determine the circular ſpace ſeen through a teleſcope, by meaſuring it's diameter in degrees and minutes. Thus, the apparent

parent diameter of the full moon, being about half a degree, if a teleſcope takes in the moon only, we ſay that the diameter of it's field is half a degree; and if you could ſee at once only the half of the moon, the diameter of the field would be the quarter of a degree.

The meaſurement of angles, then, furniſhes the means of meaſuring the apparent field; beſides, the thing is ſufficiently clear of itſelf. Suppoſing we could ſee through the inſtrument AB (*plate VIII. fig.* 8.) only the ſpace POP, and the objects which it contains: this ſpace being a circle, it's diameter will be the line POP, whoſe middle point O is in the axis of the inſtrument. Drawing, therefore, from the extremities PP the ſtraight lines PC, PC, the angle PCP will expreſs the diameter of the apparent field, and the half of this angle OCP is denominated the ſemi-diameter of the apparent field of ſuch an inſtrument. You will perfectly comprehend the meaning, then, when it is ſaid that the diameter of the apparent field of ſuch an inſtrument is one dedegree, that of another two degrees, and ſo on; as alſo when it is marked by minutes, as 30 minutes which make half a degree, or 15 minutes which make the fourth part of a degree.

But in order to form a right judgment of the value of a teleſcope, with reſpect to the apparent field, we muſt likewiſe attend to the magnifying power of the inſtrument. It may be remarked, in general, that the more a teleſcope magnifies, the ſmaller, of neceſſity, muſt be the apparent field; theſe are the

bounds which nature herſelf has preſcribed. Let us ſuppoſe an inſtrument which ſhould magnify 100 times; it is evident that the diameter of the field could not poſſibly be ſo much as two degrees: for, as this ſpace would appear 100 times greater, it would reſemble a ſpace of two hundred degrees; greater, of conſequence, than the whole viſible heavens, which, from the one extremity to the other, contain only 180 degrees, and of which we can ſee but the half at moſt at once, that is a circular ſpace of 90 degrees in diameter. From this you ſee, that a teleſcope which magnifies 100 times could not contain a field of ſo much as one degree; for this degree multiplied 100 times would give more than 90 degrees; and that, accordingly, a teleſcope which magnified 100 times would be excellent, if the diameter of it's field were ſomewhat leſs than one degree: and the very nature of the inſtrument admits not of a greater effect.

But another teleſcope, which ſhould magnify only 10 times, would be extremely defective, if it diſcovered a field of only one degree in diameter; as this field magnified 10 times would give a ſpace of no more than ten degrees in the heavens, which would be a ſmall matter, by ſetting too narrow bounds to our view. We ſhould have good reaſon, then, to reject ſuch an inſtrument altogether. Thus it would be very eaſy, with reſpect to the apparent field, to form a judgment of the excellence or defectiveneſs of inſtruments of this ſort, when the effect is taken into conſideration. For when it magnifies only 10 times, it may fairly be conjectured, that it diſcovers a field of 9 degrees; as 9 degrees taken 10 times give 90 degrees, a ſpace which our ſight is capable of embracing: and if the diameter of it's field were only 5 degrees, or leſs, this would be an inſtrument very defective indeed. Now I ſhall be able to demonſtrate, that if a teleſcope were to be conſtructed ſuch as I have been deſcribing, which ſhould magnify more than 10 times, it would be liable to this defect: the apparent field multiplied by the magnifying power would be very conſiderably under 90 degrees, and would not even ſhew the half. But when a ſmall effect is aimed at, this defect is not ſo ſenſible; for if ſuch an inſtrument magnifies only 5 times, the diameter of it's field is about 4 degrees, which, magnified 5 times, contains a ſpace of 20 degrees, with which we have reaſon to be ſatisfied: but if we wiſhed to magnify 25 times, the diameter of the field would be only half a degree, which taken 25 times, would give little more than 12 degrees, which is too little. When therefore we would magnify very much, a different arrangement of lenſes muſt be employed, which I ſhall afterward explain.

13th February, 1762.

LETTER XCII.

Determination of the apparent Field for Pocket Glaſſes.

TO aſcertain the apparent field being of very great importance in the conſtruction of teleſcopes, I proceed to the application of it to the ſmall glaſſes which I have been deſcribing.

The lens P A P, (*plate VIII. fig.* 4.) is the objective, Q B Q the ocular, and the ſtraight line E F the axis of the inſtrument, in which is ſeen, at a very great diſtance, through the inſtrument, the object E *e*, under the angle E A *e*, which repreſents the ſemi-diameter of the apparent field, for it extends as far on the other ſide downward. The point E, then, is the centre of the ſpace ſeen through the inſtrument, the radius of which, E A, as it paſſes perpendicularly through both lenſes, undergoes no refraction; and in order that this ray may have admiſſion into the eye, the eye muſt be fixed ſomewhere on the axis of the inſtrument B F, behind the ocular lens, ſo that the centre of the pupil ſhall be in the line B F; and this is a general rule for every ſpecies of teleſcope. Let us now conſider the viſible extremity of the object *e*, whoſe rays exactly fill the whole opening of the objective lens P A P; but it will be ſufficient to attend only to the ray E A, which paſſes through the centre of the objective A, as the others ſurround, and little more than ſtrengthen this ray; ſo that if it is admitted into the eye, the others, or at leaſt a conſiderable part of them, find admiſſion likewiſe; and if this ray is not admitted into the eye, though perhaps ſome of the others may enter, they are too feeble to excite an impreſſion ſufficiently powerful. Hence, this may be laid down as a rule, that the extremity e of the object is ſeen, only ſo far as the ray e A, after having paſſed through the two lenſes, is admitted into the eye.

We muſt, therefore, carefully examine the direction of this ray e A. Now, as it paſſes through the centre of the objective A, it undergoes no refraction; conformably to the rule laid down from the beginning, That rays paſſing through the centre of any lens whatever are not diverted from their direction, that is, undergo no refraction. This ray, e A, therefore, after having paſſed through the objective, would continue in the ſame direction, to meet the other rays iſſuing from the ſame point e, to the point f of the image repreſented by the objective at F f, the point f being the image of the point e of the object; but the ray meeting, at m, the concave lens, but not in it's centre, will be diverted from that direction; and inſtead of terminating in f, will aſſume the direction $m\,n$, more divergent from B F, it being the natural effect of concave lenſes to render rays always more divergent. In order to aſcertain this new direction $m\,n$, you will pleaſe to recollect that the objective lens repreſents the object E e in an inverted poſition at F f, ſo that A F is equal to the focal diſtance of this lens, which tranſports the object E e to F f. Then this image F f occupies the place

place of the object, with reſpect to the ocular lens Q B Q, which, in it's turn, tranſports that image to G g, whoſe diſtance B G muſt be as great as that of the object itſelf; and for this effect, it is neceſſary to place the ocular lens in ſuch a manner that the interval B F ſhall be equal to it's focal diſtance.

As to the magnitude of theſe images, the firſt F f is determined by the ſtraight line e A f drawn from e through the centre A of the firſt lens; and the other G g by the ſtraight line f B g drawn from the point f through the centre B of the ſecond lens. This being laid down, the ray A m directed toward the point f is refracted, and proceeds in the direction $m\,n$; and this line $m\,n$ being produced backward will paſs through the point g, for $m\,n$ has the ſame effect in the eye, as if it actually proceeded from the point g. Now, as this line $m\,n$ retires farther and farther from the axis B F, where the centre of the pupil is, it cannot enter into the eye, unleſs the opening of the pupil extends ſo far; and if the opening of the pupil were reduced to nothing, the ray $m\,n$ would be excluded from the eye, and the point e of the object could not be viſible, nor even any other point of the object out of the axis A F. There would, therefore, be no apparent field, and nothing would be ſeen, through ſuch an inſtrument, except the ſingle point E of the object, which is in it's axis. It is evident, then, that a teleſcope of this ſort diſcovers no field, but as far as the pupil expands, ſo that in proportion as the expanſion of the pupil is greater or leſs, ſo likewiſe the apparent field is great or ſmall.

In this caſe, the point *e* will therefore be ſtill viſible to the eye, if the ſmall interval B *m* does not exceed half the diameter of the eye, that the ray *m n* may find admiſſion into it; but in this caſe, likewiſe, the eye muſt be brought as cloſe as poſſible to the ocular lens: for as the ray *m n* removes from the axis F B, it would eſcape the pupil at a greater diſtance.

Now it is eaſy to determine the apparent field which ſuch an inſtrument would diſcover on the ocular lens: you have only to take the interval B *m* equal to the ſemi-diameter of the pupil, and to draw through that point *m*, and the centre of the objective lens A, the ſtraight line *m* A *e*, then this line will mark on the object the extremity *e*, which will be ſtill viſible through the inſtrument, and the angle E A *e* will give the ſemi-diameter of the apparent field. Hence you will eaſily judge, that whenever the diſtance of the lenſes A B exceeds ſome inches, the angle B A *m* muſt become extremely ſmall, as the line or the diſtance B *m* is but about the twentieth part of an inch. Now if it were intended to magnify very much, the diſtance of the lenſes muſt become conſiderable, and the conſequence would be, that the apparent field muſt become extremely ſmall. The ſtructure of the human eye, then, ſets bounds to teleſcopes of this deſcription, and obliges us to have recourſe to others of a different conſtruction, whenever we want to produce very conſiderable effect.

16th February, 1762.

LETTER XCIII.

Aſtronomical Teleſcopes, and their magnifying Powers.

I PROCEED to the ſecond ſpecies of teleſcopes, called aſtronomical, and remark that they conſiſt of only two lenſes, like thoſe of the firſt ſpecies; with this difference, that in the conſtruction of aſtronomical teleſcopes, inſtead of a concave ocular lens, we employ a convex.

The objective P A P (*plate VIII. fig.* 9.) is, as in the other ſpecies, convex, whoſe focus being at F, we fit, on the ſame axis, a ſmaller convex lens Q Q, in ſuch a manner that it's focus ſhall likewiſe fall on the ſame point F. Then placing the eye at O, ſo that the diſtance B O ſhall be nearly equal to the focal diſtance of the ocular Q Q, you will ſee objects diſtinctly, and magnified as many times as the focal diſtance of the objective A F ſhall exceed that of the ocular B F: but it is to be remarked that every object will appear in an inverted poſition, ſo that if the inſtrument were to be pointed toward a houſe, the roof would appear undermoſt, and the ground-floor uppermoſt. As this circumſtance would be aukward in viewing terreſtrial objects, which we never ſee in an inverted ſituation, the uſe of this ſpecies of teleſcopes is confined to the heavenly bodies, it being a matter of indifference in what direction they appear: it is ſufficient to the aſtronomer to know that what he ſees uppermoſt is really undermoſt, and reciprocally. Nothing, however, forbids the application of ſuch teleſcopes to terreſtrial objects; the eye ſoon becomes accuſtomed to the inverted poſition, provided the object is ſeen diſtinctly and very much magnified.

Having given this deſcription, three things fall to be demonſtrated: firſt, that by this arrangement of the lenſes objects muſt appear diſtinctly; ſecondly, that they muſt appear magnified as many times as the focal diſtance of the objective lens exceeds that of the ocular, and in an inverted poſition; and thirdly, that the eye muſt not be applied cloſe to the ocular lens, as in the firſt ſpecies, but muſt be removed to nearly the focal diſtance of the ocular.

1. As to the firſt, it is demonſtrated in the ſame manner as in the preceding caſe: the rays *e* P, *e* P, which are parallel before they enter into the objective lens, meet by refraction in the focus of this lens at F; the ocular lens muſt, of courſe, reſtore the paralleliſm of theſe rays, and diſtinct viſion requires that the rays, proceeding from every point, ſhould be nearly parallel to each other when they enter the eye. Now, the ocular lens, having it's focus at F, is placed in ſuch a manner as to render the rays F M, F M, by the refraction, parallel, and conſequently the eye will receive the rays N *o*, N *o*, parallel to each other.

2. With reſpect to the ſecond article, let us conſider the object at E *e*, (*plate VIII. fig.* 10.) but ſo as that the diſtance E A ſhall be almoſt infinite. The image of this object, repreſented by the objective lens, will therefore be F *f*, ſituated at the focal diſtance of that lens A F, and determined by the ſtraight line *e* A *f*, drawn through the centre of the lens. This image F *f*, which is inverted, occupies the place of the object with reſpect to the ocular lens, and being in it's focus, the ſecond image will be again removed to an infinite diſtance by the refraction of this lens, and will fall, for example, at G *g*, the diſtance A G being conſidered as infinite, like that of A E. Now, in order to determine the magnitude of this image, you have only to draw through the centre B of the lens, and the extremity *f* of the firſt image, the ſtraight line B *f g*. Now this ſecond image G *g* being the immediate object of viſion to the perſon who looks through the teleſcope, it is evident at once that this repreſentation is inverted; and, as it is infinitely diſtant, will appear under an angle G B *g*. But the object itſelf E *e* will appear to the naked eye under the angle E A *e*: now you are ſenſible, without being reminded, that it is indifferent to take the points A and B, in order to have the viſual angles E A *e* and G B *g*, on account of the infinite diſtance of the object. You now ſee here, as in the preceding caſe, that the triangles F A *f* and F B *f* may be conſidered as circular ſectors, the line F *f* meaſuring the arch of both, and the angles themſelves being ſo very ſmall, no ſenſible miſtake can be committed in taking the chord for the arch. As, then, the radii of theſe two ſectors are the lines A E and B F, the arches being equal to each other, it follows, as was formerly demonſtrated, that the angles F A *f* (or, which is the

ſame thing, E A *e*) and F B *f* (or, which is the ſame thing, G B *g*) have the ſame proportion to each other that the radii B F and A F have. Therefore, the angle G B *g*, under which the object is ſeen through the teleſcope, as many times exceeds the angle E A *e*, under which the object is ſeen by the naked eye, as the line A F exceeds the line B F; which was the ſecond point to be demonſtrated. I am under the neceſſity of deferring the demonſtration of my third propoſition till next poſt.

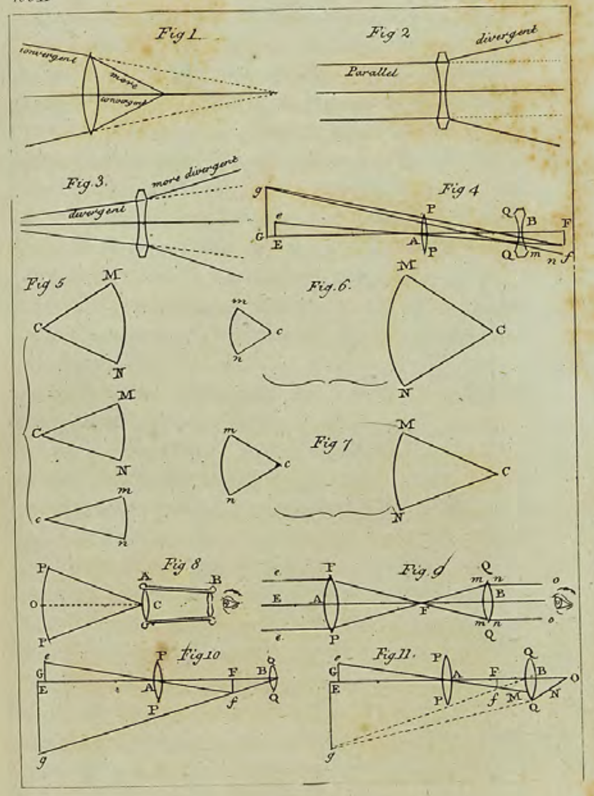
20th February, 1762.

LETTER XCIV.

Of the apparent Field, and the Place of the Eye.

IN fulfilling my engagement reſpecting the third particular propoſed, namely to determine the place of the eye behind the teleſcope, I remark that this article is moſt intimately connected with the apparent field, and that it is preciſely the field which obliges us to keep the eye fixed at the proper diſtance; for if it were to be brought cloſer, or removed farther off, we ſhould no longer diſcover ſo large a field.

The extent of the field being an article of ſuch importance, indeed ſo eſſential, in all teleſcopes, it muſt be of equal importance to determine exactly the place of the eye from which the largeſt field is diſcoverable. If the eye were to be applied cloſe to the ocular lens, we ſhould have nearly the ſame field as we have



with the pocket-glaſs, which becomes inſufferably ſmall, whenever the magnifying power is conſiderable. It is, therefore, a vaſt advantage to aſtronomical teleſcopes, that by withdrawing the eye from the ocular lens, the apparent field increaſes to a certain extent: and it is preciſely this which renders ſuch teleſcopes ſuſceptible of prodigious magnifying powers, whereas thoſe of the firſt ſpecies are, in this reſpect, extremely limited. You know that with the aſtronomical teleſcope, the magnifying power has been carried beyond two hundred times, which gives them an inconceivable ſuperiority over thoſe of the firſt ſpecies, which can ſcarcely magnify ten times; and the trifling inconvenience of the inverted poſition is infinitely overbalanced by an advantage ſo very great.

I will endeavour to put this important article in the cleareſt light poſſible.

1. The object E *e* (*plate VIII. fig.* 11.) being infinitely diſtant, let *e* be it's extremity, ſtill viſible through the teleſcope, whoſe lenſes are P A P and Q B Q, fitted on the common axis E A B O, it falls to be attentively conſidered what direction will be purſued by the ſingle ray which paſſes from the extremity *e* of the object, through the centre A of the objective lens. You will recollect that the other rays, which fall from the point *e* on the objective lens only accompany and ſtrengthen the ray in queſtion *e* A, which is the principal with reſpect to viſion.

2. Now this ray *e* A, paſſing through the centre

of the lens P P, will undergo no refraction, but will purſue it's direction in the ſtraight line A f m, and paſſing through the extremity of the image F f will fall on the ocular lens at the point m; and here it is to be obſerved, that if the ſize of the ocular lens had not extended ſo far as the point m, this ray would never have reached the eye, and the point e would have been inviſible. That is to ſay, it would be neceſſary to take the extremity e nearer to the axis, in order that the ray A f m may meet the ocular lens.

3. Now this ray A m will be refracted, by the ocular lens, in a way which it is very eaſy to diſcover. We have only to conſider the ſecond image G g, though infinitely diſtant, it is ſufficient to know that the ſtraight line B f produced will paſs through the extremity g of the ſecond image G g, which is the immediate object of viſion. Having remarked this, the refracted ray muſt aſſume the direction n O, and this produced paſſes through g.

4. As, therefore, the two lines O n and B f meet at an infinite diſtance at g, they may be conſidered as parallel to each other; and hence we acquire an eaſier method to determine the poſition of the refracted ray n O: you have only to draw it parallel to the line B f.

5. Hence it is clearly evident that the ray n O will ſomewhere meet the axis of the teleſcope at O, and as uſually, when the magnifying power is great, the point F is much nearer to the lens Q Q than to the lens P P, the diſtance B m will be ſomewhat greater than the image F f: and as the line n O is parallel to f B, the line B O will be nearly equal to B F, that is, to the focal diſtance of the ocular lens.

6. If, then, the eye is placed at O, it will receive not only the rays which proceed from the middle of the object E, but thoſe likewiſe which proceed from the extremity e, and conſequently, thoſe alſo which proceed from every point of the object; the eye would even receive at once the rays B O and n O, even ſuppoſing the pupil infinitely contracted. In this caſe, therefore, the apparent field does not depend on the largeneſs of the aperture of the pupil, provided the eye be placed at O, but the moment it recedes from this point, it muſt loſe conſiderably in the apparent field.

7. If the point m were not in the extremity of the ocular lens, it would tranſmit rays ſtill more remote from the axis, and the teleſcope would, of courſe, diſcover a larger field. In order then, to determine the real apparent field which the teleſcope is capable of diſcovering, let there be drawn, from the centre A of the objective lens, to the extremity m of the ocular, the ſtraight line A m, which, produced to the object, will mark at e the viſible extremity; and conſequently the angle E A e, or, which is the ſame thing, the angle B A m, will give the ſemi-diameter of the apparent field, which is, conſequently, greater in proportion as the extent of the ocular lens is greater.

8. As, then, in the firſt ſpecies of teleſcopes, the apparent field depended entirely on the aperture of the

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the pupil, and as in this caſe it depends entirely on the aperture of the ocular lens, there is an eſſential difference between theſe two ſpecies of inſtruments, greatly in favour of the latter. The figure which I have employed in demonſtrating this laſt article, reſpecting the place of the eye and the apparent field, may greatly aſſiſt in the elucidation of the preceding articles.

If you will be ſo good as to reflect, that the objective lens tranſports the object Ee to Ff, and that the ocular lens tranſports it from Ff to Gg; this image Gg being very diſtant from the immediate object of viſion, ought to be ſeen diſtinctly, as a good eye requires a great diſtance in order to ſee thus. This was the firſt article.

As to the ſecond, it is evident at firſt ſight, that as inſtead of the real image Ee we ſee through the teleſcope the image Gg, it muſt be inverted. Finally, this image is ſeen by the eye placed at O under the angle GOg, or BOn, whereas the object itſelf Ee appears to the naked eye under the angle EAe: the teleſcope, therefore, magnifies as many times as the angle BOn is greater than the angle EAe. Now, as the line nO is parallel to Bf, the angle BOn is equal to the angle FBf, and the angle EAe is equal to it's oppoſite and vertical angle FAf; hence the magnifying power muſt be eſtimated from the proportion between the angles FBf and FAf; accordingly, as the angle FBf contains the angle FAf as often as the line AF, that is the focal diſtance of the objective lens, contains the line BF, that is the focal diſtance of the ocular, the magnifying power will be, therefore, expreſſed by the proportion of theſe two diſtances. This is proof ſufficient that the elements of geometry may be ſucceſsfully employed in reſearches of quite a different nature; a reflection not unpleaſing to the mathematician.

23d February, 1762.

LETTER XCV.

Determination of the magnifying Power of Aſtronomical Teleſcopes, and the Conſtruction of a Teleſcope which ſhall magnify Objects a given Number of Times.

YOU now have it clearly aſcertained, not only how many times a propoſed inſtrument will magnify, but what is the mode of conſtructing a teleſcope which ſhall magnify as many times as may be wiſhed. In the firſt caſe, you have only to meaſure the focal diſtance of both lenſes, the objective as well as the ocular, in order to diſcover how much the one exceeds the other. This is performed by diviſion, and the quotient indicates the magnifying power.

Having, then, a teleſcope the focal diſtance of whoſe objective lens is two feet, and that of the ocular one inch; it is only neceſſary to enquire how often one inch is contained in two feet. Every one knows that a foot contains twelve inches, two feet, accordingly, contain twenty-four inches, which are to be divided by one. But, whatever number we divide by one, the

the quotient is always equal to the dividend; if then it is aſked, how often one inch is contained in twenty-four inches, the anſwer, without heſitation, is, twenty-four times; conſequently, ſuch a teleſcope magnifies twenty-four times, that is, repreſents diſtant objects in the ſame manner as if they were twenty-four times greater than they really are; in other words, you would ſee them through ſuch teleſcope under an angle twenty-four times greater than by the naked eye.

Let us ſuppoſe another aſtronomical teleſcope, the focal diſtance of whoſe objective lens is thirty-two feet, and that of the ocular three inches. You ſee at once that theſe two lenſes muſt be placed at the diſtance of thirty-two feet, and three inches from each other, for, in all aſtronomical teleſcopes, the diſtance of the lenſes muſt be equal to the ſum of the two focal diſtances, as has been already demonſtrated.

To find, then, how many times a teleſcope of the above deſcription magnifies, we muſt divide thirty-two feet by three inches, and, in order to this, reduce theſe thirty-two feet into inches, by multiplying them by twelve.

32
12
3|384
128

this produces 384 inches; and theſe again divided by three, the focal diſtance, in inches, of the ocular lens, gives a quotient of 128, which indicates that the propoſed teleſcope magnifies 128 times, which muſt be allowed to be very conſiderable.

Reciprocally, therefore, in order to conſtruct a teleſcope which ſhall magnify a given number of times,

ſay 100, we muſt employ two convex lenſes, the focal diſtance of the one of which ſhall be 100 times greater than that of the other; in this caſe the one will give the objective lens, and the other the ocular. Theſe muſt afterwards be fitted on the ſame axis, ſo that their diſtance ſhall be equal to the ſum of the two focal diſtances; that is, they muſt be fixed in a tube of this length, and then the eye being placed behind the ocular lens, at it's focal diſtance, will ſee objects magnified 100 times.

This arrangement may be varied without end, by aſſuming an ocular lens at pleaſure, and adapting to it an objective, whoſe focal diſtance ſhall be 100 times greater. Thus, taking an ocular lens of one inch focus, the objective muſt be of 100 inches focus, and the diſtance of the lenſes 101 inches. Or, taking an ocular of 2 inches focus, the objective muſt have it's focus at the diſtance of 200 inches, and the diſtance of the lenſes will be 202 inches. If you were to take an ocular lens of 3 inches focus, the focal diſtance of the objective muſt be 300 inches, and the diſtance of the lenſes from each other 303 inches. And if you were to take an ocular lens of 4 inches focus, the objective muſt have a focal diſtance of 400 inches, and the diſtance of the two lenſes 404 inches, and ſo on, the inſtrument always increaſing in length. If, on the contrary, you were to aſſume an ocular lens of only half an inch focus, the objective muſt have a focal diſtance of 100 half inches, that is, of fifty inches, and the diſtance between the lenſes would only be 50 inches and a half, which is little more than four feet.

And

And if an ocular of a quarter of an inch focus were to be employed, the objective would require a focal diſtance of only 100 quarters of an inch, or 25 inches, and the diſtance between the two lenſes 25 inches and a quarter, that is little more than two feet.

Here, then, are ſeveral methods of producing the ſame effect, that of magnifying 100 times; and if every thing elſe were equal, we ſhould not heſitate about giving the preference to the laſt, as being the ſhorteſt, for here the teleſcope, being reduced to little more than two feet, would be more manageable than one much longer.

No one, then, would heſitate about preferring the ſhorteſt teleſcopes, provided all other circumſtances were the ſame, and all the different ſpecies repreſented objects in the ſame degree of perfection. But, though they all poſſeſs the ſame magnifying power, the repreſentation is by no means equally clear and diſtinct. That of two feet in length certainly magnifies 100 times, as well as the others; but on looking through ſuch a teleſcope, objects will appear not only dark, but blunt and confuſed, which is undoubtedly a very great defect. The laſt teleſcope but one, whoſe objective lens is 50 inches focus, is leſs ſubject to theſe defects, but the dimneſs and confuſion are ſtill inſupportable: and theſe defects diminiſh in proportion as we employ greater objective lenſes; and are reduced to almoſt nothing, on employing an objective lens of 300 inches, with an ocular of 3 inches focus. On increaſing theſe meaſurements, the repreſentation becomes ſtill clearer and more diſtinct; ſo that, in

this

this reſpect, long teleſcopes are preferable to ſhort, though otherwiſe leſs commodious. This circumſtance impoſes on me a new taſk, that of farther explaining two very eſſential articles in the theory of teleſcopes: the one reſpects the clearneſs, or degree of light in which objects are ſeen: and the other the diſtinctneſs and accuracy of expreſſion with which they are repreſented. Without theſe two qualities, all magnifying power, however great, procures no advantage for the contemplation of objects.

27th February, 1762.

LETTER XCVI.

Degree of Clearneſs.

IN order to form a judgment of the degree of clearneſs in which objects are repreſented by the teleſcope, I ſhall recur to the ſame principles which I endeavoured to elucidate, in treating the ſame ſubject with reference to the microſcope.

And, firſt, it muſt be conſidered that, in this reſearch, it is not propoſed to determine the degree of light reſident in objects themſelves, and which may be very different, not only in different bodies, as being in their nature more or leſs luminous, but in the ſame body, according as circumſtances vary. The ſame bodies, when illuminated by the ſun, have undoubtedly more light than when the ſky is overcaſt, and in the night their light is wholly extinguiſhed;

but

but different bodies illuminated may differ greatly, in point of brightneſs, according as their colours are more or leſs lively. We are not enquiring, then, into that light or brightneſs which reſides in objects themſelves; but, be it ſtrong or faint, we ſay that a teleſcope repreſents the object in perfect clearneſs, when it is ſeen through the inſtrument as clearly as by the naked eye; ſo that if the object be dim, we are not to expect that the teleſcope ſhould repreſent it as clear.

Accordingly, in reſpect of clearneſs, a teleſcope is perfect, when it repreſents the object as clearly as it appears to the naked eye. This takes place, as in the microſcope, when the whole opening of the pupil is filled with the rays which proceed from every point of the object, after being tranſmitted through the teleſcope. If a teleſcope furniſhes rays ſufficient to fill the whole opening of the pupil, no greater degree of clearneſs need be deſired; and, ſuppoſing it could ſupply rays in greater profuſion, this would be entirely uſeleſs, as the ſame quantity preciſely, and no more, could find admiſſion into the eye.

Here, then, attention muſt be paid chiefly to the aperture of the pupil, which, being variable, prevents our laying down a fixed rule, unleſs we regulate ourſelves according to a certain given aperture, which is ſufficient, when the pupil, in a ſtate of the greateſt contraction, is filled with rays; and, for this purpoſe, the diameter of the pupil is uſually ſuppoſed to be one line, twelve of which make an inch; we ſometimes ſatisfy ourſelves with even the half of this, allowing to the diameter of the pupil only half a line, and in ſome caſes ſtill leſs.

If you will pleaſe to conſider, that the light of the ſun exceeds that of the moon 300,000 times, though even that of the moon is by no means inconſiderable, you will be ſenſible that a ſmall diminution in point of clearneſs can be of no great conſequence in the contemplation of objects. Having premiſed this, all that remains is to examine the rays which the teleſcope tranſmits into the eye, and to compare them with the pupil; and it will be ſufficient to conſider the rays which proceed from a ſingle point of the object (*plate IX. fig.* 1.) that, for example, which is in the axis of the teleſcope.

I. The object being infinitely diſtant, the rays which fall from it on the ſurface of the objective lens P A P are parallel to each other: all the rays, then, which come from the centre of the object, will be contained within the lines L P, L P, parallel to the axis E A. All theſe rays taken together are denominated the *faſcicle* of rays which fall on the objective lens, and the breadth of this faſcicle is equal to the extent or aperture of the objective lens, the diameter of which is P A P.

II. This faſcicle, or little bundle, of rays is changed, by the refraction of the objective lens, into a conical or pointed figure P F P, and having croſſed at the focus F, it forms a new cone *m* F *m*, terminated by the ocular lens; hence it is evident that the baſis of this cone *m m* is as many times ſmaller than the breadth of the faſcicle P P, as the diſtance F B is ſhorter than the diſtance A F.

III. Now theſe rays F *m*, F *m*, on paſſing through the ocular lens Q B Q, become again parallel to each other, and form the faſcicle of rays *n o*, *n o*, which enter into the eye, and there depict the image of the point of the object whence they originally proceeded.

IV. The queſtion, then, reſolves itſelf into the breadth of this faſcicle of rays *n o*, *n o*, which enter into the eye; for if this breadth *nn* or *oo* is equal to, or greater than, the opening of the pupil, it will be filled with them, and the eye will enjoy all poſſible clearneſs; that is, the object will ſeem as clear as if you were to look at it with the unaſſiſted eye.

V. But if this faſcicle *n n*, or *o o*, were of much leſs breadth than the diameter of the pupil, it is evident that the repreſentation muſt become ſo much more obſcure; which would be a great defect in the teleſcope. In order to remedy it, the faſcicle muſt, therefore, be at leaſt half a line in breadth, and it would be ſtill better to have it a whole line in breadth, this being the uſual aperture of the pupil.

VI. It is evident that the breadth of this ſecond faſcicle has a certain relation to that of the firſt, which it is very eaſy to determine. You have only to ſettle how many times the diſtance *n n* or *m m* is leſs than the diſtance P P, which is the aperture of the objective lens. But, the diſtance P P is in the ſame proportion to the diſtance *m m*, as the diſtance A F to the diſtance B F, on which the magnifying power depends; accordingly, the magnifying power itſelf diſcovers how many times the faſcicle LP, LP, is broader than the faſcicle *n o*, *n o*, which enters into the eye.

VII. Since, then, the breadth *n n* or *o o* muſt be one line, at leaſt half a line, the aperture of the objective lens PP muſt at leaſt contain as many half lines as the magnifying power indicates; thus, when the teleſcope is to magnify 100 times, the aperture of it's objective lens muſt have a diameter of 100 half lines, or 50 lines, which make 4 inches and 2 lines.

VIII. You ſee, then, that, in order to avoid obſcurity, the aperture of the objective lens muſt be greater, in proportion as the magnifying power is greater. And, conſequently, if the objective lens employed is not ſuſceptible of ſuch an aperture, the teleſcope will be defective in reſpect of clearneſs of repreſentation.

Hence it is abundantly evident, that, in order to magnify very greatly, it is impoſſible to employ ſmall objectives, whoſe focal diſtance is too ſhort, as a lens formed by the arches of ſmall circles cannot have a great aperture.

1ſt March, 1762.

LETTER XCVII.

Aperture of Objective Lenſes.

YOU have now ſeen that the magnifying power determines the ſize or extent of the objective lens, in order that objects may appear with a ſufficient degree of clearneſs. This determination reſpects only the ſize or aperture of the objective lens; however the focal diſtance is affected by it likewiſe, for the larger the lens is, the greater muſt be it's focal diſtance.

The reaſon of this is evident, as in order to form a lens whoſe focal diſtance is, for example, two inches, it's two ſurfaces muſt be arches of a circle whoſe radius is likewiſe about two inches: I have therefore repreſented (*plate IX. fig.* 2.) two lenſes P and Q, the arches of which are deſcribed with a radius of two inches. The lens P, being the thicker, is much greater than the lens Q; but I ſhall demonſtrate afterwards that thick lenſes are ſubject to other inconveniencies, and theſe ſo great as to oblige us to lay them altogether aſide. The lens Q, then, will be found more adapted for uſe, being compoſed of ſmaller arches of the ſame circle; and as it's focal diſtance is two inches, it's extent or aperture *m n* may ſcarcely exceed one inch. Hence this may be laid down as a general rule, that the focal diſtance of a lens muſt always be twice greater than the diameter of it's aperture *m n*; that is, the aperture of a lens muſt, of neceſſity, be ſmaller than half the focal diſtance.

Having remarked, then, that in order to magnify 100 times, the aperture of the objective lens muſt exceed 4 inches, it follows, that the focal diſtance muſt exceed 8 inches; I ſhall preſently demonſtrate that the double is not ſufficient, and that the focal diſtance of this lens muſt be increaſed beyond 300 inches. The diſtinctneſs of the expreſſion of the image requires this great increaſe, as ſhall afterwards be ſhewn; I ſatisfy myſelf with remarking at preſent,

that with regard to the geometrical figure of the lens, the aperture cannot be greater than half it's focal diſtance.

Here, therefore, I ſhall go ſomewhat more into the detail, reſpecting the opening of the objective, which every magnifying power requires: and I remark, firſt, that though a ſufficient degree of clearneſs requires an opening of four inches, when the teleſcope is to magnify 100 times, we ſatisfy ourſelves, in aſtronomical inſtruments, with one of three inches, the diminution of clearneſs being ſcarcely perceptible. Hence artiſts have laid it down as a rule, that, in order to magnify 100 times, the opening of the objective lens muſt be three inches, and for other magnifying powers in that proportion. Thus, in order to magnify 50 times, it is ſufficient that the opening of the objective lens be an inch and a half; to magnify 25 times, three quarters of an inch ſuffice, and ſo of other powers.

Hence we ſee that for ſmall magnifying powers, a very ſmall opening of the objective lens is ſufficient, and that, conſequently, a moderate focal diſtance may anſwer. But if you wiſhed to magnify 200 times, the opening of the objective muſt be ſix inches, or half a foot, which requires a very large lens, whoſe focal diſtance muſt exceed even 100 feet, in order to obtain a diſtinct and exact expreſſion. For this reaſon, great magnifying powers require very long teleſcopes, at leaſt, according to the uſual arrangement of lenſes which I have explained. But, for ſome time paſt, artiſts have been ſucceſsfully employing themſelves in diminiſhing this exceſſive length. The opening of the objective, however, muſt follow the rule laid down, as clearneſs neceſſarily depends on it.

Were you deſirous, therefore, of conſtructing a teleſcope which ſhould magnify 400 times, the opening of the objective lens muſt be twelve inches, or a foot, let the focal diſtance be rendered as ſmall as you will: and if you wiſhed to magnify 4,000 times, the opening of the objective muſt be ten feet, a very great ſize indeed, and too much ſo for any artiſt to execute; and this is the principal reaſon, why we can never hope to carry the magnifying power ſo far, unleſs ſome great prince would be at the expenſe of providing and executing lenſes of ſuch magnitude; and, after all, perhaps, they would not ſucceed.

A teleſcope, however, which ſhould magnify 4,000 times, would diſcover many wonderful things in the heavens. The moon would appear 4,000 times larger than to the naked eye; in other words, we ſhould ſee her as if ſhe were 4,000 times nearer to us than ſhe is. Let us enquire, then, to what a degree we might be able to diſtinguiſh the different bodies which ſhe may contain. The diſtance of the moon from the earth is calculated to be 52,000 German miles;[*] the 4,000th part of which is 13 miles: ſuch a teleſcope would, accordingly, ſhew us the moon as if ſhe were only 13 miles diſtant; and, conſequently,

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[*] For the proportion of theſe to meaſurement in Engliſh miles, ſee Vol. I. Letter I. page 3.

we ſhould be enabled to diſcover in her the ſame things which we diſtinguiſh in objects removed to the ſame diſtance. Now, from the top of a mountain, we can eaſily diſcern other mountains more than 13 miles diſtant. There can be no doubt, then, that, with ſuch an inſtrument, we ſhould diſcover on the ſurface of the moon many things to fill us with ſurprize. But, in order to determine whether the moon is inhabited by creatures ſimilar to thoſe of the earth, a diſtance of 13 miles is ſtill too great; we muſt have, in order to this effect, a teleſcope which ſhould magnify ten times more, that is 40,000 times, and this would require an objective lens of 100 feet aperture, an enterprize which human art will never be able to execute. But, with ſuch an inſtrument, we ſhould ſee the moon as if ſhe were no farther diſtant than from Berlin to Spandau, and good eyes might eaſily diſcern men at this diſtance, if any there were, but too indiſtinctly, it muſt be allowed, to be completely aſſured of the fact.

As we muſt reſt ſatisfied with wiſhing, on this ſubject, mine ſhould be to have at once a teleſcope which ſhould magnify 100,000 times;[*] the moon would then appear as if ſhe were only half a mile diſtant. The aperture of the objective lens of this teleſcope muſt be 250 feet, and we ſhould ſee, at leaſt, the larger animals which may be in the moon.

6th March, 1762.

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[*] Dr. Herſchel's teleſcopes actually magnify 6,500 times.