

circles (as in PLATE VII. *Fig. 15.*); of which the arches PAP and PBP are the fourth part of the whole circumference, so that each contains 90 degrees; this would, consequently, produce an insufferable confusion.

10. The arches, then, which form the surfaces of a lens, must contain much less than 90 degrees: if they contained so much as 60, the diffusion of the image would be even then insupportable. Authors who have treated the subject, admit of 30 degrees at most: and some fix the boundary at 20 degrees. A lens of this last description is represented by *Fig. 16.* of Plate VII. in which the arches PAP and PBP contain only 20 degrees, each being but the eighteenth part of the whole circumference of its respective circle.

11. But if this lens were to supply the place of the object-glass in a telescope, the arches PAP and PBP must contain still many degrees less. For though the diffusion of the image be perceptible of itself, the magnifying power multiplies it as many times as it does the object. Therefore, the greater the magnifying power proposed, the fewer must be the number of degrees which the surfaces of the lens contain.

12. When the telescope is intended to magnify 100 times, you will recollect that the aperture of the object-glass must be 3 inches, and its focal distance 360 inches, which is equal to the radii with which the two arches PAP and PBP are described; hence it follows that each of these two arches contains but half a degree; and it is distinctness of expression which requires an arch so small. If it were intended to magnify 200 times, half a degree would be still too much, and the measure of the arch, in that case, ought not to exceed the third part of a degree. This arch, however, must receive an extent of 6 inches; the radius of the circle must therefore

be so much greater, and consequently also the focal distance. This is the true reason why great magnifying powers require telescopes of such considerable length.

*9th March 1762.*

LETTER XCIX.—DIMINUTION OF THE APERTURE OF LENSES, AND OTHER MEANS OF LESSENING THE SPACE OF DIFFUSION, TILL IT IS REDUCED TO NOTHING.

WHEN the space of an object-glass is too great to admit of distinctness of expression, it may be very easily remedied: you have only to cover the lens with a circle of pasteboard, leaving an opening in the centre, so that the lens may transmit no other rays but those which fall upon it through the opening, and that those which before passed through the extremities of the lens may be excluded; for as no rays are transmitted but through the middle of the lens, the smaller the opening is, the smaller likewise will be the space of diffusion. Accordingly, by a gradual diminution of the opening, the space of diffusion may be reduced at pleasure.

Here the case is the same as if the lens were no larger than the opening in the pasteboard, thus the covered part becomes useless, and the opening determines the size of the lens; this then is the remedy employed to give object-glasses any given extent.

PP is the object-glass (PLATE VII. *Fig. 17.*), before which is placed the pasteboard NN, having the opening MM, which is now the extent of the lens. This opening MM is here nearly the half of what it would be were the pasteboard removed; the space of diffusion is therefore much smaller. It is remarked, that the space of diffusion, in this case, is only the fourth part of what it was before. An

opening MM, reduced to a third of PP, would render the space of diffusion nine times less. Thus the effect of this remedy is very considerable; and on covering the extremities of the lens ever so little, the effect of it becomes perceptible.

If, therefore, a telescope labours under this defect, that it does not represent objects sufficiently distinct, as a series of images blended together must of necessity produce confusion, you have only to contract the aperture of the object-glass by a covering of pasteboard such as I have described, and this confusion will infallibly disappear. But a defect equally embarrassing is the consequence;—the degree of brightness is diminished. You will recollect that every degree of the magnifying power requires a certain aperture of the object-glass, that as many rays may be transmitted as are necessary to procure a sufficient illumination. It is vexatious, therefore, in curing one defect, to fall into another; and in order to the construction of a very good telescope, it is absolutely necessary that there should be sufficient brightness of illumination, without injuring distinctness in the representation.

But can there be no method of diminishing, nay of totally reducing, the space of diffusion of object-glasses, without diminishing the aperture? This is the great inquiry which has for some time past engaged the attention of the ingenious, and the solution of which promises such a field of discovery in the science of dioptrics. I shall have the honour, at least, of laying before you, the means which scientific men have suggested for this purpose.

As the focus of the rays which pass through the middle of a convex lens is more distant from the lens, than the focus of the rays which pass through the extremities, it has been remarked that concave lenses produce a contrary effect. This has suggested

the inquiry, whether it might not be possible to combine a convex with a concave lens, in such a manner, that the space of diffusion should be entirely annihilated; while, in other respects, this compound lens should produce the same effect as an ordinary simple object-glass? You know that concave lenses are measured by their focal distance as well as those which are convex; with this difference, that the focus of the concave is only imaginary, and falls before the lens, whereas the focus of convex lenses is real, and falls behind them. Having made this remark, we reason as follows:

1. If we place (PLATE VII. *Fig. 18.*) behind a convex lens PAP, a concave one QBQ of the same focal distance, the rays which the convex lens would collect in its focus will be refracted by the concave, so that they will again become parallel to each other, as they were before passing through the convex lens.

2. In this case, therefore, the concave lens destroys the effect of the convex, and it is the same thing as if the rays had proceeded in their natural direction, without undergoing any refraction. For the concave lens, having its focus at the same point F, (*Fig. 10.*) restores the parallelism of the rays, which would otherwise have met at the point F.

3. If the focal distance of the concave lens were smaller than that of the convex, it would produce a greater effect, and would render the rays divergent, as in *Fig. 19.* of Plate VII.: the incident parallel rays LM, EA, LM, passing through the two lenses, would assume the directions NO, BF, NO, which are divergent from each other. These two lenses together produce, therefore, the same effect as a simple concave lens, which would impress on the incident parallel rays the same divergence. Two such lenses joined together, of which the concave has

a smaller focal distance than the convex, are therefore equivalent to a simple concave lens.

4. But if the concave lens *Q Q* (PLATE VII. *Fig. 20.*) has a greater focal distance than the convex lens *P P*, it is not even sufficient to render parallel to each other the rays which the convex lens by itself would collect in its focus *F*: these rays, therefore, continue convergent, but their convergence will be diminished by the concave lens, so that the rays, instead of meeting in the point *F*, will meet in the more distant point *O*.

5. These two lenses joined together will produce, then, the same effect as a simple convex lens which should have its focus at *O*, as it would collect the parallel rays *LM*, *EA*, *LM*, equally in the same point. It is therefore evident that two lenses may be combined an infinite variety of ways, the one being convex and the other concave, so that their combination shall be equivalent to a given convex lens.

6. Such a double object-glass may therefore be employed in the construction of telescopes, instead of the simple one, to which it is equivalent; and the effect as to the magnifying power will be just the same. But the space of diffusion will be quite different, and it may happen to be greater or less than that of a simple object-glass; and in this last case, the double object-glass will be greatly preferable to the simple one.

7. But farther, it has been found possible to arrange two such lenses so that the space of diffusion is reduced absolutely to nothing, which is undoubtedly the greatest advantage possible in the construction of telescopes. Calculation enables us to determine this arrangement, but no artist has hitherto been found capable of reducing it to practice.

13th March 1762.

# LETTER C.—OF COMPOUND OBJECT-GLASSES.

THE combination of two lenses, of which I have now given the idea, is denominated a compound object-glass: the end proposed from them is, that all the rays, as well those which pass through the extremities of a lens, as those which pass through the middle, should be collected in a single point, so that only one image may be formed, without diffusion, as in simple object-glasses. Could artists succeed in effecting such a construction, very great advantages would result from it, as you shall see.

It is evident, first, that the representation of objects must be much more distinct, and more exactly expressed, as vision is not disturbed by the apparition of that series of images which occupy the space of diffusion when the object-glass is simple.

Again, as this space of diffusion is the only reason which obliges us to give to simple object-glasses such an excessive focal distance, in order to render the inconvenience resulting from it imperceptible, by employing compound object-glasses we are relieved from that cumbersome expedient, and are enabled to construct telescopes incomparably shorter, yet possessing the same magnifying power.

When, employing a single object-glass, you want to magnify a hundred times, the focal distance cannot be less than thirty feet, and the length of the telescope becomes still greater on account of the eye-glass, whose focal distance must be added; a small object-glass would produce, from its greater space of diffusion, an intolerable confusion. But a length of thirty feet is not only very inconvenient, but artists seldom succeed in forming lenses of so great a focal distance. You will readily perceive the reason of this; for the radius of the surfaces of such a lens must likewise be thirty feet, and it is very difficult to

describe exactly so great a circle, and the slightest aberration renders all the labour useless.

Accidents of this sort are not to be apprehended in the construction of compound object-glasses, which may be formed of smaller circles, provided they are susceptible of the aperture which the magnifying power requires. Thus, in order to magnify one hundred times, we have seen that the aperture of the object-glass must be three inches; but it would be easy to construct a compound object-glass whose focal distance should be only one hundred inches, and which could admit an aperture of more than three inches: therefore, as the focal distance of the eye-glass must be one hundred times smaller, it would be one inch; and the interval between the lenses being the sum of their focal distances, the length of the telescope would be only one hundred and one inches, or eight feet five inches, which is far short of thirty feet.

But it appears to me, that a compound object-glass, whose focal distance should be fifty inches, might easily admit an aperture of three inches, and even more: taking, then, an eye-glass of half an inch focus, you will obtain the same magnifying power of one hundred times, and the length of the telescope will be reduced one half, that is to four feet and less than three inches. Such a telescope, then, would produce the same effect as a common one of thirty feet, which is assuredly carrying it as far as need be wished.

If such a compound object-glass could be made to answer, you would only have to double all these measurements in order to have one which should admit an aperture of six inches; and this might be employed to magnify two hundred times, making use of an eye-glass of half an inch focus as the two hundredth part of the focal distance of the object-glass,

which would, in this case, be one hundred inches. Now, a common telescope which should magnify two hundred times, must exceed one hundred feet in length; whereas this one, which is constructed with a compound object-glass, is reduced to about eight feet, and is perfectly accommodated to use, whereas a telescope of one hundred feet long would be an unwieldy and almost useless load.

The subject might be carried still much farther, and by again doubling the measurements, we might have a compound object-glass whose focal distance should be two hundred inches, or sixteen feet eight inches, which should admit of an aperture of twelve inches, or one foot: taking, then, an eye-glass of half an inch focus, as two hundred inches contain four hundred half inches, we should have a telescope capable of magnifying four hundred times, and still abundantly manageable, being under seventeen feet; whereas were we to attempt to produce the same magnifying power with a simple object-glass, the length of the telescope must exceed three hundred feet, and consequently could be of no manner of use, on account of that enormous size.

They have at Paris a telescope one hundred and twenty feet long, and one at London of one hundred and thirty feet; but the dreadful trouble of mounting, and pointing them to the object, almost annihilates the advantages expected from them. From this you will conclude of what importance it would be to succeed in the construction of the compound lenses which I have been describing. I suggested the first idea of them several years ago, and since then artists of the greatest ability in England and France have been attempting to execute them. Repeated efforts and singular skill in the artist are undoubtedly requisite. Indeed I have made, with the assistance of an able mechanician of our Academy, some not

unsuccessful attempts; but the expense attending such an enterprise has obliged me to give it up.

But the Royal Society of London last year announced, that an eminent artist, of the name of Dollond,\* had fortunately succeeded; and his telescopes are now universally admired. An able artist of Paris, named Passemont, boasts of a similar success. Both these gentlemen did me the honour, some time ago, to correspond with me on the subject; but as the point in question was chiefly how to surmount certain great difficulties in the practical part, which I never attempted, it is but fair that I should relinquish to them the honour of the discovery. The theory alone is my province, and it has cost me much profound research, and many painful calculations, the very sight of which would terrify you. I shall therefore take care not to perplex you farther with this abstruse inquiry.

16th March 1762.

#### LETTER CI.—FORMATION OF SIMPLE OBJECT-GLASSES.

IN order to give you some idea of the researches which led me to the construction of compound object-glasses, I must begin with the formation of the simple lens.

Observe, first, that the two surfaces of a lens may be formed in an infinity of different ways, by taking circles of which the surfaces are segments, either equal or unequal to each other, the focal distance, however, remaining always the same.

\* The first Achromatic Telescope ever constructed, was made by Chester More Hall, Esq. of More-hall in Essex, in the year 1733, no less than *twenty-four* years before the period alluded to by our author. This invaluable instrument is, therefore, in every view of the matter, a British invention. See the article *Optics*, in the *Edinburgh Encyclopædia*, vol. xv. p. 479, note, for a full account of Mr. Hall's labours.—Ed.

The same figure is usually given to both surfaces of a lens, or, as the surfaces of a lens are represented by arches of a circle, both surfaces are formed with radii equal to each other. Facility of execution has undoubtedly recommended this figure, as the same basin serves to form both surfaces, and most artists are provided with but few basins.

Suppose, then, a convex lens, both whose surfaces are polished on the same basin, one of twenty-four inches radius, so that each surface shall be an arch of the circle whose radius is twenty-four inches: this lens will be convex on both sides, and will have its focal distance at twenty-four inches, according to the common calculation; but as the focus depends on the refraction, and as the refraction is not absolutely the same in every species of glass, in which we find a very considerable diversity, according as the glass is more or less white and hard, this calculation of the focus is not strictly accurate; and usually the focal distance of the lens is somewhat less than the radius of its two surfaces, sometimes the tenth part, sometimes the twelfth: accordingly, the supposed lens, the radius of whose surfaces is twenty-four inches, will have its focus at the distance of about twenty-two inches, if it is formed of the same species of glass of which mirrors are commonly manufactured; though even in glass of this sort we meet with a small diversity in respect of refraction.

We see afterwards, that on making the two surfaces of the lens unequal, an infinity of other lenses may be formed, which shall all have the same focal distance; for on taking the radius of one of the surfaces less than twenty-four inches, that of the other surface must be taken greater in proportion, according to a certain rule. The radius of one of the surfaces may always be taken at pleasure; and by means of a certain rule, the radius of the other may be found,

in order that the focal distance may become the same as if each surface had been formed on a radius of twenty-four inches. The following table exhibits several such lenses, which have all the same focal distance.

<i>Lenses.</i>	<i>Radius of the first Surface.</i>	<i>Radius of the Second Surface.</i>
I.	24	24
II.	21	28
III.	20	30
IV.	18	36
V.	16	48
VI.	15	60
VII.	14	84
VIII.	12	156
IX.	12	infinity.

In the last form, the radius of one surface is only 12 inches, or the half of 24 inches; but that of the other becomes infinite: or rather, this surface is an arch of a circle infinitely great; and as such an arch differs nothing from a straight line, this may be considered as a plane surface, and such a lens is plano-convex.

Were we to assume the radius of a surface still smaller than 12 inches, the other surface must be made concave, and the lens will become convexo-concave; it will, in that case, bear the name of *meniscus*, several figures of which are represented in the following table:—

<i>Meniscus.</i>	<i>Radius of the Convex Surface.</i>	<i>Radius of the Concave Surface.</i>
X.	11	132
XI.	10	60
XII.	9	36
XIII.	8	24
XIV.	6	12
XV.	4	6
XVI.	3	4

Here, then, is a new species of lenses, the last of which is represented in Fig. 22. of Plate VII., so

that we have now sixteen different species, which have all the same focal distance; and this is about 22 inches, a little more or less, according to the nature of the glass.

When, therefore, the only question is, What focal distance the lens ought to have? it is a matter of indifference according to which of these forms you go to work; but there may be a very great difference in the space of diffusion to which each species is subjected, this space becoming smaller in some than in others. When a simple object-glass is to be employed, as is usually done, it is by no means indifferent of what figure you assume it, for that which produces the smallest space of diffusion is to be preferred. Now, this excellent property does not belong to the first species, where the two surfaces are equal; but nearly to species VII., which possesses the quality, that when you turn toward the object its more convex surface, or that whose radius is smallest, the space of diffusion is found to be about one-half less than when the lens is equally convex on both sides: this, therefore, is the most advantageous figure for simple object-glasses, and practitioners are accordingly agreed in the use of it.

It is evident, then, that in order to ascertain the space of diffusion of a lens, it is not sufficient to know its focal distance; its species likewise must be determined, that is, the radii of each surface; and you must carefully distinguish which side is turned to the object.

After this explanation, it is necessary to remark, that in order to discover the combination of two lenses which shall produce no diffusion of image, it is absolutely necessary to take into the account the figure of both surfaces of each glass, and to resolve the following problem: *What must be the radii of the surfaces of two lenses, in order to reduce to nothing the space of*

*diffusion*? The solution requires the most profound researches of the most sublime geometry; and supposing these to have been successful, the artist has, after all, many difficulties to surmount. The basins must have precisely that curve which the calculation indicates; nor is that sufficient, for in the operation of forming the lens on the basin, the basin suffers from the friction in its turn; hence it becomes necessary to rectify its figure from time to time, with all possible accuracy, for if all these precautions are not strictly observed, it is impossible to ensure success; and it is no easy matter to prevent the lens from assuming a figure somewhat different from that of the basin in which it is moulded. You must be sensible, from all this, how difficult it must be to carry to perfection this important article in dioptrics.

20th March 1762.

LETTER CII.—SECOND SOURCE OF DEFECT AS TO  
DISTINCTNESS OF REPRESENTATION BY THE TELE-  
SCOPE. DIFFERENT REFRACTIBILITY OF RAYS.

You have now seen in what manner it may be possible to remedy that defect in lenses which arises from the different refraction of rays, as those which pass through the extremities of a lens do not meet in the same point with those which pass through its middle, the effect of which is an infinity of images dispersed through the space of diffusion. But this is not the only defect; there is another, of so much more importance that it seems impossible to apply a remedy, as the cause exists, not in the glass, but in the nature of the rays themselves.

You will recollect that there is a great variety in rays, with respect to the different colours of which they convey the impression. I have compared this diversity to that which we meet with in musical

notes, having laid it down as a principle, that each colour is attached to a certain number of vibrations. But supposing that this explanation should still appear doubtful, it is beyond all doubt, that rays of different colours likewise undergo different refractions in their passage from one transparent medium to another; thus, red rays undergo the least refraction, and violet the greatest, though the difference is almost imperceptible. Now, all the other colours, as orange, yellow, green, and blue, are contained, with respect to refraction, within these two limits. It must likewise be remarked, that white is a mixture of all the colours which by refraction are separated from each other.

In fact, when a white ray  $OP$ , (PLATE VII. *Fig. 23.*) or a ray of the sun, falls obliquely on a piece of glass  $ABCD$ , instead of pursuing its course in the direction  $PQ$ , it not only deviates from this, but divides into a variety of rays  $Pr$ ,  $Ps$ ,  $Pt$ ,  $Pv$ : the first of which  $Pr$ , the one that deviates least, represents the red colour, and the last  $Pv$ , which deviates most, the violet colour. The dispersion  $rv$  is indeed much smaller than it appears in the figure; the divergence, however, always becomes more perceptible.

From this different refrangibility of rays, according to their different colours, are produced the following phenomena with respect to dioptric glasses:—  
1. Let  $PP$  (*Fig. 24.*) be a convex lens, on the axis of which  $OR$ , at a very great distance  $AO$ , is the object  $Oo$ , the image of which, as represented by the lens, we are to determine, putting aside here the first irregularity, that which respects diffusion; or, which amounts to the same thing, attending to those rays only which pass through the centre of the lens  $AB$ , as if its extremities were covered with a circle of pasteboard.

2. Let us now suppose the object  $Oo$  to be red, so that all its rays shall be of the same nature; the lens will somewhere represent the image of it  $Rr$  equally red; the point  $R$  is, in this case, denominated the focus of the red rays, or of those which undergo the least refraction.

3. But if the object  $Oo$  is violet, as rays of this colour undergo the greatest refraction, the image  $Vv$  will be nearer the lens than  $Rr$ ; this point  $V$  is called the focus of violet rays.

4. If the object were painted some other intermediate colour between red and violet, the image would fall between the points  $R$  and  $V$ , would be always very distinct, and terminated by the straight line  $oB$ , drawn from the extremity  $o$  of the object, through the centre of the lens, this being a general rule for all colours.

5. But if the colour of the object is not pure, as is the case in almost all bodies; or if the object is white, which is a mixture of all colours, the different species of rays will then be separated by refraction, and each will represent an image apart. That which is formed of red rays will be at  $Rr$ ; and that which is produced by the violet, at  $Vv$ ; and the whole space  $RV$  will be filled with images of the intermediate colours.

6. The lens  $PP$ , then, will represent a succession of images of the object  $Oo$ , disposed through the small space  $RV$ , of which the most remote from the lens is red, and the nearest  $Vv$  violet, and the intermediate images of the intermediate colours, according to the order of the colours as they appear in the rainbow.

7. Each of these images will be abundantly distinct in itself, and all terminated by the straight line  $oBv$ , drawn from the extremity  $o$  of the object, through the centre of the lens  $B$ ; but they could

not be viewed together without a very perceptible confusion.

8. Hence, then, is produced a new space of diffusion, as in the first irregularity; but differing from it in this—that the latter is independent on the aperture of the lens, and that each image is painted of a particular colour.

9. This space of diffusion  $RV$  depends on the focal distance of the lens, so as to be always about the 28th part; when, therefore, the focal distance of the lens  $PP$  is 28 feet, the space  $RV$  becomes equal to an entire foot, that is, the distance between the red image  $Rr$  and the violet  $Vv$  is one foot. If the focal distance were twice as great, or 56 feet, the space  $RV$  would be two feet; and so of other distances.

10. Hence the calculation of the focal distance of a lens becomes uncertain, as the rays of each colour have their separate focus; when, therefore, the focus of a lens is mentioned, it is always necessary to announce the colour that we mean. But rays of an intermediate nature are commonly understood, those between red and violet, namely the green.

11. Thus, when it is said, without farther explanation, that the focal distance of such a lens is 56 feet, we are to understand that it is the green image which falls at that distance; the red image will fall about a foot farther off, and the violet a foot nearer.

Here, then, is a new circumstance of essential importance, to which attention must be paid in the construction of dioptrical instruments.

*23d March 1762.*



LETTER CIII.—MEANS OF REMEDYING THIS DEFECT BY COMPOUND OBJECT-GLASSES.

It is necessary carefully to distinguish this new diffusion, or multiplication of the image, arising from the different refrangibility of rays, as being of different colours from the first diffusion, occasioned by the aperture of the lens, in as much as the rays which pass through the extremities form another image than those which pass through its middle. This new defect must accordingly be remedied differently from the first.

You will please to recollect that I have proposed two methods for remedying the preceding defect; the one consisted in an increase of the focal distance, in order to diminish the curve of the surfaces of the lens. This remedy introduces instruments extremely long whenever a great magnifying power is required. The other consists in a combination of two lenses, the one convex, and the other concave, to modify the refraction, so that all the rays transmitted through these lenses may meet in the same point, and the space of diffusion be totally reduced.

But neither of these remedies affords the least assistance toward removing the inconvenience arising from the different refrangibility of rays. The first even increases the evil; for the more that the focal distance is increased, the more considerable becomes the space through which the coloured images are dispersed. Neither does the combination of two or more lenses furnish any assistance; for we are assured, from both theory and experience, that the images of different colours remain always separated, however great the number of lenses through which the rays are transmitted, and that the more the lens magnifies, the more the difference increases.

This difficulty appeared so formidable to the great *Newton*, that he despaired of finding a remedy for a defect which he believed absolutely inseparable from dioptrical instruments, when the vision is produced by refracted rays. For this reason he resolved to give up refraction altogether, and to employ mirrors instead of object-glasses, as reflection is always the same for rays of every nature. This idea has procured for us those excellent reflecting telescopes, whose surprising effects are so justly admired, and which I shall describe after I have explained every thing relative to refractive instruments.

On being convinced that it was impossible to remedy the different refrangibility of rays, by a combination of several lenses, I remarked that the reason of it was founded on the law of refraction, which is the same in every species of glasses; and I perceived, that if it were possible to employ other transparent substances, whose refraction should be considerably different from that of glass, it might be very possible to combine such substance with glass, in such a manner that all the rays should unite in the formation of a single image, without any space of diffusion. In pursuance of this idea, I found means to compose object-glasses of glass and water, wholly exempt from the effect of the different refrangibility of rays, which consequently would produce as good an effect as mirrors.

I executed my idea with two meniscuses, or concavo-convex lenses (PLATE VII. *Fig. 25.*), the one of which is AACC, and the other BBCC, which I joined together with the concave surfaces toward each other, filling the void between them with water, so that the rays which entered by the lens AACC must pass through the water enclosed between the two lenses, before they went off through CCBB. Each ray undergoes, then, four refractions: the first

on passing from the air into the lens AACC; the second on passing from this lens into the water; the third on passing thence into the other lens CCBB; the fourth on passing from this lens into the air.

As the four surfaces of these two lenses here enter into consideration, I found means to determine their semidiameters, so that of whatever colour a ray of light might be, after having undergone these four refractions, it should re-unite in the same point, and the different refrangibility no longer produce different images.

These object-glasses, compounded of two lenses and water, were found subject at first to the former defect, namely, that of the rays which pass through the extremities forming a different focus from what is formed by those which pass through the middle; but, after much painful research, I found means to proportion the radii of the four surfaces in such a manner, that these compound object-glasses became wholly exempted from the defects of both the classes specified. But it was necessary, to this effect, to execute so exactly all the measurements prescribed by the calculation, that the slightest aberration must become fatal to the whole process; I was therefore obliged to abandon the construction of these object-glasses.\*

Besides, this project could remedy only the inconveniences which affect the object-glass, and the eye-glass might still labour under some defect as great, which it would be impossible to remedy in the same manner. Several eye-glasses are frequently employed in the construction of telescopes, which I shall describe afterwards: we should not, therefore,

\* Object-glasses of this kind, even if executed in the most correct manner, are incapable of producing the effects which our author expected from them.—*Ed.*

gain much by a too scrupulous adherence to the object-glass only, while we overlook the other lenses, though their effect may not be greatly perceptible relatively to that of the object-glass.

But whatever pains these researches may have cost me, I frankly declare, that I entirely give up at present the construction of object-glasses compounded of glasses and water; as well on account of the difficulty of execution, as that I have since discovered other means, not of destroying the effect of the different refrangibility of rays, but of rendering it imperceptible. This shall be the subject of my next letter.

27th March 1762.

#### LETTER CIV.—OTHER MEANS MORE PRACTICABLE.

SINCE the reflecting telescope came into general use, refracting ones have been so run down, that they are on the point of being wholly laid aside. The construction of them has accordingly for some time past been wholly suspended, under a firm persuasion that every effort to raise them to a state of perfection would be useless, as the great *Newton* had demonstrated that the insurmountable difficulties arising from the different refrangibility of rays, was absolutely inseparable from the construction of telescopes.

If this sentiment be well founded, there is no telescope capable of representing objects, but with a confusion insupportable in proportion to the greatness of the magnifying power. However, though there are telescopes extremely defective in this respect, we likewise meet with some that are excellent, and nowise inferior to the so much boasted reflecting telescopes. This is undoubtedly a very great paradox; for if this defect really attached to

the subject, we should not find a single exception. Such an exception, therefore—and we have the testimony of experience that it exists—well merits every degree of attention.

We are to inquire, then, how it happens that certain telescopes represent the object abundantly distinct, while others are but too much subject to the defect occasioned by the different refrangibility of rays. I think I have discovered the reason, which I submit in the following reflections:—

1. It is indubitably certain that the object-glass represents an infinity of images of each object, which are all arranged over the same space of diffusion, and each of which is painted its own proper colour, as I have demonstrated in the preceding letter.

2. Each of these images becomes an object, with respect to the eye-glass, which represents each separately, in the colour proper to it; so that the eye discovers, through the telescope, an infinity of images, disposed in a certain order, according to the refraction of the lens.

3. And if, instead of one eye-glass, we were to employ several, the same thing will always take place, and instead of one image, the telescope will represent an infinity to the eye, or a series of images, each of which expresses a separate object, but of a particular colour.

4. Let us now consider (PLATE VII. *Fig.* 26.) the last images presented by the telescope to an eye placed at  $O$ , and let  $Rr$  be the red image, and  $Vv$  the violet, those of the other colours being between these two, according to the order of their different refrangibility. I have not in this figure introduced the lenses of the telescope, the only point at present being to show in what manner the eye sees the images. Only we must conceive the distance of the eye  $O$  from these images to be very great.

5. All these images  $Rr$  and  $Vv$ , with the intermediate, are situated, then, on the axis of the telescope  $ORV$ , and terminated by a certain straight line,  $rv$ , denominated the terminatrix of all the images.

6. As I have represented these images in the figure, the red image  $Rr$  is seen by the eye at  $O$ , under the angle  $ROr$ , which is greater than the angle  $VOv$ , under which the violet image  $Vv$  is seen. The violet rays which, from the image  $Vv$ , enter into the eye, are therefore blended with the red which come from the part  $Rr$  of the red image  $Rr$ .

7. Consequently, the eye cannot see the violet image without a mixture of rays of other colours, but which correspond to different points of the object itself; thus the point  $n$  of the red image is confounded in the eye with the extremity  $v$  of the violet image, from which a very great confusion must arise.

8. But the ray  $rO$  not being mixed with the others, the extremity seen will appear red, or the image will seem bordered with red, which afterward successively blends with these other colours, so that the object will appear with a party-coloured border; a fault very common in telescopes, to which some, however, are less subject than others.

9. If the greater image  $Rr$  were the violet, and  $Vv$  the red, the confusion would be equally offensive, with this difference only, that the extremities of the object would then appear bordered with violet instead of red.

10. The confusion depends, then, on the position of the terminating straight line  $rv$ , with relation to the line  $VO$ , and the diversity which may take place in it; the result must be, that the confusion will be sometimes greater and sometimes less.

11. Let us now consider the case in which the

last images represented by the telescope are so arranged, that the straight terminating line  $vr$  being produced, would pass precisely into the eye. The eye will then see (PLATE VII. *Fig. 27.*), along a single ray  $vrO$ , all the extremities; and, in general, all the points which correspond to one and the same point of the object will be conveyed to the eye by a single ray, and will there, consequently, be distinctly represented.

12. Here, then, is a case in which, notwithstanding the diversity of images, the eye may see the object distinctly, without any confusion of the different parts, as happened in the preceding case. This advantage, then, will be obtained when the terminating line  $vr$ , being produced, passes through the place of the eye  $O$ .

13. As the arrangement of the last images  $Rr$  and  $Vv$  depends on the disposition of the eye-glasses, in order to rescue telescopes from the defect imputed to them, nothing more is requisite but to arrange these lenses in such a manner, that the terminating line of the last images  $vr$  shall pass through the eye; and telescopes thus constructed will always be excellent.

30th March 1762.

#### LETTER CV.—RECAPITULATION OF THE QUALITIES OF A GOOD TELESCOPE.

On taking a general review of the subject, you will readily admit that an excellent telescope is a most valuable commodity, but rarely to be met with, being subject to so many defects, and so many qualities being requisite, each of which has an essential influence on the construction of the instrument. As the number of the good qualities is considerable, in order that no one of them may escape your obser-

vation, I shall again go over the ground, and make a distinct enumeration of them.

1. The first respects the magnifying power; and the more that a telescope magnifies objects, the more perfect undoubtedly it is, provided that no other good quality is wanting. Now, the magnifying power is to be estimated from the number of times that the diameter of the object appears greater than to the naked eye. You will recollect that, in telescopes of two lenses, the magnifying power is so many times greater as the focal distance of the object-glass exceeds that of the eye-glass. In telescopes consisting of more lenses than two, the determination of the magnifying power is more intricate.

2. The second property of a good telescope is brightness. It is always very defective when it represents the object obscurely, and as through a mist. In order to avoid this defect, the object-glass must be of such a size as is regulated by the magnifying power. Artists have determined that, in order to magnify 300 times, the aperture of the object-glass ought to be three inches diameter; and for every other magnifying power, in proportion. And when objects are not very luminous of themselves, it would be proper to employ object-glasses of a still greater diameter.

3. The third quality is distinctness or accuracy of representation. In order to produce this, the rays which pass through the extremities of the object-glass ought to meet in the same point with those which pass through the middle, or at least the aberration should not be perceptible. When a simple object-glass is employed, its focal distance must exceed a certain limit proportional to the magnifying power. Thus, if you wish to magnify 100 times, the focal distance of the object-glass must be at least 30 feet. It is the destination, therefore, which imposes the

necessity of making telescopes so excessively long, if we want to obtain a very great magnifying power. Now, in order to remedy this defect, an object-glass composed of two lenses may be employed; and could artists succeed in the construction of them, we should be enabled very considerably to shorten telescopes, while the same magnifying power remained. You will have the goodness to recollect what I have already suggested at some length on this subject.

4. The fourth quality regards likewise the distinctness or purity of representation, as far as it is affected by the different refrangibility of rays of different colours. I have shown how that defect may be remedied; and as it is impossible that the images formed by different rays should be collected in a single one, the point in question is to arrange the lenses in the manner I have described in the preceding letter; that is, the terminating line of the last images must pass through the eye. Without this, the telescope will have the defect of representing objects surrounded with the colours of the rainbow; but the defect will disappear on arranging the lenses in the method I have pointed out. But to this effect, more than two lenses must be employed, in order to a proper arrangement. I have hitherto spoken only of telescopes with two lenses, one of which is the object-glass, and the other the eye-glass; and you know that their distance from each other is already determined by their focal distances, so that here we are not at liberty to make any alteration. It happens fortunately, however, that the terminating line which I have mentioned passes nearly through the place of the eye, so that the defect arising from the colours of the rainbow is almost imperceptible, provided the preceding defect is remedied, especially when the magnifying power is

not very great. But when the power is considerable, it would be proper to employ two eye-glasses, in order entirely to annihilate the colours of the rainbow, as in this case the slightest defects, being equally magnified, become insupportable.

5. The fifth and last good quality of a telescope is a large apparent field, or the space which the instrument discovers at once. You recollect that small pocket-glasses with a concave eye-glass are subject to the defect of presenting a very small field, which renders them incapable of magnifying greatly. The other species, that with a convex eye-glass, is less subject to this defect; but as it represents the object inverted, telescopes of the first species would be preferable, did they discover a larger field, which depends on the diameter of the aperture of the eye-glass; and you know we cannot increase this aperture at pleasure, because it is determined by focal distance. But by employing two or three, or even more eye-glasses, we have found means to render the apparent field greater; and this is an additional reason for employing several lenses in order to procure a telescope in all respects excellent.

To these good qualities another may be still added, that the representation shall not be inverted by the instrument, as by astronomical telescopes. But this defect may be easily remedied, if it be one, by the addition of two more eye-glasses, as I shall show in my next letter.

3d April 1762.

#### LETTER CVI.—TERRESTRIAL TELESCOPES WITH FOUR LENSES.

I HAVE treated at considerable length of telescopes composed of two convex lenses, known by the name of astronomical tubes, because they are commonly used for observing the heavenly bodies.

You will readily comprehend that the use of such instruments, however excellent they may be, is limited to the heavens, because they represent objects in an inverted position, which is very awkward in contemplating terrestrial bodies, as we would rather wish to view them in their natural situation; but on the discovery of this species of telescope, means were quickly found of remedying that defect, by doubling, if I may say so, the same telescope. For as two lenses invert the object, or represent the image inverted, by joining a similar telescope to the former, for viewing the same image, it is again inverted, and this second representation will exhibit the object upright. Hence arose a new species of telescopes, composed of four lenses, called terrestrial telescopes, from their being designed to contemplate terrestrial objects; and the method of constructing them follows.

1. The four lenses A, B, C, D, (PLATE VII. *Fig.* 21.) enclosed in the tube MMNN, represent the telescope in question; the first of which, A, directed toward the object, is denominated the object-glass, and the other three, BCD, the eye-glass. These four lenses are all convex, and the eye must be placed at the extremity of the tube, at a certain distance from the last eye-glass D, the determination of which shall be afterwards explained.

2. Let us consider the effect which each lens must produce when the object O o, which is viewed through the telescope, is at a very great distance. The object-glass will first represent the image of this object at P p, its focal distance, the magnitude of the image being determined by the straight line drawn from the extremity o, through the centre of the lens A. This line is not represented in the figure, that it may not be embarrassed with too many lines.

3. This image, P p, occupies the place of the object with respect to the second lens B, which is placed in such a manner that the interval BP shall be equal to its focal distance, in order that the second image may be thence transported to an infinite distance, as Q q, which will be inverted as the first P p, and terminated by the straight line drawn from the centre of the lens B through the extremity p.

4. The interval between these two first lenses A, B is equal, therefore, to the sum of their focal distances; and were the eye placed behind the lens B, we should have an astronomical telescope, through which the object O o would be seen at Q q, and consequently inverted, and magnified as many times as the distance AP exceeds the distance BP. But instead of the eye, we place behind the lens B, at some distance, the third lens C, with respect to which the image Q q occupies the place of the object, as in fact it receives the rays from this image Q q, which being at a very great distance, the lens C will represent the image of it, at its focal distance, in R r.

5. The image Q q being inverted, the image R r will be upright, and terminated by the straight line drawn from the extremity q through the centre of the lens C, which will pass through the point r. Consequently the three lenses A, B, C together, represent the object O o at R r, and this image R r is upright.

6. Finally, we have only to place the last lens in such a manner that the interval D R shall be equal to its focal distance; this lens D will again transport the image R r to an infinite distance, as S s, the extremity of which, s, will be determined by the straight line drawn from the centre of the lens D through the extremity r; and the eye placed behind this lens

will in fact see this image  $Ss$  instead of the real object  $Oo$ .

7. Hence it is easy to ascertain how many times this telescope, composed of four lenses, must magnify the object; you have only to attend to the two couple of lenses,  $A, B$  and  $C, D$ , each of which separately would be an astronomical telescope. The first pair of lenses  $A$  and  $B$  magnifies as many times as the focal distance of the first lens  $A$  exceeds that of the second lens  $B$ ; and so many times will the image formed by it,  $Qq$ , exceed the real object  $Oo$ .

8. Farther, this image  $Qq$  occupying the place of the object with respect to the other pair of lenses  $C$  and  $D$ , it will be again multiplied as many times as the focal distance of the lens  $C$  exceeds that of the lens  $D$ . These two magnifying powers added, give the whole magnifying power produced by the four lenses.

9. If, then, the first pair of lenses,  $A$  and  $B$ , magnify ten times, and the other pair,  $C$  and  $D$ , three times, the telescope will magnify the object thrice ten, that is thirty times; and the aperture of the object-glass  $A$  must correspond to this magnifying power, according to the rule formerly laid down.

10. Hence you see, then, that on separating from a terrestrial telescope the two last lenses  $C$  and  $D$ , there would remain an astronomical telescope, and that these two lenses,  $C$  and  $D$ , would likewise form such a telescope. A terrestrial telescope, therefore, consists of two astronomical ones; and reciprocally, two astronomical telescopes combined form a terrestrial one.

This construction is susceptible of endless variations, some preferable to others, as I shall afterwards demonstrate.

*6th April 1762.*

# LETTER CVII.—ARRANGEMENT OF LENSES IN TERRESTRIAL TELESCOPES.

You have seen how, by the addition of two convex lenses to an astronomical telescope, a terrestrial one is produced, which represents the object upright. The four lenses of which a terrestrial telescope is composed, are susceptible of an infinite variety of arrangement, with respect to both focus and distance. I shall explain those which are of most essential importance, and refer you to Plate VII. Fig. 28.

1. With respect to their distances, I have already remarked, that the interval between the two first lenses,  $A$  and  $B$ , is the sum of their focal distances; and the same thing holds as to the last lenses  $C$  and  $D$ : for each pair may be considered as a simple telescope, composed of two convex lenses. But what must be the interval between the two middle lenses  $B$  and  $C$ ? May it be fixed at pleasure? As it is certain that, whether this interval be great or small, the magnifying power, always compounded of the two which each pair would produce separately, must continue the same.

2. On consulting experience, we soon perceive that when the two middle lenses are placed very near each other, the apparent field almost entirely vanishes; and the same thing takes place when they are too far separated. In both cases, to whatever object the telescope is pointed, we discover only a very small part of it.

3. For this reason artists bring the last pair of lenses nearer to the first, or remove them to a greater distance, till they discover the largest field, and delay fixing the lenses till they have found this situation. Now they have observed, that in settling this most advantageous arrangement, the distance

of the middle lenses, B and C, is always greater than the sum of the focal distances of these same two lenses.

4. You will readily conclude that this distance cannot depend on chance, but must be supported by a theory, and that affording a termination much more exact than what experience alone could have furnished. As it is the duty of a natural philosopher to investigate the causes of all the phenomena which experience discovers, I proceed to unfold the true principles which determine the most advantageous distance BC between the two middle lenses. For this purpose I refer to Plate VII. Fig. 29.

5. As all the rays must be conveyed to the eye, let us attend to the direction of that one which, proceeding from the extremity O of the visible object, passes through the centre A of the object-glass; for unless this ray is conveyed to the eye, this extremity O will not be visible. Now this ray undergoes no refraction in the object-glass, for it passes through the centre A; it will therefore proceed in a straight line to the second lens, which it will meet in its extremity *b*, as this is the last ray transmitted through the lenses.

6. This ray, being refracted by the second lens, will change its direction so as to meet somewhere at *n* the axis of the lenses; this would have happened to be the focus of this lens, had the ray A *b* been parallel to the axis; but as it proceeds from the point A, its reunion with the axis at *n* will be more distant from the lens B than its focal distance.

7. We must now place the third lens C in such a manner that the ray, after having crossed the axis at *n*, may meet it exactly in its extremity *c*; from which it is evident, that the greater the aperture of this lens C is, the farther it must be removed from

the lens B, and the greater the interval BC becomes: but, on the other hand, care must be taken not to remove the lens C beyond that point, as in this case the ray would escape it, and be transmitted no farther. This circumstance, then, determines the just distance between the two middle lenses B and C, conformably to experience.

8. This lens C will produce a new refraction of the ray in question, which will convey it precisely to the extremity *d* of the last eye-glass D, which, being smaller than C, will render the line *c d* somewhat convergent toward the axis, and will thus undergo, in the last lens, such a degree of refraction as will reunite it with the axis at less than its focal distance; and there it is exactly that the eye must be placed, in order to receive all the rays transmitted through the lenses, and to discover the greatest field.

9. Thus we are enabled to procure a field whose diameter is almost twice as large as with an astronomical telescope of the same magnifying power. By means, then, of these telescopes with four lenses, we obtain a double advantage; the object is represented upright, and a much larger field is discovered—both circumstances of much importance.

10. Finally, it is possible to find such an arrangement of these four lenses as, without affecting either of the advantages now mentioned, shall entirely do away the defect arising from the colours of the rainbow, and at the same time represent the object with all possible distinctness. But few artists can attain this degree of perfection.

*10th April 1762.*



LETTER CVIII.—PRECAUTIONS TO BE OBSERVED IN THE CONSTRUCTION OF TELESCOPES. NECESSITY OF BLACKENING THE INSIDE OF TUBES. DIAPHRAGMS.

AFTER these researches respecting the construction of telescopes, I must suggest and explain certain precautions necessary to be used; which, though they relate neither to the lenses themselves nor to their arrangement, are nevertheless of such importance, that if they are not very carefully observed, the best instrument is rendered entirely useless. It is not sufficient that the lenses should be arranged in such a manner that all the rays which fall upon them shall be transmitted through these lenses to the eye; care must be taken, besides, to prevent the transmission of extraneous rays through the telescope, to disturb the representation. Let the following precautions, then, be taken.

1. The lenses of which a telescope is composed must be enclosed in a tube, that no other rays, except those which are transmitted through the object-glass, may reach the other lenses. For this effect, the tube must be so very close throughout, that no chink admits the smallest portion of light. If by any accident the tube shall be perforated ever so slightly, the extraneous light admitted would confound the representation of the object.

2. It is likewise of importance to blacken throughout the inside of the telescope, of the deepest black possible, as it is well known that this colour does not reflect the rays of light, be they ever so powerful. You must have observed, accordingly, that the tubes of telescopes are always blackened internally. A single reflection will show the necessity of it.

3. The object-glass A (PLATE VII. *Fig.* 31.) transmits not only the rays of the object represented

by the telescope, but those also which by the extremities enter all around in great abundance; such is the ray  $ba$ , which falls on the inside upon the frame of the tube at  $i$ : if, therefore, the tube were white inwardly, or of any other colour, it would be illuminated by this ray, and of itself would generate new rays of light, which must of necessity be conveyed through the other lenses, and disturb the representation, by mingling with the proper rays of the object.

4. But if the inside of the tube be blackened deeply, no new rays will be produced, let the light be ever so strong. This blackening must be carried through the whole length of the telescope, as there is no black so deep as not to generate, when illuminated, some faint light. Supposing, then, that some extraneous rays were to make their way to the second lens B, the black of the tube, pursuing their course, would easily absorb them altogether. There is a brilliant black, which, for this reason, it would be very improper to employ.

5. But even this precaution is not sufficient, it is necessary likewise to furnish the inside of the tube with one or more diaphragms, perforated with a small circular aperture, the better to exclude all extraneous light; but care must be taken that they do not exclude the rays of the object which the instrument is intended to represent. See PLATE VII. *Fig.* 30.

6. It is necessary to observe at what place in the tube the proper rays of the object are most contracted; this must be at the points where their images are represented, for there all the rays are collected together. Now, the object-glass A represents the image in its focus at M. You have only, then, to compute the magnitude of this image, and there to fix your diaphragm, whose aperture  $m n$

shall be equal to the magnitude of the image, or rather somewhat greater. For if the aperture were less than the image, there would be a proportional loss of the apparent field, which is always a great defect.

7. These are the observations respecting the diaphragm, which apply to astronomical telescopes composed of two convex lenses. In terrestrial telescopes two images are represented within the tube; besides the first at M, represented by the object-glass in its focus, and which the second lens B transports to an infinite distance, the third lens represents a second image in its focus N, which is upright, whereas the former was inverted. At N, therefore, is the proper place to fix a second diaphragm perforated with an aperture  $n n$ , of the magnitude of the image there represented.

8. These diaphragms, aided by the blackness of the inside of the tube, produce likewise an excellent effect with respect to distinctness of representation. It must be carefully observed, however, that the greater the field is which the telescope discovers, the less is to be expected from these diaphragms, as in that case the images become greater, so that the aperture of the diaphragms must be so enlarged as to render them incapable of any longer excluding the extraneous rays. So much the greater care, therefore, must be taken thoroughly to blacken the inside of the tube, and to make it larger, which considerably diminishes the unpleasant effect of which I have been speaking.

13th April 1762.

LETTER CIX.—IN WHAT MANNER TELESCOPES REPRESENT THE MOON, THE PLANETS, THE SUN, AND THE FIXED STARS. WHY THESE LAST APPEAR SMALLER THROUGH THE TELESCOPE THAN TO THE NAKED EYE. CALCULATION OF THE DISTANCE OF THE FIXED STARS, FROM A COMPARISON OF THEIR APPARENT MAGNITUDE WITH THAT OF THE SUN.

I AM persuaded, that by this time you are very well pleased to be relieved at length from the dry theory of telescopes, which is rendered agreeable only by the importance of the discoveries which they have enabled us to make.

What pleasing surprise is felt on seeing very distant objects as distinctly as if they were one hundred times nearer to us, or more especially in cases where there is no possibility of reaching them, which holds with respect to the heavenly bodies! And you are already disposed to admit, that with the aid of the telescope, many wonderful things relating to the stars have been discovered.

On viewing the moon one hundred times nearer than she really is, many curious inequalities are discernible; such as excessive heights and profound depths, which from their regularity resemble rather works of art than natural mountains. Hence a very plausible argument is deduced, to prove that the moon is inhabited by reasonable creatures. But we have proofs still more satisfactory in simply contemplating the almighty power, in union with the sovereign wisdom and goodness, of the Great Creator.

Thus the most important discoveries have been made respecting the planets, which, to the unassisted eye, appear only as so many luminous points; but which, viewed through a good telescope, resemble the moon, and appear even still much greater.

But you will be not a little surprised, when I assure you, that with the assistance of the best telescope, even one which magnifies more than two hundred times, the fixed stars still appear only as points, nay still smaller than to the naked eye. This is so much the more astonishing, that it is certain the telescope represents them such as they would appear were we two hundred times nearer. Are we not hence reduced to the necessity of concluding, that here telescopes fail to produce their effect? But this idea presently vanishes, on considering that they discover to us millions of little stars which, without their aid, must have for ever escaped the eye. We likewise perceive the distances between the stars incomparably greater; for two stars which to the naked eye seemed almost to touch each other, when viewed through the telescope, are seen at a very considerable distance; a sufficient proof of the effect of the telescope.

What, then, is the reason that the fixed stars appear to us smaller through the telescope than to the naked eye? In resolving this question, I remark, first, that the fixed stars appear greater to the naked eye than they ought to do, and that this arises from a false light, occasioned by their twinkling. In fact, when the rays proceeding from a star come to paint their image at the bottom of the eye, on the retina, our nerves are struck by it only in one point; but, by the lustre of the light the adjacent nerves likewise undergo a concussion, and produce the same feeling which would be communicated if the image of the object painted on the retina were much greater. This happens on looking, in the night, at a very distant light. It appears much greater than when we view it at a small distance; and this increase of magnitude is occasioned only by a false glare. Now, the more that a telescope magnifies, the more this

accident must diminish; not only because the rays are thereby rendered somewhat fainter, but because the real image at the bottom of the eye becomes greater; so that it is no longer a single point which supports the whole impression of the rays. Accordingly, however small the stars may appear through a telescope, we may confidently affirm, that to the naked eye they would appear still much smaller but for this accidental false light, and that as many times as the telescope magnifies.

Hence it follows, that as the fixed stars appear only like so many points, though magnified more than 200 times, their distance must be inconceivable. It will be easy for you to form a judgment how this distance may be computed. The diameter of the sun appears under an angle of 32 minutes: if, therefore, the sun were 32 times farther off, he would appear under an angle of one minute; and, consequently, still much greater than a fixed star viewed through the telescope, the diameter of which does not exceed two seconds, or the thirtieth part of a minute. The sun, therefore, must be thirty times more, that is 960 times, farther removed, before his appearance could be reduced to that of a fixed star observed with the assistance of a telescope. But the fixed star is 200 times farther off than the telescope represents it; and, consequently, the sun must be 200 times 960, that is, 192,000 times farther off than he is, before he could be reduced to the appearance of a fixed star. It follows, that if the fixed stars were bodies as large as the sun, their distances would be 192,000 times greater than that of the sun. Were they still greater, their distances must be still so many times greater; and supposing them even many times smaller, their distances must always be more than a thousand times greater than that of the

sun. Now the distance of the sun from our globe is about 96,000,000 of English miles.

It is impossible, undoubtedly, to think of this immense distance of the fixed stars, and of the extent of the whole universe, without astonishment. What must be the power of that Great Being who created this vast fabric, and who is the absolute Master of it? Let us adore Him with the most profound veneration.

*17th April 1762.*

LETTER CX.—WHY DO THE MOON AND THE SUN  
APPEAR GREATER AT RISING AND SETTING THAN  
AT A CERTAIN ELEVATION? DIFFICULTIES ATTEND-  
ING THE SOLUTION OF THIS PHENOMENON.

You must have frequently remarked, that the moon, at rising and setting, appears much larger than when she is considerably above the horizon; and every one must give testimony to the truth of this phenomenon. The same observation has been made with respect to the sun. This appearance has long been a stumbling-block to philosophers; and, viewed in whatever light, difficulties almost insuperable present themselves.

It would be ridiculous to conclude, that the moon's body is really greater when she is in the horizon than when she has attained her greatest elevation. For, besides that such an idea would be absurd in itself, it must be considered, that when the moon appears to us in the horizon, she appears to other inhabitants of our globe more elevated, and consequently smaller. Now, it is impossible that the same body should be, at the same time, greater and smaller.

It would be almost equally ridiculous to attempt the solution of this strange phenomenon, by sup-

posing that the moon is nearer to us when she appears in the horizon, than when she is arrived at a great elevation, from our certain knowledge that a body appears greater in proportion as it is nearer us; and you know that the more distant any object is, the smaller it appears. It is for this reason precisely that the stars appear so extremely small, though their real magnitude be prodigious.

But however plausible this idea may seem, it is totally destitute of foundation; for it is undoubtedly certain, that the moon is at a greater distance from us at rising and setting, than when at a greater elevation. The demonstration follows: (PLATE VII. *Fig. 32.*)

Let the circle ABD be the earth, and the moon at L. This being laid down, an inhabitant at A will see the moon in his zenith, or the most elevated point of the heavens. But another inhabitant at D, where the line DL touches the surface of the earth, will see the moon at the same time in his horizon; so that the moon will appear, at the same instant, to the spectator A in his zenith, and to the other spectator D in his horizon. It is evident, however, that the last distance DL is greater than the first AL, and consequently the moon is more distant from those who see her in the horizon, than from those who see her near their zenith. Hence it clearly follows, that the moon, when seen in the horizon, ought to appear smaller, being then in fact farther from us than when arrived at a great elevation. It is astonishing, therefore, that observation should be in direct contradiction to this, and that the moon should appear much greater when viewed near the horizon, than in the summit of the heavens.

The more this phenomenon is investigated, the more strange it appears, and the more worthy of attention: it being undoubtedly certain, that the