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.

17*th April* 1762.

LETTER CX.—WHY DO THE MOON AND THE SUN APPEAR GREATER AT RISING AND SETTING THAN AT A CERTAIN ELEVATION? DIFFICULTIES ATTENDING 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 supposing 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

moon, when most remote, that is, in the horizon, ought to appear smaller, whereas, nevertheless, every one is decidedly of opinion that she then appears considerably greater. This contradiction is evident, and even seems to overturn all the principles laid down in optics, which, however, are as clearly demonstrable as any in geometry.

I have purposely endeavoured to set this difficulty in its strongest light, in order to make you the more sensible of the importance of the true solution. Without entering into a discussion of this universal judgment, formed from appearances, respecting the prodigious magnitude of the moon in the horizon, I shall confine myself to the principal question: Is it true, in fact, that the moon, when near the horizon, actually appears greater?

You know that we are possessed of infallible means of exactly measuring the heavenly bodies, by ascertaining the number of degrees and minutes which they occupy in the heavens; or, which amounts to the same thing, by measuring (PLATE VII. *Fig.* 33.) the angle EOF, formed by the lines EO and FO, drawn from the opposite points of the moon, to the eye of the spectator O; and this angle EOF is what we call the apparent diameter of the moon. We have likewise instruments perfectly adapted to the purpose of exactly determining this angle. Now, when we employ such an instrument in measuring the moon's diameter, first at her rising, and afterward, when she has gained her greatest elevation, we actually find her diameter somewhat less in the first case than in the other, as the inequality of distance requires. There cannot remain the shadow of doubt as to this; but, for that very reason, the difficulty, instead of diminishing, gathers strength; and it will be asked with so much the more eagerness—How comes it that the whole world agrees in imagining

the moon to be greater when rising or setting, though her apparent diameter is then in reality smaller? and, What can be the reason of this delusion, to which men are universally subject? The astronomer, who knows perfectly well that the moon's apparent diameter is then smaller, falls nevertheless into the same deception as the most ignorant clown.

20*th April* 1762.

LETTER CXI.—REFLECTIONS ON THE QUESTION RESPECTING THE MOON'S APPARENT MAGNITUDE. PROGRESS TOWARD A SOLUTION OF THE DIFFICULTY. ABSURD EXPLANATIONS.

YOU would scarcely have believed that the simple appearance of the moon involved so many difficulties; but I hope I shall be able to clear the way toward a solution, by the following reflections:—

1. It is not astonishing that our judgment respecting the magnitude of objects should not always be in correspondence with the visual angle under which we see it: of this daily experience furnishes sufficient proof. A cat, for example, appears, when very near, under a greater angle than an ox at the distance of 100 paces. I could never, at the same time, imagine the cat to be larger than the ox: and you will please to recollect, that our judgment respecting magnitude is always intimately connected with that of distance; so that if we commit a mistake in the calculation of distance, our judgment respecting magnitude becomes, of necessity, erroneous.

2. In order to elucidate this more clearly, it sometimes happens that a fly passing suddenly before the eye, without our thinking of it, if our sight is fixed on a distant object we imagine at first that the fly is at a great distance; and as it appears under a very considerable angle, we take it for a moment to be

a large fowl, which at the proper distance would appear under the same angle. It is, then, incontestably certain, that our judgment respecting the magnitude of objects is not regulated by the visual angle under which they are seen, and that there is a very great difference between the apparent magnitude of objects, and the calculated or computed magnitude. The first is regulated by the visual angle, and the other depends on the distance to which we suppose the object to be removed.

3. To avail myself of this remark, I farther observe, that we ought not to say that we see the moon greater in the horizon than at a considerable elevation. This is absolutely false, for we then see her even somewhat less. But, to speak accurately, we ought to say that we judge and compute the moon greater when she is in the horizon; and this is literally true with the unanimous consent of all mankind. This is sufficient to reconcile the apparent contradiction formerly suggested; for nothing prevents our judging or computing the moon to be greater when she rises or sets, though she is seen under a smaller visual angle.

4. We are no longer, then, called upon to explain why we see the moon greater in the horizon, which is impossible, for, in reality, she then appears smaller, as may be demonstrated by measuring the visual angle. The difficulty, therefore, is reduced to this: Wherefore do we judge or compute the moon to be greater when in those situations? or rather, we must endeavour to account for this whimsical computation. The thing is not surprising in itself, as we know a thousand cases in which we estimate objects to be very great, though we see them under very small angles.

5. We have only to say, then, that when the moon is rising or setting, we suppose her to be at a

greater distance than when she has attained a certain elevation. Whenever this computation is settled, whatever may be the cause of it, the consequence is necessary, that we must likewise conclude the moon to be greater in proportion. For, in every case, the more distant we estimate any object to be, the greater we presume it is, and this in the same proportion. As soon as I imagine, by whatever illusion, that a fly passing close before my eye is at the distance of 100 paces, I am obliged, almost whether I will or no, to suppose it as many times greater as 100 paces exceed the real distance of the fly from my eyes.

6. We are now, therefore, reduced to a new question: Wherefore do we presume that the moon is at a greater distance when she is seen in the horizon? and, Wherefore is this illusion so universal as not to admit of a single exception? For the illusion of imagining that the moon is then at a much greater distance is altogether unaccountable. It is undoubtedly true that the moon is then really a little more distant, as I demonstrated in my last letter; but the difference is so trifling as to be imperceptible. Besides, the sun, though 100 times more distant than the moon, does not appear so, and the eye estimates even the fixed stars as nearly at the same distance.

7. Though, therefore, when the moon is in the horizon, she is actually a little more distant, this circumstance cannot affect the present question; and this universal computation, which induces the whole world to imagine the moon to be then at a much greater distance than she really is, must be founded on reasons entirely different, and capable of producing universal illusion. For, as the computation is unquestionably erroneous, the reasons which determine us to make it must necessarily be very striking.

8. Some philosophers have attempted to explain this phenomenon, by alleging that it is occasioned by the intervention of various objects between us

and the moon, such as cities, villages, forests, and mountains. This, say they, is the reason that she then appears to be much farther off; whereas, when she has attained a considerable elevation, as no other body intervenes, she must appear to be nearer. But this explanation, however ingenious it may at first sight appear, is destitute of solidity. On looking at the moon in the horizon, through a small aperture made in any body which shall conceal the intermediate objects, she nevertheless still seems greater. Besides, we do not always imagine that objects, between which and us many other bodies interpose, are more distant. A great hall, for example, when quite empty, usually appears much larger than when filled with company, notwithstanding the numerous objects then interposed between us and the walls of the apartment.

24th April 1762.

LETTER CXII.—AN ATTEMPT TOWARD THE TRUE EXPLANATION OF THIS PHENOMENON: THE MOON APPEARS MORE DISTANT WHEN IN THE HORIZON THAN WHEN AT A GREAT ELEVATION.

WE are still, then, very far from the true solution of this universal illusion, under which all, without exception, are induced to imagine the moon to be much greater when in the horizon than when considerably elevated. I have already remarked, that this phenomenon is so much the more unaccountable, from its being demonstrable that the moon's apparent diameter is then even somewhat less: we ought not, therefore, to say, that we then see the moon greater, but that we imagine her to be so.

Accordingly, I have very often observed our judgment of objects to differ very widely from vision itself. We do not hesitate, for example, to conclude,

that a horse 100 paces distant is larger than a dog one pace distant, though the apparent magnitude of the dog is unquestionably greater; or, which amounts to the same thing, though the image of the dog painted on the bottom of the eye be greater than that of the horse. Our judgment in this case is regulated by taking distance into the account; and laying it down that the horse is much farther off than the dog, we conclude he is much larger.

It is very probable, therefore, that the same circumstance may take place respecting the moon's appearance, and induce us to reckon the moon greater when in the horizon than at a considerable elevation. In the case of the horse, our computation of distance was founded in truth; but here, as it is absolutely erroneous, the illusion must be singularly unaccountable, but must, at the same time, have a certain foundation, as its prevalence is universal, and cannot therefore be imputed to caprice. Wherein can it consist? This is to be the subject of our present inquiry.

1. Every one considers the azure expanse of heaven as a flattened arch, the summit of which is much nearer to us than the under part, where it meets the horizon. A person, accordingly, standing on a plane AB (PLATE VII. *Fig.* 34.) which extends as far as his sight, perceives the vault of heaven, commonly called the firmament, under the figure AEFB, in which the distances CA and CB are much greater than from the *zenith* to C.

2. This idea is likewise beyond all question a mere illusion, there being in reality no such vault surrounding and enclosing us on every side. It is a void of immense extent, as it reaches to the most distant of the fixed stars—an interval that far exceeds all power of imagination. I use the word *void*, to distinguish it from gross terrestrial bodies.

For, near the earth, space is occupied by our atmosphere; and beyond, by that fluid, infinitely more subtile, which we call *Ether*.

3. Though this vault, however, has no real existence, it possesses an undoubted reality in our imagination; and all mankind, the philosopher as well as the clown, are subject to the same illusion. On the surface of this arch we imagine the sun, the moon, and all the stars, to be disposed like so many brilliant studs affixed to it; and though we have a perfect conviction of the contrary, we cannot help giving way to the illusion.

4. This being laid down, when the moon is in the horizon, imagination attaches her to the point A or B of this supposed vault, and hence we conclude her distance to be as much greater as we consider the line CA or CB to be greater than CZ; but when she ascends and approaches the zenith, we imagine she comes nearer; and if she reaches the very zenith, we think she is at the least possible distance.

5. The illusion as to distance necessarily involves that which respects magnitude. As the moon at A appears much farther from C than in the zenith, we are in a manner forced to conclude that the moon is really so much greater; and that in the same proportion that the distance CA appears to exceed the distance CZ. All will not, perhaps, agree in determining this proportion; one will say, the moon appears to him twice as great when in the horizon; another will say three times; and the generality will declare for the medium between two and three; but every one will infallibly agree in asserting that the moon appears larger.

6. It may be necessary here to present you with the demonstration of this proposition. The computation of magnitude is necessarily involved in the computation of distance. When the moon is near

the horizon, we see her (PLATE VII. *Fig.* 35.) under a certain angle, say MCA, the spectator being at C; and when she is at a very great elevation, let NCD be the angle under which we see her. It is evident that these two angles MCA and NCD are nearly equal to each other, the difference being imperceptible.

7. But, in the first case, as we estimate the moon's distance to be much greater, or equal to the line CA, with reference to the imaginary vault above described, it follows, that we compute the moon's diameter to be equal to the line MA. But, in the other case, the distance of the moon CD appears much smaller; and consequently, as the angle NCD is equal to the angle MCA, the computed magnitude DN will be much smaller than the computed magnitude AM.

8. To put this beyond a doubt, you have only to cut off from the lines CM and CA, the parts C *d* and C *n*, equal to the lines CD and CN; and as in the two triangles C *d n* and CDN, the angles at the point C are equal, the triangles themselves are likewise so, and consequently the line DN will be equal to the line *d n*; but *d n* is evidently smaller than AM, and that as many times as the distance C *d* and CD is less than CA. This is a clear demonstration of the reason why we estimate the moon to be greater when in the horizon than when near the zenith.

29*th April* 1762.

LETTER CXIII.—THE HEAVENS APPEAR UNDER THE FORM OF AN ARCH FLATTENED TOWARD THE ZENITH.

You will charge me, no doubt, with pretending to explain one illusion by another equally unaccount-

able. It may be said, that the imaginary vault of heaven is altogether as inconceivable as the increased appearance of the moon and the other heavenly bodies, when in or near the horizon. The objection is not without foundation, and therefore lays me under the necessity of attempting to explain the true reason why the heavens appear in the form of an arch flattened toward the summit. The following reflections may, perhaps, be received as an acquittance of my engagement.

1. In order to account for this imaginary vault, it will be alleged that it proceeds from the appearance of the heavenly bodies, as seeming more remote when in the horizon than when near to or in the zenith. This is undoubtedly a formal *petitio principii*, as logicians call it, or a begging of the question, which every one is entitled to reject as a ground of reasoning. In truth, having said above, that the imaginary vault of heaven makes the moon in the horizon appear farther off than when near the zenith, it would be ridiculous to affirm, that the thing which leads us to imagine the existence of such a vault is, that horizontal objects appear more distant than vertical.

2. It was not, however, useless to suggest the idea of this imaginary vault, though it may not carry us a great way forward; and after I shall have explained, wherefore the heavenly bodies appear more remote when viewed near the horizon, you will be enabled to comprehend, at the same time, the reason of that two-fold universal illusion, namely, the apparently increased magnitude of the heavenly bodies, when in the horizon, and the flattened arch of heaven.

3. The whole, then, reverts to this, to explain wherefore the heavenly bodies, when seen in the horizon, appear more remote than when at a considerable elevation. I now affirm, it is because these objects appear less brilliant; and this imposes on me the double task of demonstrating why these objects display less brilliancy when in or near the horizon, and of explaining how this circumstance necessarily involves the idea of a greater distance. I flatter myself I shall be enabled to discharge both of these to your satisfaction.

4. The phenomenon itself will not be called in question. However greater the sun's lustre may be at noon, which it is then impossible to ascertain, you know that in the morning and evening, when he is rising or setting, it is possible to contemplate his body without any injury to the eye; and the same thing takes place with respect to the moon and all the stars, whose brilliancy is greatly diminished in the vicinity of the horizon. We accordingly do not see the smaller stars when at a small elevation above the horizon, though they are sufficiently discernible at a certain height.

5. This being established beyond a possibility of doubt, the cause of this difference of illumination remains to be investigated. It is abundantly evident that we can trace it only in our atmosphere, or the body of air which encompasses our earth, in as far as it is not perfectly transparent. For if it were, so that all the rays should be transmitted through it, without undergoing any diminution, there could be no room to doubt that the stars must always shine with the same lustre, in whatever region of the heavens they might be discovered.

6. But the air, a substance much less fine and subtile than ether, whose transparency is perfect, is continually loaded with heterogeneous particles, rising into it above the earth, such as vapours and exhalations, which destroy its transparency; so that if a ray should fall in with such a particle, it would

be intercepted, and almost extinguished by it. It is accordingly evident, that the more the air is loaded with such particles, which prevent the transmission of light, the more rays must be lost by the interception; and you know that a very thick mist deprives the air of almost all its transparency, to such a degree, that it is frequently impossible to distinguish objects at three paces distance.

7. Let the points marked in Plate VII. Fig. 36. represent such particles scattered through the air, whose number is greater or less, according as the air is more or less transparent. It is evident, that many of the rays which pervade that space must be lost, and that the loss must be greater in proportion as the space which they had to run through that air is greater. We see, then, that distant objects become invisible in a fog, while such as are very near the eye may be still perceptible, because the rays of the first meet in their progress a greater number of particles which obstruct their transmission.

8. We must hence conclude, that the longer the space is through which the rays of the heavenly bodies have to pass through the atmosphere, in order to reach our eyes, the more considerable must be their loss or diminution. Of this you can no longer entertain any doubt. All that remains, then, is simply to demonstrate, that the rays of the stars which we see in or near our horizon, have a longer space of the atmosphere to pervade than when nearer the zenith. When this is done, you will easily comprehend why the heavenly bodies appear much less brilliant when near the horizon than at the time of rising and setting. This shall be the subject of my next letter.

1st May 1762.

LETTER CXIV.—REASON ASSIGNED FOR THE FAINTNESS OF THE LIGHT OF THE HEAVENLY BODIES IN THE HORIZON.

WHAT I have just advanced, namely, that the rays of the heavenly bodies, when in the horizon, have a larger portion of our atmosphere to pervade, may appear somewhat paradoxical, considering that the atmosphere universally extends to the same height, so that at whatever point the star may be, its rays must always penetrate through the whole of that height before it can reach our eyes. The following reflections, I flatter myself, will give you complete satisfaction on the subject.

1. It is first of all necessary to form a just idea of the atmosphere which surrounds our globe. For this purpose the interior circle ABCD, (PLATE VII. *Fig.* 37.) shall represent the earth, and the exterior dotted circle *a b c d* shall mark the height of the atmosphere. Let it be remarked, that universally in proportion as the air rises above the surface of the earth, it becomes always more transparent and subtile, so that at last it is imperceptibly lost in the ether which fills the whole expanse of heaven.

2. The grosser air, that which is most loaded with the particles that intercept and extinguish the rays of light, is universally found in the lower regions, near the surface of the earth. It becomes, therefore, more subtile as we ascend, and less obstructive of the light; and, at the height of 5 English miles, has become so transparent, as to occasion no perceptible obstruction whatever of the light. The distance, then, between the interior circle and the exterior, may be fixed at 5 English miles nearly, whereas the semidiameter of the globe contains about 3982 of such miles; so that the height of the

atmosphere is a very small matter compared with the magnitude of the globe.

3. Let us now consider (PLATE VII. *Fig.* 38.) a spectator at A, on the surface of the earth; and drawing from the centre of the globe G, through A, the line GZ, it will be directed toward the zenith of the spectator. The line AS, which is perpendicular, and touches the earth, will be horizontal to it. Consequently, he will see a star at Z in his zenith, or in the summit of the heavens; but a star at S will appear to him in the horizon at its rising or setting. Each of these stars may be considered as infinitely distant from the earth, though it was impossible to represent this in the figure.

4. Now you have only to cast your eye once more on the figure, to be satisfied that the rays proceeding from S have a much longer space to travel through the atmosphere, than those from the star Z, before they reach the spectator at A. Those from the star Z have only to pass through the perpendicular height of the atmosphere *a* A, which is not above 5 English miles, whereas those that come from the star S have to travel the whole space *h* A, which is evidently much longer; and could the figure be represented more conformably to the fact, so as to exhibit the radius G A 3982 times longer than the height A *a*, we should find the distance A *h* to exceed 40 such miles.

5. It is farther of importance to remark, that the rays of the star Z have but a very small space to travel through the lower region of the atmosphere, which is most loaded with vapour; whereas the rays of the star S have a much longer course to perform through that region, and are obliged to graze, if I may use the expression, along the surface of the earth. The conclusion, then, is obvious. The rays of the star Z undergo scarcely any diminution of lustre, but those

of the star S must be almost extinguished, from so long a passage through the grosser air.

6. It is indisputably certain, then, that the stars which we see in the horizon must appear with a lustre extremely diminished; and it will simply account to you for a well-known fact, that you can, without any inconvenience, fix your eyes steadily on the rising or setting sun; whereas at noon, or at a considerable elevation, his lustre is insupportable. This is the first point I undertook to demonstrate; I proceed to the second, namely, to prove that it is the diminution of light which forces us almost to imagine the heavenly bodies at a much greater distance than when we see them in all their lustre.

7. The reason must be sought in terrestrial bodies, with which we are every day conversant, and respecting whose distance we form a judgment. But, for the same reason that rays of light, in passing through the air, undergo some diminution of lustre, it is evident, that the farther an object is removed from us, the more of its lustre it loses, and the more obscure it becomes in proportion. Thus, a very distant mountain appears quite dark; but, on a nearer approach, we can easily discover trees on it, and other minuter objects, which it was impossible to distinguish at a very remote distance.

8. This observation, so general, and which never misleads us in contemplating terrestrial bodies, has produced in us from our childhood this fundamental principle, from which we conclude objects to be distant in proportion as the rays of light which they emit are weakened. It is in virtue of this principle, therefore, that we conclude the moon to be farther off at rising and setting than at a considerable elevation; and, for the same reason, we conclude she is so much greater. You will, I flatter myself, admit this reasoning to be solid, and this embarrassing

phenomenon to be as clearly elucidated as the nature of the subject permits.

4th May 1762.

Letter CXV.—Illusion respecting the distance of objects, and the diminution of lustre.

The principle of our imagination, by which I have endeavoured to explain the phenomenon of the moon's greater apparent magnitude in the horizon than at a considerable elevation, is so deeply rooted in our nature, as to become the source of a thousand similar illusions, some of which I will take the liberty to suggest.

We have been habituated from infancy, almost involuntarily, to imagine objects to be distant in proportion as their lustre is diminished; and, on the other hand, very brilliant objects appear to be nearer than they really are. This illusion can proceed only from an ill-regulated imagination, which very frequently misleads us. It is nevertheless so natural, and so universal, that no one is capable of guarding against it, though the error, in many cases, is extremely palpable, as I have shown in the instance of the moon; but we are equally deceived in a variety of other instances, as I shall presently make appear.

1. It is a well-known illusion, that the flame of a conflagration in the night appears much nearer than it really is. The reason is obvious; the fire blazes in all its lustre; and in conformity to a principle pre-established in the imagination, we always conclude it to be nearer than it is in reality.

2. For the same reason, a great hall, the walls of which are perfectly white, always appears smaller. White, you know, is the most brilliant colour: hence

we conclude the walls of such an apartment to be too near; and, consequently, the apparent magnitude is thereby diminished.

3. But in an apartment hung with black, as is the custom in mournings, we perceive the directly opposite effect. The apartment now appears considerably more spacious than it really is. Black is undeniably the most gloomy of colours, for it reflects scarcely any light on the eye; hence the walls of an apartment in deep mourning seem more distant than they are, and consequently greater; but let the black hangings be removed, and the white colour re-appear, and the apartment will seem contracted.

4. No class of men avail themselves more of this natural and universal illusion than painters. The same picture, you know, represents some objects as at a great distance, and others as very near; and here the skill of the artist is most conspicuous. It is not a little surprising, that though we know to absolute certainty all the representations of a picture to be expressed on the same surface, and consequet at nearly the same distance from the eye, we should be, nevertheless, under the power of illusion, and imagine some to be quite near, and others extremely distant. This illusion is commonly ascribed to a dexterous management of light and shade, which undoubtedly furnish the painter with endless resources. But you have only to look at a picture, to be sensible, that the objects intended to be thrown to a great distance, are but faintly and even indistinctly expressed. Thus, when the eye is directed to very remote objects, we easily perceive, for example, that they are men; but it is impossible to distinguish the parts, such as the eyes, the nose, the mouth; and it is in conformity to this appearance that the painter represents objects. But those which he intends should appear close to us, he displays in all the

brightness of colouring, and is at pains clearly to express each minute particular. If they are persons, we can distinguish the smallest lineaments of the face, the folds of the drapery, &c.: this part of the representation seems, I may say, to rise out of the canvass, while other parts appear to sink and retire.

5. On this illusion, therefore, the whole art of painting entirely rests. Were we accustomed to form our judgment in strict conformity to truth, this art would make no more impression on us than if we were blind. To no purpose would the painter call forth all his powers of genius, and employ the happiest arrangement of colours; we should coldly affirm, on that piece of canvass there is a red spot, here a blue one; there a black stroke, here some whitish lines; every thing is on the same plane surface; there is no rising nor sinking; therefore no real object can be represented in this manner: the whole would in this case be considered as a scrawling on paper, and we should perhaps fatigue ourselves to no purpose in attempting to decypher the meaning of all these different coloured spots. Would not a man, in such a state of perfection, be an object of much compassion, thus deprived of the pleasure resulting from the productions of an art at once so amusing and so instructive?

8th May 1762.

LETTER CXVI.—ON THE AZURE COLOUR OF THE HEAVENS.

YOU are now enabled to comprehend the reason why the sun and moon appear much greater when in the horizon than at a considerable elevation. It consists in this, that we then unintentionally compute these bodies to be at a greater distance, a computation founded on the very considerable diminution

which their lustre in that position undergoes, from the longer passage which the rays have to force through the lower region of the atmosphere, which is the most loaded with vapours and exhalations, whereby the transparency is diminished. This is a brief recapitulation of the reflections which I have taken the liberty to suggest on this subject.

This quality of the air, which diminishes transparency, might at first sight be considered as a defect. But on attending to consequences, we shall find it so far from being such, that we ought, on the contrary, to acknowledge in it the infinite wisdom and goodness of the CREATOR. To this impurity of the air we are indebted for that wonderful and ravishing spectacle which the azure of the heavens presents to the eye; for the opaque particles, which obstruct the rays of light, are illuminated by them, and afterwards re-transmit their own proper rays, produced in their surface by a violent agitation, as is the case in all opaque bodies. Now, it is the number of vibrations communicated to them which represents to us this magnificent azure; a circumstance which well deserves to be completely unfolded.

1. I observe, first, that these particles are extremely minute and considerably distant from each other, besides their being delicately fine and almost wholly transparent. Hence it comes to pass, that each separately is absolutely imperceptible, so that we can be affected by them only when a very great number transmit their rays at once to the eye, and nearly in the same direction. The rays of several must therefore be collected, in order to excite a sensation.

2. Hence it clearly follows, that such of these particles as are near to us escape our senses, for they must be considered as points dispersed through the mass of air.

But such as are very distant from the eye, as (PLATE VII. *Fig.* 39.) the points *a b c*, collect in the eye O, almost according to the same direction, their several rays, which thus become sufficiently strong to affect the sight, especially when it is considered that similar particles more remote, *e f g h*, as well as others more near, concur in producing this effect.

3. The azure colour which we see in the heavens when serene, is nothing else, then, but the result of all these particles dispersed through the atmosphere, especially of such as are very remote: it may be affirmed, therefore, that they are in their nature blue, but a blue extremely clear, which does not become sufficiently deep and perceptible, except when they are in a very great number, and unite their rays according to the same direction.

4. Art has the power of producing a similar effect. If, on dissolving a small quantity of indigo in a great quantity of water, you let that water fall drop by drop, you will not perceive in the separate drops the slightest appearance of colour; and on pouring some of it into a small goblet, you will perceive only a faint bluish colour. But if you fill a large vessel with the same water, and view it at a distance, you will perceive a very deep blue. The same experiment may be made with other colours. Burgundy wine, in very small quantities, appears only to be faintly reddish; but in a large flask completely filled, the wine appears of a deep red.

5. Water, in a large and deep vessel, presents something like colour; but, in a small quantity, is altogether clear and limpid. This colour is commonly more or less of a greenish cast, which may warrant us in saying, that the minute particles of water are likewise so, but of a colour so delicately fine, that a great mass of it must be collected before the colour can be perceptible, because the rays of a

multitude of particles then concur toward producing this effect.

6. As it appears probable, from this observation, that the minute particles of water are greenish, it might be maintained, that the reason why the sea, or the water of a lake or pool, appears green, is the very same that gives the heavens the appearance of azure. For it is more probable that all the particles of the air should have a faintly bluish cast, but so very faint as to be imperceptible till presented in a prodigious mass, such as the whole extent of the atmosphere, than that this colour is to be ascribed to vapours floating in the air, but which do not appertain to it.

7. In fact, the purer the air is, and the more purged from exhalation, the brighter is the lustre of heaven's azure; which is a sufficient proof that we must look for the reason of it in the nature of the proper particles of the air. Extraneous substances mingling with it, such as exhalations, become, on the contrary, injurious to that beautiful azure, and serve to diminish its lustre. When the air is overloaded with such vapours, they produce fogs near the surface, and entirely conceal from us the azure appearance; when they are more elevated, as is frequently the case, they form clouds, which frequently cover the whole face of the sky, and present a very different colour from that of this azure of the pure air. This, then, is a new quality of air, different from those formerly explained—subtility, fluidity, and elasticity; namely, the minute particles of air are in their nature bluish.

11*th May* 1762.

Letter CXVII.—What the appearance would be were the Air perfectly transparent.

Independent of the beautiful spectacle of the azure heavens, procured for us by this colour of the circumambient air, we should be miserable in the extreme were it perfectly transparent, and divested of those bluish particles; and we have here a new reason for adoring the infinite wisdom and goodness of the Creator.

That you may have full conviction of the truth of my assertion, let us suppose the air to be quite transparent, and similar to the ether, which, we know, transmits all the rays of the stars, without intercepting so much as one, and contains no particles themselves illuminated by rays, for such a particle could not be so, without intercepting some of the rays which fell upon it. If the air were in this state, the rays of the sun would pass freely through it, without the re-transmission of any light to the eye: we should receive, then, those rays only which came to us immediately from the sun. The whole heavens, except the spot occupied by the sun, would appear, therefore, completely dark; and instead of this brilliant blue, we should discover nothing on looking upward, but the deepest black and the most profound night.

Plate VII. Fig. 40. represents the sun EF, and the point O is the eye of a spectator, which would receive from above no other rays but those of the sun, so that all illumination would be limited to the space of the small angle EOF. On directing the eye toward any other quarter of the heavens, say toward M, not a single ray would be emitted from it, and the appearance would be the same as if we looked into total darkness; now every place which transmits no ray of light is black. But here the stars

must be excepted, which are spread over the whole face of the heavens; for on directing the eye toward M, nothing need prevent the rays of the stars which may be in that quarter from entering into it; nay, they would have even still more force, as they could suffer no diminution of lustre from the atmosphere, such as I am now supposing it. All the stars, therefore, would be visible at noon-day, as in the darkest night; but it must be considered, that this whole day would be reduced to the space of the little angle EOF; all the rest of the heavens would be black as night.

At the same time, stars near the sun would be invisible; and we should not be able to see, for example, the star N, for on looking to it the eye would likewise receive the rays of the sun, with which it must be struck so forcibly, that the feeble light of the star could not excite any sensation. I say nothing of the impossibility of keeping the eye open in attempting to look toward N. This is too obvious not to be understood.

But on opposing to the sun an opaque body, which shall intercept his rays, you could not fail to see the star N, however near it might be to the sun. It is easy to comprehend in what a dismal state we should then be. This proximity of lustre insupportable, and darkness the most profound, must destroy the organs of vision, and quickly reduce us to total blindness. Of this some judgment may be formed from the inconvenience we feel on passing suddenly from darkness into light.

Now this dreadful inconvenience is completely remedied by the nature of the air, from its containing particles opaque to a very small degree, and susceptible of illumination. Accordingly, the moment the sun is above the horizon, nay somewhat earlier, the whole atmosphere becomes illuminated with his

rays, and we are presented with that beautiful azure which I have described, so that our eyes, whichever way directed, receive a great quantity of rays generated in the same particles. Thus, on looking toward M (*Fig.* 40.), we perceive a great degree of light produced by this brilliant azure of the heavens.

This very illumination of the atmosphere prevents our seeing the stars by day: the reason of this is obvious. It far exceeds that of the stars, and the greater light always makes the lesser to disappear; and the nerves of the retina at the bottom of the eye, being already struck by a very strong light, are no longer sensible to the impression made by the feebler light of the stars.

You will please to recollect that the light of the full moon is upwards of 300,000 times more faint than that of the sun; and this will convince you, that the light proceeding from the stars is a mere nothing in comparison with the light of the sun. But the illumination of the heavens in the day-time, even though the sun should be overclouded, is so great, as many thousand times to exceed the light of the full moon.

You must have frequently perceived, that in the night, when the moon is full, the stars appear much less brilliant, and that those only of superior magnitude are visible, especially in the moon's vicinity; a sufficient proof that the stronger light always absorbs the feebler.

It is then an unspeakable benefit, that our atmosphere begins to be illuminated by the sun, even before he rises, as we are thereby prepared to bear the vivacity of his rays, which would otherwise be insupportable, that is, if the transition from night to day were instantaneous. The season during which the atmosphere is gradually illuminated before sun-rising, and continues to be illuminated after he sets, is denominated twilight. This subject, from its importance, merits a particular explanation, which I propose to attempt in my next letter; and thus one article in physics naturally runs into another.

15*th May* 1762.

Letter CXVIII.—Refraction of rays of Light in the Atmosphere, and its effects. Of the Twilight. Of the apparent rising and setting of the Heavenly Bodies.

In order to explain the cause of the twilight, or that illumination of the heavens which precedes the rising of the sun, and continues some time after he is set, I must refer you to what has been already demonstrated respecting the horizon and the atmosphere.

Let the circle AOBD (Plate VII. *Fig.* 41.) represent the earth, and the dotted circle *a o b d* the atmosphere; let a point O be assumed on the surface of the earth, through which draw the straight line HORI, touching the earth at O, and this line HI will represent the horizon, which separates that part of the heavens which is visible to us from that which is not. As soon as the sun has reached this line, he appears in the horizon, both at rising and setting, and the whole atmosphere is then completely illuminated. But let us suppose the sun before his rising to be still under the horizontal line at S; from which the ray STR, grazing the earth at T, may reach the point of the atmosphere situated in our horizon; the opaque particles which are there will already be illuminated by that ray, and consequently have become visible. Accordingly, some time before the rising of the sun, the atmosphere *b o* R over our horizon begins to be illuminated at R; and in proportion as the sun approaches the horizon, a

greater part of it will be illuminated, till it becomes at length completely luminous.

This reflection leads me forward to another phenomenon equally interesting, and very intimately connected with it, namely, that the atmosphere discovers to us the body of the sun and of the other stars, some time before they get above the horizon, and some time after they have fallen below, by means of the refraction which rays of light undergo on passing from the pure ether into the grosser air, which constitutes our atmosphere; of this I proceed to give you the demonstration.

1. Rays of light do not continue to proceed forward in a straight line any longer than they move through a transparent medium of the same nature. As soon as they pass from one medium to another, they are diverted from their rectilinear direction—their path is as it were broken off; and this is what we call refraction, which I formerly explained at considerable length, and demonstrated that rays, on passing from air into glass, and reciprocally, are thus broken or refracted.

2. Now air being a different medium from ether, when a ray of light passes from ether into air, it must of necessity undergo some refraction.

Thus, the arch of the circle AMB (PLATE VII. *Fig.* 42.) terminating our upper atmosphere, if a ray of light MS, from the ether, falls upon it at M, it will not proceed straight forward in the same direction MN, but will assume, on entering into the air, the direction MR, somewhat different from MN; and the angle NMR is denominated the angle of refraction, or simply the refraction.

3. I have already remarked, that the refraction is greater in proportion as the ray SM falls more obliquely on the surface of the atmosphere, or as the angle BMS is smaller or more acute. For if

the ray SM falls perpendicularly on the surface of the atmosphere, that is, if the angle BMS is a right angle, no refraction will take place, but the ray will pursue its progress in the same straight line. This rule is universally applicable to every kind of refraction, whatever may be the nature of the two media through which the rays travel.

4. Let the arch of the circle AOB (PLATE VII. *Fig.* 43.) represent the surface of the earth, and the arch EMF terminate the atmosphere. If you draw at O the line OMV, touching the surface of the earth at O, it will be horizontal. And if the sun is still under the horizon at S, so as to be still invisible, (for no one of his rays can yet reach us in a straight line) the ray SM, being continued in a straight line, would pass over us to N; but as it falls on the atmosphere at M, and in a very oblique direction, the angle FMS, being very acute, it will thence undergo a very considerable refraction; and instead of proceeding forward to N, would assume the direction MO, so that the sun would be actually visible to a person at O, though still considerably below the horizon at S; or, which is the same thing, below the horizontal line OMV.

5. However, as the ray MO, which meets the eye, is horizontal, we assign that direction to the sun himself, and imagine him to be actually at V., that is, in the horizon, though he is still below it. And reciprocally, as often as we see the sun, or any other star, in the horizon, we are assured they are still below it, according to the angle SMV, which astronomers have observed to be about half a degree, or, more exactly, 32 minutes.

6. In the morning, then, we see the sun before he has reached our horizon, that is, while he is yet an angle of 32 minutes below it; and in the evening a

considerable time after he is really set, as we see him till he has descended an angle of 32 minutes. We call that the true rising and setting of the sun, when he is actually in the horizon; and the commencement of his appearance in the morning, and disappearing at night, we denominate the apparent rising and setting.

7. This refraction of the atmosphere, which renders the apparent rising and setting of the sun both earlier and later than the real, procures for us the benefit of a much longer day than we should enjoy, did not the atmosphere produce this effect. Such is the explanation of a very important phenomenon in nature.

18*th May* 1762.

LETTER CXIX.—THE STARS APPEAR AT A GREATER ELEVATION THAN THEY ARE. TABLE OF REFRACTIONS.

YOU have now, no doubt, a clear idea of this singular effect of our atmosphere, by which the sun and the other heavenly bodies are rendered visible in the horizon, though considerably below it, whereas they would be invisible but for the refraction. For the same reason, the sun, and all the heavenly bodies, always appear at a greater elevation above the horizon than they really are. It is necessary, therefore, carefully to distinguish the apparent elevation of a star, from what it would be were there no atmosphere. I shall endeavour to set this in the clearest light possible.

1. Let the arch AOB (PLATE VII. *Fig.* 44.) be part of the surface of the earth, and O the spot where we are, through which draw the straight line HOR,

touching the surface, and this line HOR will represent the true horizon. From O let there be drawn perpendicularly the straight line OZ, which is the same thing as suspending a given weight by a cord. This line is said to be vertical, and the point Z of the heavens, in which it terminates, is called the zenith. This line OZ, then, is perpendicular to the horizontal line HOR, so that one being known, the other must be known likewise.

2. This being laid down, let there be a star at S: (PLATE VII. *Fig.* 45.) were there no atmosphere, the ray SMO would proceed in a straight line to the eye at O, and we should see it in the same direction OMS, where it would actually be—that is, we should see it in its true place. Let us then measure the angle SOR, formed by the ray SO with the horizon OR, and this angle is named the height of the star, or its elevation above the horizon. We measure also the angle SOZ, formed by the ray SO with the vertical line OZ terminating in the zenith: and as the angle ZOR is a right angle, or 90 degrees, we have only to subtract the angle SOZ from 90 degrees, to have the angle SOR, which gives the true elevation of the star.

3. But let us now attend to the atmosphere, which I suppose terminated by the arch HDNMR, (*Fig.* 44.); and I remark, first, that the preceding ray SM of the star S, on entering into M in the atmosphere, does not proceed directly forward to the eye at O, but, from the refraction, will assume another direction, as M P, and consequently will not meet the eye at O: so that if this star sent down to the earth only that ray S M, to a person at O it would be absolutely invisible. But it must be considered, that every luminous point emits its rays in all directions, and that all space is filled with them.

4. There will be, then, among others, some ray, as S N, which is broken or refracted on entering the atmosphere at N; so that its continuation N O shall pass precisely to an eye at O. The refracted ray N O is not, therefore, in a straight line with the ray S M; and if N O be produced forward to *s*, the continuation N *s* will form an angle with the ray N S, namely the angle S N *s*, which is what we call the refraction, and which is greater in proportion as the angle S N R, under which the ray S N enters into the atmosphere, is more acute, as was demonstrated in the preceding letter.

5. It is the ray N O, consequently, which paints in the eye the image of the star S, and which renders it visible: and as this ray comes in the direction N O, as if the star were in it, we imagine the star likewise to be situated in the direction N O, or in that line continued somewhere at *s*. This point *s* being different from the real place of the star S, we call *s* the apparent place of the star, which must be carefully distinguished from its place S, where the star would be seen were there no atmosphere.

6. Since, then, the star is seen by the ray N O, the angle N O R, which this ray N O makes with the horizon, is the apparent altitude of the star; and when by a proper instrument we measure the angle N O R, we are said to have found the apparent altitude of the star; the real altitude being, as we have shown, the angle R O S.

7. Hence it is evident, that the apparent altitude R O N, is greater than the real altitude R O M, so that the stars appear to us at a greater elevation above the horizon than they really are; for the same reason they appear already in the horizon while they are still below it. Now, the excess of the apparent

altitude above the true, is the angle M O N, which does not differ from the angle S N *s*, and which we call the refraction. For, though the angle S N *s*, as being the external angle to the triangle S N O, is equal to the two internal and opposite angles taken together, namely, S O N and N S O, we may consider, on account of the immense distance of the stars, the lines O S and N S as parallel, and consequently the angle O S N vanishes; so that the angle S O N is nearly equal to the angle of refraction S N *s*.

8. Having found, then, the apparent altitude of a star, you must subtract from it the refraction, in order to have the real altitude, which there is no other method of discovering. For this purpose, astronomers have been at much pains to ascertain the refraction to be subtracted from each apparent altitude, that is, to determine how much must be deducted in order to reduce the apparent to the real altitude.

9. From a long series of observations, they have been at length enabled to construct a table, called the table of refraction, in which is marked for every apparent altitude the refraction or angle to be subtracted. Thus, when the apparent altitude is nothing, that is, when the star appears in the horizon, the refraction is 32 minutes; the star is, accordingly, an angle of actually 32 minutes below the horizon. But if the star has acquired any degree of elevation, be it ever so inconsiderable, the refraction becomes much less. At the altitude of 15 degrees it is no more than four minutes; at the altitude of 40 degrees it is only one minute; and as the altitude increases, the refraction always becomes less, till at length it entirely disappears, at the altitude of 90 degrees.

10. This is the case when a star is seen in the very zenith; for its elevation is then 90 degrees, and the real and apparent altitude is the same: and we are fully assured that a star seen in the zenith is actually there, and that the refraction of the atmosphere does not change its place, as at every other degree of altitude.

THE END.

J. Brewster, Printer,
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