LETTER XCVIII.

On Diſtinctneſs in the Expreſſion: On the Space of Diffuſion occaſioned by the Aperture of Objective Lenſes, and conſidered as the firſt Source of Want of Diſtinctneſs in the Repreſentation.

DISTINCTNESS of expreſſion is a quality of ſo much importance in the conſtruction of teleſcopes, that it ſeems to take precedence of all the others which I have been endeavouring to explain; for it muſt be allowed, that a teleſcope which does not repreſent diſtinctly the images of objects muſt be very defective. I muſt, therefore, unfold the reaſons of this want of diſtinctneſs, that we may apply more ſucceſsfully to the means of remedying it.

They appear ſo much the more abſtruſe, that the principles hitherto laid down do not diſcover the ſource: in fact, this defect is thus to be accounted for, one of the principles on which I have hitherto proceeded is not ſtrictly true, though not far from the truth.

You will recollect that it has been laid down as a principle, that a convex lens collects into one point of the image all the rays which come from one point of the object. Were this ſtrictly true, images repreſented by lenſes would be as diſtinctly expreſſed as the object itſelf, and we ſhould be under no apprehenſion of defect in regard to this.

Here, then, lies the defectiveneſs of this principle; lenſes

lenſes have the property now aſcribed to them only around their centre; the rays which paſs through the extremities of a lens collect in a different point from thoſe which paſs toward the centre, though all proceed from the ſame point of the object; hence are produced two different images, which occaſion indiſtinctneſs.

In order to ſet this in the cleareſt light, let us conſider the convex lens PP, *(plate IX. fig. 3.)* on the axis of which is placed the object E *e*, of which the point E, ſituated upon the axis, emits the rays EN, EM, EA, EM, EN, to the ſurface of the lens. To the direction of theſe rays, as changed by refraction, we muſt now pay attention.

I. The ray EA, which paſſes through the centre A of the lens, undergoes no refraction, but proceeds forward in the ſame direction, on the ſtraight line ABF.

II. The rays EM and EM, which are neareſt to the firſt, undergo a ſmall refraction, by which they will meet with the axis ſomewhere at F, which is the place of the image F*f*, as has been explained in ſome of my preceding letters on this ſubject.

III. The rays EN and EN, which are more remote from the axis EA, and which paſs toward the extremities NN of the lens, undergo a refraction ſomewhat different, which collects them, not at the point F, but at another point G nearer the lens, and theſe rays repreſent another image G*g*, different from the firſt F*f*.

IV. Let us now carefully attend to this particular circumſtance,

circumſtance, not hitherto remarked; it is this, that the rays paſſing through the lens, toward it's extremities, repreſent another image G *g*, than what is repreſented by thoſe paſſing near the centre MAM.

V. If the rays EN, EN, were to retire ſtill farther from the centre A, and to paſs through the points PP of the lens, their point of re-union would be ſtill nearer to the lens, and would form a new image, nearer than even G *g*.

VI. Hence you will eaſily perceive, that the firſt image F *f*, which is named the principal image, is formed only by the rays which are almoſt infinitely near the centre; and that according as the rays retire from it, toward the extremities of the lens, a particular image is formed nearer the lens, till thoſe paſſing cloſe to the extremities form the laſt, G *g*.

VII. All the rays, therefore, which paſs through the lens PP repreſent an infinity of images diſpoſed between F *f* and G *g*; and at every diſtance from the axis the refraction of the lens produces a particular image, ſo that the whole ſpace between F and G is filled with a ſeries of images.

VIII. This ſeries of images is accordingly denominated the diffuſion of the image; and when all theſe rays afterwards enter into any eye, it is natural that the viſion ſhould be ſo much diſturbed, as the ſpace FG, through which the image is diffuſed, is more conſiderable. If this ſpace FG could be reduced to nothing, no confuſion or indiſtinctneſs need to be apprehended.

IX. The greater portions of their reſpective circles that

that the arches PAP and PBP are, the greater likewiſe is FG the ſpace of diffuſion. You ſee a good reaſon, then, for rejecting all lenſes of too great thickneſs, or in which the arches which form the ſurfaces of the lens are conſiderable ſegments of their circles; (as in *plate IX. fig.* 4.) 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.

X. 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.* 5. of *plate IX.* in which the arches PAP and PBP contain only 20 degrees, each being but the eighteenth part of the whole circumference of it's reſpective circle.

XI. But if this lens were to ſupply the place of the objective 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 the object is. Therefore, the greater the magnifying power propoſed, the fewer muſt be the number of degrees, which the ſurfaces of the lens contain.

XII. When the teleſcope is intended to magnify 100 times, you will recollect, that the aperture of

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the objective lens muſt be 3 inches, and it's 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 objective lens 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 objective lenſes any given extent.

PP is the objective lens (*plate IX. fig.* 6.) 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 objective lens by a covering of paſteboard ſuch as I have deſcribed, and this confuſion will infallibly diſappear. But a defect equally embarraſſing

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 objective lens, 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 objective lenſes, without diminiſhing the aperture? This is the great enquiry 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 dioptricks. 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 enquiry, 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 objective? 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:

I. If we place (*plate IX. fig.* 7.) behind a convex lens P A P, a concave one Q B Q of the ſame focal diſtance, the rays which the convex lens would collect in it's 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.

II. 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 it's focus at the ſame point F, reſtores the paralleliſm of the rays, which would otherwiſe have met at the point F.

III. 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.* 8. of *plate IX*: the incident parallel rays L M, E A, L M, paſſing through the two lenſes, would aſſume the directions N O, B F, N O, 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 a fmaller focal diftance than the convex, are therefore equivalent to a fimple concave lens.

IV. But if the concave lens Q Q *(plate IX. fig. 9.)* has a greater focal diftance than the convex lens P P, it is not even fufficient to render parallel to each other the rays which the convex lens by itfelf would collect in it's focus F: thefe rays, therefore, continue convergent, but their convergence will be diminifhed by the concave lens, fo that the rays, inftead of meeting in the point F, will meet in the more diftant point O.

V. Thefe two lenfes joined together will produce, then, the fame effect, as a fimple convex lens which fhould have it's focus at O, as it would collect the parallel rays L M, E A, L M, equally in the fame point. It is therefore evident that two lenfes may be combined an infinite variety of ways, the one being convex and the other concave, fo that their combination fhall be equivalent to a given convex lens.

VI. Such a double objective lens may, therefore, be employed in the conftruction of telefcopes, inftead of the fimple to which it is equivalent; and the effect, as to the magnifying power, will be juft the fame. But the fpace of diffufion will be quite different, and it may happen to be greater or lefs than that of a fimple objective, and in this laft cafe, the double objective will be greatly preferable to the fimple.

VII. But farther, it has been found poffible to arrange two fuch lenfes fo that the fpace of diffufion is reduced abfolutely to nothing, which is, undoubtedly,

edly, the greateft advantage poffible in the conftruction of telefcopes. Calculation enables us to determine this arrangement, but no artift has hitherto been found capable of reducing it to practice.

13th March, 1762.

LETTER C.

Of Compound Objective Lenfes.

THE combination of two lenfes, of which I have now given the idea, is denominated a compound objective: the end propofed from them is, that all the rays, as well as thofe which pafs through the extremities of a lens, as thofe which pafs through the middle, fhould be collected in a fingle point, fo that only one image may be formed, without diffufion, as in fimple objectives. Could artifts fucceed in effecting fuch a conftruction, very great advantages would refult from it, as you fhall fee.

It is evident, firft, that the reprefentation of objects muft be much more diftinct, and more exactly expreffed, as vifion is not difturbed by the apparition of that feries of images which occupy the fpace of diffufion, when the objective is fimple.

Again, as this fpace of diffufion is the only reafon which obliges us to give to fimple objectives fuch an exceffive focal diftance, in order to render the inconvenience refulting from it imperceptible; by employing compound objectives we are relieved from that cumberfome expedient, and are enabled to con-

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ſtruct teleſcopes incomparably ſhorter, yet poſſeſſing the ſame magnifying power.

When, employing a ſingle objective, 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 ocular lens, whoſe focal diſtance muſt be added; a ſmall objective would produce, from it's greater ſpace of diffuſion, an intolerable confuſion. But, a length of thirty feet is not only very incommodious, 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 objective lenſes, 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 objective lens muſt be three inches; but it would be eaſy to conſtruct a compound objective 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 ocular 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

and one inches, or eight feet five inches, which is far ſhort of thirty feet.

But it appears to me, that a compound objective, whoſe focal diſtance ſhould be fifty inches, might eaſily admit an aperture of three inches, and even more: taking then an ocular 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 to be wiſhed.

If ſuch a compound objective 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 ocular of half an inch focus, as the two hundredth part of the focal diſtance of the objective, 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 objective, 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 objective whoſe focal diſtance ſhould be two hundred inches, or ſixteen feet eight

inches,

inches, which ſhould admit of an aperture of twelve inches or one foot: taking, then, an ocular 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 objective lens, 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 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 expence attending ſuch an enterprize 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

named Paſſament, 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 enquiry.

16th March, 1762.

LETTER CI.

Formation of Simple Objective Lenſes.

IN order to give you ſome idea of the reſearches which led me to the conſtruction of compound objective lenſes, 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 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,

undoubtedly, recommended this figure, as the ſame baſon ſerves to form both ſurfaces, and moſt artiſts are provided with but few baſons.

Suppoſe, then, a convex lens, both whoſe ſurfaces are poliſhed on the ſame baſon, 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 it's 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 it's two ſurfaces, ſometimes the tenth part, ſometimes the twelfth; accordingly, the lens ſuppoſed, the radius of whoſe ſurfaces is twenty-four inches, will have it's 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

faces 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.

Lenſes.	Radii of the firſt Surface.	Radii of the ſecond Surface.
I.	24	24
II.	21	28
III.	20	30
IV.	18	36
V.	16	48
VI.	15	60
VII.	14	84
VIII.	13	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;

concave; it will, in that caſe, bear the name of *meniſcus*, ſeveral figures of which are preſented in the following table.

Meniſcus.	Radius of the Convex Surface.	Radius of the Concave Surface.
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.* 11 of *plate IX.* ſo that we have now 16 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 objective lens 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

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 it's 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 objective lenſes, 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 it's focal diſtance, it's 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, pleaſe 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 baſons muſt have preciſely that curve which the calculation indicates; nor is that ſufficient, for in the operation of forming the lens on the baſon, the baſon ſuffers from the friction in it's turn; hence it becomes neceſſary to rectify it's figure

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 baſon 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 dioptricks.

20th March, 1762.

LETTER CII.

Second Source of Defect, as to Diſtinctneſs of Repreſentation by the Teleſcope. Different Refrangibility 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 it's 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, the cauſe exiſting not in the glaſs, but in the nature of the rays themſelves.

You will recollect that there is 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

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 (*plate IX. fig.* 12.) a white ray O P, or a ray of the ſun, falls obliquely on a piece of glaſs A B C D, inſtead of purſuing it's courſe in the direction P Q, it not only deviates from this, but divides into a variety of rays P *r*, P *s*, P *t*, P *v*: the firſt of which P *r*, the one that deviates leaſt, repreſents the red colour, and the laſt P *v*, which deviates moſt, the violet colour. The diſperſion *r v* 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 dioptrick glaſſes.

I. Let P P (*plate IX. fig.* 13.) be a convex lens, on the axis of which O R, at a very great diſtance A O, is the object O *o*, 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

which amounts to the ſame thing, attending to thoſe rays only which paſs through the centre of the lens A B, as if it's extremities were covered with a circle of paſteboard.

II. Let us now ſuppoſe the object O *o* to be red, ſo that all it's rays ſhall be of the ſame nature; the lens will ſomewhere repreſent the image of it R *r* equally red; the point R is, in this caſe, denominated the focus of the red rays, or of thoſe which undergo the leaſt refraction.

III. But if the object O *o* is violet, as rays of this colour undergo the greateſt refraction, the image V *v* will be nearer the lens than R *r*; this point V is called the focus of violet rays.

IV. 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 *o* B, drawn from the extremity *o* of the object, through the centre of the lens, this being a general rule for all colours.

V. 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 R *r*; and that which is produced by the violet, at V *v*; and the whole ſpace R V will be filled with images of the intermediate colours.

VI. The lens PP, then, will repreſent a ſucceſſion of images of the object O *o* diſpoſed through the ſmall

ſmall ſpace R V, of which, the moſt remote from the lens, is red, and the neareſt V *v* violet, and the intermediate images of the intermediate colours; according to the order of the colours as they appear in the rainbow.

VII. Each of theſe images will be abundantly diſtinct in itſelf, and all terminated by the ſtraight line *o* B *v r*, 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.

VIII. 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.

IX. This ſpace of diffuſion R V depends on the focal diſtance of the lens, ſo as to be always about the twenty-eighth part; when, therefore, the focal diſtance of the lens P P is 28 feet, the ſpace R V becomes equal to an entire foot, that is, the diſtance between the red image R *r* and the violet V *v* is one foot. If the focal diſtance were twice as great, or 56 feet, the ſpace R V would be two feet, and ſo of other diſtances.

X. 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

intermediate nature are commonly underſtood, thoſe between red and violet, namely the green.

XI. 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 Objectives.

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 it's 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,

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 objective lenſes, as reflection is always the ſame for rays of every nature. This idea has procured for us thoſe excellent reflecting teleſcopes, whoſe ſurprizing effects are ſo juſtly admired, and which I ſhall deſcribe after I have explained every thing relating to refracting inſtruments.

On

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 objective lenſes, 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 meniſque, or concavo-convex lenſes, *(plate IX. fig.* 14.) the one of which is A A C C, and the other B B C C, 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 A A C C muſt paſs through the water incloſed between the two lenſes, before they went off through C C B B. Each ray undergoes, then, four refractions: the firſt on paſſing from the air into the lens A A C C; the ſecond, on paſſing from this lens into the water; the third on paſſing thence into the other lens C C B B; the fourth, on paſſing from this lens into the air.

As the four ſurfaces of theſe two lenſes here enter into

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 objectives, 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 objectives 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 objectives.

Beſides, this project could remedy only the inconveniences which affect the objective lens, and the ocular lens might ſtill labour under ſome defect as great, which it would be impoſſible to remedy in the ſame manner. Several ocular lenſes are frequently employed in the conſtruction of teleſcopes, which I ſhall deſcribe afterwards; we ſhould not, therefore, gain much by a too ſcrupulous adherence to the objective only, while we overlook the other lenſes,

 though

though their effect may not be greatly perceptible relatively to that of the objective.

But, whatever pains thefe refearches may have coft me, I frankly declare, that I entirely give up, at prefent, the conftruction of objectives compounded of glaffes and water; as well on account of the difficulty of execution, as that I have fince difcovered other means, not of deftroying the effect of the different refrangibility of rays, but of rendering it imperceptible. This fhall be the fubject of my next letter.

27th March, 1762.

LETTER CIV.

Other Means more practicable.

SINCE the reflecting telefcope came into general ufe, refracting inftruments have been fo run down, that they are on the point of being wholly laid afide. The conftruction of them has, accordingly, for fome time paft, been wholly fufpended, under a firm perfuafion that every effort to raife them to a ftate of perfection would be ufelefs, as the great *Newton* had demonftrated that the infurmountable difficulties arifing from the different refrangibility of rays, was abfolutely infeparable from the conftruction of telefcopes.

If this fentiment be well founded, there is no telefcope capable of reprefenting objects, but with a confufion

confufion infupportable in proportion to the greatnefs of the magnifying power. However, though there are telefcopes extremely defective in this refpect, we likewife meet with fome that are excellent, and nowife inferior to the fo much boafted reflecting telefcopes. This is, undoubtedly, a very great paradox; for if this defect really attached to the fubject, we fhould not find a fingle exception. Such an exception, therefore, and we have the teftimony of experience that it exifts, well merits every degree of attention.

We are to enquire, then, how it comes that certain telefcopes reprefent the object abundantly diftinct; while others are but too much fubject to the defect occafioned by the different refrangibility of rays. I think I have difcovered the reafon, which I fubmit in the following reflections.

I. It is indubitably certain that the objective lens reprefents an infinity of images of each object, which are all arranged over the fame fpace of diffufion, and each of which is painted it's own proper colour, as I have demonftrated in the preceding Letter.

II. Each of thefe images becomes an object, with refpect to the ocular lens, which reprefents each feparately, in the colour proper to it; fo that the eye difcovers, through the telefcope, an infinity of images, difpofed in a certain order, according to the refraction of the lens.

III. And if, inftead of one ocular glafs, we were to employ feveral, the fame thing will always take place, and inftead of one image, the telefcope will

Ee 2 reprefent

repreſent an infinity to the eye, or a ſeries of images, each of which expreſſes a ſeparate object, but of a particular colour.

IV. Let us now conſider (*plate IX. fig.* 15.) the laſt images preſented, by the teleſcope, to an eye placed at O; and let R r be the red image, and V v 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 ſhew 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.

V. All theſe images R r and V v, with the intermediate, are ſituated, then, on the axis of the teleſcope O R V, and terminated by a certain ſtraight line, $r\ v$, denominated the terminatrix of all the images.

VI. As I have repreſented theſe images in the figure, the red image R r is ſeen by the eye at O, under the angle R O r, which is greater than the angle V O v, under which the violet image V v is ſeen. The violet rays which, from the image V v, enter into the eye, are, therefore, blended with the red which come from the part R r of the red image R r.

VII. 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 vio-

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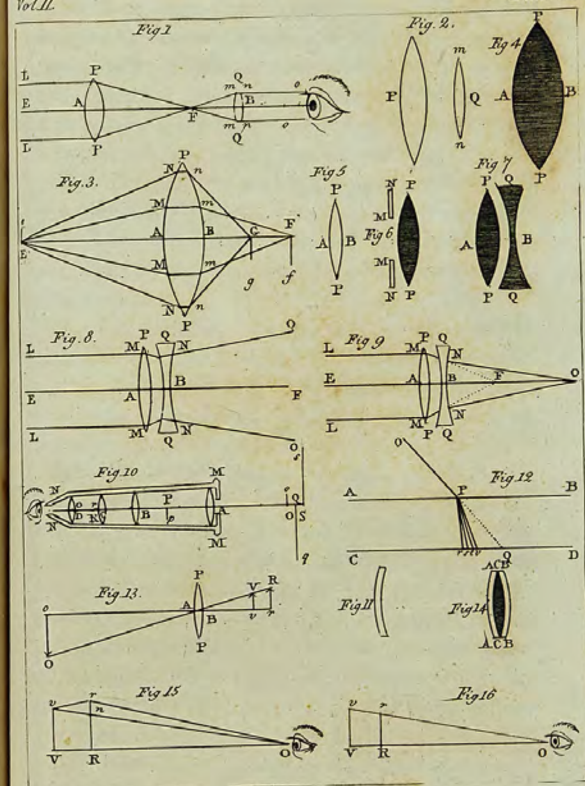
Vol. II. Plate IX



let image, from which a very great confuſion muſt ariſe.

VIII. But the ray *r* O 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.

IX. If the greater image R *r* were the violet and V *v* 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.

X. The confuſion depends, then, on the poſition of the terminating ſtraight line *r v*, with relation to the line V O, and the diverſity which may take place in it; the reſult muſt be, that the confuſion will be ſometimes greater and ſometimes leſs.

XI. Let us now conſider the caſe, in which the laſt images, repreſented by the teleſcope, are ſo arranged, that the ſtraight terminating line *v r* being produced, would paſs preciſely into the eye. The eye will then ſee (*plate IX. fig.* 16.) along a ſingle ray *v r* O, 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.

XII. 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 *v r*, being produced, paſſes through the place of the eye O.

XIII. As the arrangement of the laſt images R *r* and V *v* depends on the diſpoſition of the ocular lenſes, 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 *v r* 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, that no one of them may eſcape your obſervation, I ſhall again go over the ground, and make a diſtinct enumeration of them.

I. The firſt reſpects the magnifying power; and the more that a teleſcope magnifies objects, the more perfect

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 objective lens exceeds that of the ocular. In teleſcopes conſiſting of more lenſes than two, the determination of the magnifying power is more intricate.

II. 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 objective lens 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 objective 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 objectives of a ſtill greater diameter.

III. The third quality is diſtinctneſs or accuracy of repreſentation. In order to this, the rays which paſs through the extremities of the objective lens, ought to meet in the ſame point with thoſe which paſs through the middle, or that, at leaſt, the aberration ſhould not be perceptible. When a ſimple objective is employed, it's 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 objective 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 objective 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.

IV. 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 ſhewn 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 a proper arrangement. I have hitherto ſpoken only of teleſcopes with two lenſes, one of which is the objective, and the other the ocular; and you know that their diſtance from each other is already determined by their focal diſtances, ſo that here

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 ocular lenſes, in order entirely to annihilate the colours of the rainbow: as in this caſe, the ſlighteſt defects, being equally magnified, become inſupportable.

V. 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 ocular lens, 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 ocular, 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 ocular lens; 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 ocular lenſes, 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

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 ocular lenſes, as I ſhall ſhew 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 aukward 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 a new ſpecies of teleſcopes, compoſed of four lenſes, called terreſtrial teleſcopes, from their being deſigned

ſigned to contemplate terreſtrial objects: and the method of conſtructing them follows.

I. The four lenſes A, B, C, D, (*plate IX. fig.* 10.) incloſed in the tube M M N N, repreſent the teleſcope in queſtion; the firſt of which, A, directed toward the object, is denominated the objective lens, and the other three, B C D, the ocular. 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 ocular lens D, the determination of which ſhall be afterwards explained.

II. 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 objective lens will firſt repreſent the image of this object at P *p*, it's 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.

III. 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 B P ſhall be equal to it's 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*.

IV. 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 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 A P exceeds the diſtance B P. 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 it's focal diſtance in R *r*.

V. 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.

VI. Finally, we have only to place the laſt lens in ſuch a manner that the interval D R ſhall be equal to it's 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 S *s*, inſtead of the real object O *o*.

VII. 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

firſt pair of lenſes A and B magnifies as many times, as the focal diſtance of the firſt lens A exceeds that of the ſeconds lens B; and ſo many times will the image formed by it, Q *q*, exceed the real object O *o*.

VIII. Farther, this image Q *q* 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 produced by the four lenſes.

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

X. 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; and, reciprocally, two aſtronomical teleſcopes combined form a terreſtrial.

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

6th April, 1762.

LETTER

LETTER CVII.

Arrangement of Lenſes in Terreſtrial Teleſcopes.

YOU have now 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 X. fig.* 1.

I. 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.

II. 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.

III. 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.

IV. 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 B C between the two middle lenſes. For this purpoſe I refer to *plate X. fig.* 2.

V. 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 objective lens; for unleſs this ray is conveyed to the eye, this extremity *o* will not be viſible. Now, this ray undergoes no refraction in the objective lens, for it paſſes through the centre A; it will therefore proceed in a ſtraight line to the ſecond lens, which it will meet in it's extremity *b*, as this is the laſt ray tranſmitted through the lenſes.

VI. This ray, being refracted by the fecond lens, will change it's direction fo as to meet fomewhere, at *n*, the axis of the lenfes; 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, it's reunion with the axis at *n* will be more diftant from the lens B, than it's focal diftance.

VII. We muft now place the third lens C in fuch a manner that the ray, after having croffed the axis at *n*, may meet it exactly in it's extremity *c*, from which it is evident that the greater the aperture of this lens C is, the farther it muft be removed from the lens B, and the greater the interval B C becomes; but on the other hand, care muft be taken not to remove the lens C beyond that point, as in this cafe the ray would efcape it, and be tranfmitted no farther. This circumftance, then, determines the juft diftance between the two middle lenfes B and C, conformably to experience.

VIII. This lens C will produce a new refraction of the ray in queftion, which will convey it precifely to the extremity *d* of the laft ocular lens D, which, being fmaller than C, will render the line *c d* fomewhat convergent toward the axis, and will thus undergo, in the laft lens, fuch a degree of refraction as will reunite it with the axis at lefs than it's focal diftance; and there it is exactly that the eye muft be placed, in order to receive all the rays tranfmitted through the lenfes, and to difcover the greateft field.

IX. Thus we are enabled to procure a field whofe diameter is almoft twice as large as with an aftronomical

mical telefcope of the fame magnifying power. By means, then, of thefe telefcopes, with four lenfes, we obtain a double advantage, the object is reprefented upright, and a much larger field is difcovered: both, circumftances of much importance.

X. Finally, it is poffible to find fuch an arrangement of thefe four lenfes, as, without affecting either of the advantages now mentioned, fhall entirely do away the defect arifing from the colours of the rainbow, and at the fame time reprefent the object with all poffible diftinctnefs. But few artifts can attain this degree of perfection.

10th April, 1762.

LETTER CVIII.

Precautions to be obferved in the Conftruction of Telefcopes. Neceffity of blackening the Infide of Tubes. Diaphragms.

AFTER thefe refearches refpecting the conftruction of telefcopes, I muft fuggeft and explain certain precautions neceffary to be ufed; which, though they relate neither to the lenfes themfelves, nor to their arrangement, are neverthelefs of fuch importance, that if they are not very carefully obferved, the beft inftrument is rendered entirely ufelefs. It is not fufficient that the lenfes fhould be arranged in fuch a manner that all the rays which fall upon them fhall be tranfmitted through thefe lenfes to the eye; care muft be taken, befides, to prevent the

the tranfmiffion of extraneous rays through the telefcope, to difturb the reprefentation. Let the following precautions, then, be taken.

I. The lenfes, of which a telefcope is compofed, muft be inclofed in a tube, that no other rays, except thofe which are tranfmitted through the objective, may reach the other lenfes. For this effect, the tube muft be very clofe throughout, that not a chink admit the fmalleft portion of light. If by any accident the tube fhall be perforated ever fo flightly, the extraneous light admitted would confound the reprefentation of the object.

II. It is likewife of importance to blacken, throughout, the infide of the telefcope, of the deepeft black poffible, as it is well known that this colour reflects not the rays of light, be they ever fo powerful. You muft have obferved, accordingly, that the tubes of telefcopes are always blackened internally. A fingle reflection will fhew the neceffity of it.

III. The objective lens A, (*plate* X. *fig*. 3.) tranfmits not only the rays of the object reprefented by the telefcope, but thofe alfo which by the extremities enter all around in great abundance; fuch is the ray *b a*, which falls, on the infide, 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 itfelf would generate new rays of light, which muft of neceffity be conveyed through the other lenfes, and difturb the reprefentation by mingling with the proper rays of the object.

IV. But if the infide of the tube be blackened deeply,

deeply, no new rays will be produced, let the light be ever fo ftrong. This blackening muft be carried through the whole length of the telefcope, as there is no black fo deep as not to generate, when illuminated, fome faint light: fuppofing, then, that fome extraneous rays were to make their way to the fecond lens B, the black of the tube, purfuing their courfe, would eafily abforb them altogether. There is a brilliant black, which, for this reafon, it would be very improper to employ.

V. But even this precaution is not fufficient, it is neceffary likewife to furnifh the infide of the tube with one or more diaphragms, perforated with a fmall circular aperture, the better to exclude all extraneous light; but care muft be taken that they exclude not the rays of the object which the inftrument is intended to reprefent. See *plate* X. *fig*. 4.

VI. It is neceffary to obferve at what place, in the tube, the proper rays of the object are moft contracted; this muft be at the points where their images are reprefented, for there all the rays are collected together. Now, the objective lens *A* reprefents the image in it's focus at M. You have only, then, to compute the magnitude of this image, and there to fix your diaphragm, whofe aperture *m n* fhall be equal to the magnitude of the image, or rather fomewhat greater. For if the aperture were lefs than the image, there would be a proportional lofs of the apparent field, which is always a great defect.

VII. Thefe are the obfervations, refpecting the

 diaphragm,

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 objective in it's focus, and which the ſecond lens B tranſports to an infinite diſtance, the third lens C repreſents a ſecond image in it's 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.

VIII. 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,

13*th 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 ſurprize 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 ſurprized, 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,

quently, ftill much greater than a fixed ftar viewed through the telefcope, the diameter of which does not exceed two feconds, or the thirtieth part of a minute. The fun, therefore, muft be thirty times more, that is 960 times, farther removed, before his appearance could be reduced to that of a fixed ftar obferved with the affiftance of a telefcope. But the fixed ftar is 200 times farther off than the telefcope reprefents it; and, confequently, the fun muft 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 ftar. It follows, that if the fixed ftars were bodies as large as the fun, their diftances would be 192,000 times greater than that of the fun. Were they ftill greater, their diftances muft be ftill fo many times greater; and fuppofing them even many times fmaller, their diftances muft always be more than a thoufand times greater than that of the fun. Now the diftance of the fun from our globe is about 15,000,000 of German miles.

It is impoffible, undoubtedly, to think of this immenfe diftance of the fixed ftars, and of the extent of the whole univerfe, without aftonifhment. What muft be the power of that GREAT BEING who created this vaft fabric, and who is the abfolute Mafter of it? Let us adore Him with the moft profound veneration.

17th April, 1762.

LETTER

LETTER CX.

Why do the Moon, and the Sun, appear greater at rifing and fetting, than at a certain Elevation? Difficulties attending the Solution of this Phenomenon.

YOU muft have frequently remarked, that the moon, at rifing and fetting, appears much larger than when fhe is confiderably above the horizon; and every one muft give teftimony to the truth of this phenomenon. The fame obfervation has been made with refpect to the fun. This appearance has long been a ftumbling-block to philofophers; and, viewed in whatever light, difficulties almoft infuperable prefent themfelves.

It would be ridiculous to conclude, that the moon's body is really greater, when fhe is in the horizon, than when fhe has attained her greateft elevation. For, befides that fuch an idea would be abfurd in itfelf, it muft be confidered, that when the moon appears to us in the horizon, fhe appears to other inhabitants of our globe, more elevated, and confequently fmaller. Now, it is impoffible that the fame body fhould be, at the fame time, greater and fmaller.

It would be almoft equally ridiculous to attempt the folution of this ftrange phenomenon, by fuppofing that the moon is nearer to us when fhe appears in the horizon, than when fhe 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 diftant any object is, the

fmaller

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 X. fig. 5.)*

Let the circle A B D 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 D L 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 D L is greater than the firſt A L, 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

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 it's 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 X. fig. 6.)* the angle E O F, formed by the lines E O and F O, drawn from the oppoſite points of the moon, to the eye of the ſpectator O; and this angle E O F 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.

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.

20th 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.

I. 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.

II. 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.

III. 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

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.

IV. 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 ſurprizing 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.

V. 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.

VI. 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.

VII. 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.

VIII. 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 fight appear, is deftitute of folidity. On looking at the moon in the horizon, through a fmall aperture made in any body which fhall conceal the intermediate objects, fhe neverthelefs ftill feems greater. Befides, we do not always imagine that objects, between which and us many other bodies interpofe, are more diftant. A great hall, for example, when quite empty, ufually appears much larger than when filled with company, notwithftanding the numerous objects then interpofed 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 diftant when in the Horizon, than when at a great Elevation.

WE are ftill, then, very far from the true folution of this univerfal illufion, under which all, without exception, are induced to imagine the moon to be much greater when in the horizon, than when confiderably elevated. I have already remarked, that this phenomenon is fo much the more unaccountable, from it's being demonftrable that the moon's apparent diameter is then even fomewhat lefs: we ought not, therefore, to fay, that we then fee the moon greater, but that we imagine her to be fo.

Accordingly, I have very often obferved our judgment

ment of objects to differ very widely from vifion itfelf. We do not hefitate, for example, to conclude, that a horfe 100 paces diftant is larger than a dog one pace diftant, though the apparent magnitude of the dog is unqueftionably greater, or, which amounts to the fame thing, though the image of the dog, painted on the bottom of the eye, be greater than that of the horfe. Our judgment, in this cafe, is regulated by taking diftance into the account, and laying it down that the horfe is much farther off than the dog, we conclude he is much larger.

It is very probable, therefore, that the fame circumftance may take place refpecting the moon's appearance, and induce us to reckon the moon greater, when in the horizon, than at a confiderable elevation. In the cafe of the horfe, our computation of diftance was founded in truth; but here, as it is abfolutely erroneous, the illufion muft be fingularly unaccountable, but muft, at the fame time, have a certain foundation, as it's prevalence is univerfal, and cannot, therefore, be imputed to caprice. Wherein can it confift? This is to be the fubject of our prefent enquiry.

I. Every one confiders the azure expanfe of heaven as a flattened arch, the fummit of which is much nearer to us than the under part, where it meets the horizon. A perfon, accordingly, ftanding on a plane AB (*plate X. fig. 7.*) which extends as far as his fight perceives the vault of heaven, commonly called the firmament, under the figure A E F B, in which

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the diſtances C A and C B are much greater than from the zenith to C.

II. This idea is likewiſe, beyond all queſtion, a mere illuſion; there being, in reality, no ſuch vault ſurrounding and incloſing 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*.

III. 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 into the illuſion.

IV. 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 C A or C B to be greater than C Z; but when, as 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.

V. The illuſion, as to diſtance, neceſſarily involves that

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 C A appears to exceed the diſtance C Z. 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.

VI. 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 X. fig.* 8.) under a certain angle, ſay M C A, the ſpectator being at C: and, when ſhe is at a very great elevation, let N C D be the angle under which we ſee her. It is evident that theſe two angles M C A and N C D are nearly equal to each other, the difference being imperceptible.

VII. But, in the firſt caſe, as we eſtimate the moon's diſtance to be much greater, or equal to the line C A, with reference to the imaginary vault above deſcribed, it follows, that we compute the moon's diameter to be equal to the line M A. But, in the other caſe, the diſtance of the moon C D appears much ſmaller, and, conſequently, as the angle N C D is equal to the angle M C A, the computed

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magnitude D N will be much ſmaller than the computed magnitude A M.

VIII. To put this beyond a doubt, you have only to cut off from the lines C M and C A, the parts C *d* and C *n* equal to the lines C D and C N; and as in the two triangles C *d n* and C D N, the angles at the point C are equal, the triangles themſelves are likewiſe ſo, and, conſequently, the line D N will be equal to the line *d n*; but *d n* is evidently ſmaller than A M, and that, as many times as the diſtance C *d* and C D is leſs than C A. 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.

29th April, 1762.

LETTER CXIII.

The Heavens appear under the Form of an Arch flattened toward the Zenith.

YOU will tax me, no doubt, with pretending to explain one illuſion by another equally unaccountable. 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

lowing reflections may, perhaps, be received as an acquittance of my engagement.

I. 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.

II. 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.

III. 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

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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.

IV. 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.

V. 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.

VI. But the air, a ſubſtance much leſs fine and ſubtile than ether, whoſe tranſparency is perfect, is continually

continually loaded with heterogeneous particles, riſing into it above the earth, ſuch as vapours and exhalations, which deſtroy it's 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 it's tranſparency, to ſuch a degree, that it is frequently impoſſible to diſtinguiſh objects at three paces diſtance.

VII. Let the points marked, in *plate X. fig.* 9. 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.

VIII. 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

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which we fee in, or near, our horizon, have a longer fpace of the atmofphere to pervade, than when nearer the zenith. When this is done, you will eafily comprehend, why the heavenly bodies appear much lefs brilliant when near the horizon, than at the time of rifing and fetting. This fhall be the fubject of my next letter.

1ſt May, 1762.

LETTER CXIV.

Reafon affigned for the Faintnefs of the Light of Heavenly Bodies in the Horizon.

WHAT I have juft advanced, namely, that the rays of the heavenly bodies, when in the horizon, have a larger portion of our atmofphere to pervade, may appear fomewhat paradoxical, confidering that the atmofphere univerfally extends to the fame height, fo that, at whatever point the ftar may be, it's rays muft always penetrate through the whole of that height, before it can reach our eyes. The following reflections, I flatter myfelf, will give you complete fatisfaction on the fubject.

I. It is, firft of all, neceffary to form a juft idea of the atmofphere which furrounds our globe. For this purpofe, the interior circle A B C D *(plate X. fig.* 10.*)* fhall reprefent the earth, and the exterior dotted circle *a b c d* fhall mark the height of the atmofphere. Let it be remarked that, univerfally, in proportion as the air rifes above the furface of the earth, it becomes always more tranfparent and fubtile, fo that, at laft, it is imperceptibly loft in the ether, which fills the whole expanfe of heaven.

II. The groffer air, that which is moft loaded with the particles that intercept and extinguifh the rays of light, is univerfally found in the lower regions, near the furface of the earth. It becomes, therefore, more fubtile as we afcend, and lefs obftructive of the light; and, at the height of a German mile, has become fo tranfparent, as to occafion no perceptible obftruction whatever, of the light. The diftance, then, between the interior circle and the exterior, may be fixed at a German mile, nearly, whereas the femi-diameter of the globe contains about 860 of fuch miles: fo that the height of the atmofphere is a very fmall matter, compared with the magnitude of the globe.

III. Let us now confider, (*plate X. fig.* 11.) a fpectator at A, on the furface of the earth; and drawing from the centre of the globe G, through A, the line G Z, it will be directed toward the zenith of the fpectator. The line A S, which is perpendicular, and touches the earth, will be horizontal to it. Confequently, he will fee a ftar at Z in his zenith, or in the fummit of the heavens; but a ftar at S will appear to him in the horizon, at it's rifing or fetting. Each of thefe ftars may be confidered as infinitely diftant from the earth, though it was impoffible to reprefent this in the figure.

IV. Now you have only to caft your eye once more on the figure, to be fatisfied that the rays proceeding from S have a much longer fpace to travel through

through the atmofphere, than thofe from the ftar Z, before they reach the fpectator at A. Thofe from the ftar Z have only to pafs through the perpendicular height of the atmofphere *a* A, which is not above a German mile; whereas thofe that come from the ftar S have to travel the whole fpace *b* A, which is evidently much longer; and could the figure be reprefented more conformably to the fact, fo as to exhibit the radius G A 860 times longer than the height A *a*, we fhould find the diftance A *b* to exceed 40 fuch miles.

V. It is farther of importance to remark, that the rays of the ftar Z have but a very fmall fpace to travel through the lower region of the atmofphere, which is moft loaded with vapour; whereas the rays of the ftar S have a much longer courfe to perform through that region, and are obliged to crawl, if I may ufe the expreffion, along the furface of the earth. The conclufion, then, is obvious. The rays of the ftar Z undergo fcarcely any diminution of luftre, but thofe of the ftar S muft be almoft extinguifhed from fo long a paffage through the groffer air.

VI. It is indifputably certain, then, that the ftars which we fee in the horizon, muft appear with a luftre extremely diminifhed; and it will fimply account to you for a well-known fact, that you can, without any inconvenience, fix your eyes fteadily on the rifing or fetting fun, whereas at noon, or at a confiderable elevation, his luftre is infupportable. This is the firft point I undertook to demonftrate; I proceed to the fecond, namely, to prove that it is the

the diminution of light which forces us, almoft, to imagine the heavenly bodies at a much greater diftance, than when we fee them in all their luftre.

VII. The reafon muft be fought in terreftrial bodies, with which we are every day converfant, and refpecting whofe diftance we form a judgment. But for the fame reafon that rays of light, in paffing through the air, undergo fome diminution of luftre, it is evident, that the farther an object is removed from us, the more of it's luftre it lofes, and the more obfcure it becomes in proportion. Thus a very diftant mountain appears quite dark; but, on a nearer approach, we can eafily difcover trees on it, and other minuter objects, which it was impoffible to diftinguifh at a very remote diftance.

VIII. This obfervation, fo general, and which never mifleads us in contemplating terreftrial bodies, has produced in us, from our childhood, this fundamental principle, from which we conclude objects to be diftant 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 rifing and fetting, than at a confiderable elevation; and for the fame reafon we conclude fhe is fo much greater. You will, I flatter myfelf, admit this reafoning to be folid; and this embarraffing phenomenon to be as clearly elucidated as the nature of the fubject permits.

4th May, 1762.

LETTER

LETTER CXV.

Illusion respecting the Distance of Objects, and the Diminution of Lustre.

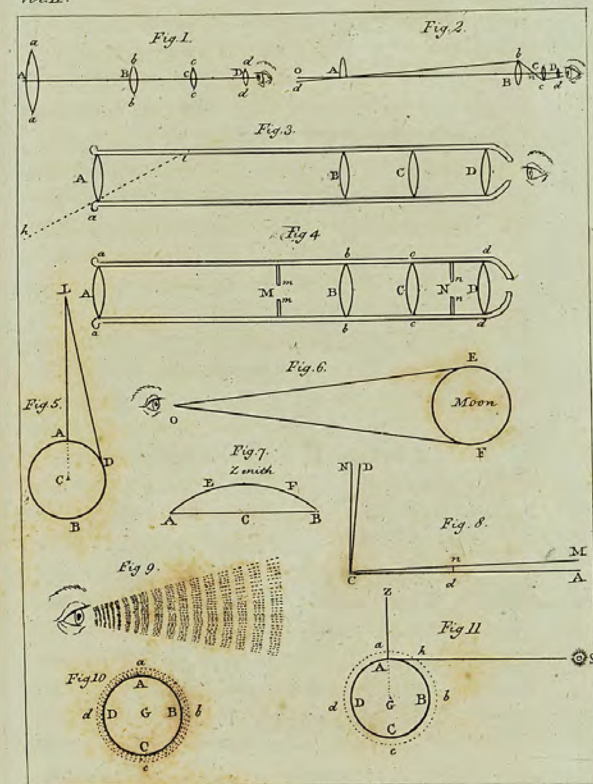
THE principle of our imagination, by which I have endeavoured to explain the phenomenon of the moon's greater apparent magnitude in the horizon than at a considerable elevation, is so deeply rooted in our nature as to become the source of a thousand similar illusions, some of which I will take the liberty 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 shewed in the instance of the moon: but we are equally deceived in a variety of other instances. As I shall presently make appear.

I. 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 it's lustre, and in conformity to a principle pre-established in the imagination, we always conclude it to be nearer than it is in reality.

II. For

Vol. II. Plate X.



II. 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.

III. 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.

IV. 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 ſurprizing, that though we know, to abſolute certainty, all the repreſentations of a picture to be expreſſed on the ſame ſurface, and, conſequently, 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 dextrous management of light and ſhade; which, undoubtedly, furniſh the painter with endleſs refources. But you have only to look at a picture to be fenfible, that the objects intended to be thrown to a great diftance, are but faintly and even indiftinctly expreffed. Thus, when the eye is directed to very remote objects, we eafily perceive, for example, that they are men, but it is impoffible to diftinguifh the parts, fuch as the eyes, the nofe, the mouth; and it is in conformity to this appearance, that the painter reprefents objects. But thofe which he intends fhould appear clofe to us, he difplays in all the brightnefs of colouring, and is at pains clearly to exprefs each minute particular. If they are perfons, we can diftinguifh the fmalleft lineaments of the face, the folds of the drapery, &c.: this part of the reprefentation feems, I may fay, to rife out of the canvas, while other parts appear to fink and retire.

V. On this illufion, therefore, the whole art of painting entirely refts. Were we accuftomed to form our judgment in ftrict conformity to truth, this art would make no more impreffion on us than if we were blind. To no purpofe would the painter call forth all his powers of genius, and employ the happieft arrangement of colours, we fhould coldly affirm, on that piece of canvas, there is a red fpot, here a blue one; there a black ftroke, here fome whitifh lines: every thing is on the fame plane furface; there is no rifing nor finking; therefore no real object can be reprefented in this manner: the whole would, in this cafe, be confidered as a fcrawling on paper, and we fhould, perhaps, fatigue ourfelves to no purpofe, in attempting to decypher the meaning of all thefe

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different coloured fpots. Would not a man, in fuch a ftate of perfection, be an object of much compaffion, thus deprived of the pleafure refulting from the productions of an art, at once fo amufing, and fo inftructive?

8th May, 1762.

LETTER CXVI.

On the Azure Colour of the Heavens.

YOU are now enabled to comprehend the reafon why the fun and moon appear much greater when in the horizon, than at a confiderable elevation. It confifts in this, that we then unintentionally compute thefe bodies to be at a greater diftance, a computation founded on the very confiderable diminution which their luftre, in that pofition, undergoes, from the longer paffage which the rays have to force, through the lower region of the atmofphere, which is the moft loaded with vapours and exhalations, whereby the tranfparency is diminifhed. This is a brief recapitulation of the reflections which I have taken the liberty to fuggeft on this fubject.

This quality of the air, which diminifhes tranfparency, might, at firft fight, be confidered as a defect. But on attending to confequences, we fhall find it fo far from being fuch, that we ought, on the contrary, to acknowledge in it the infinite wifdom and goodnefs of the CREATOR. To this impurity of the air we are indebted for that wonderful and ravifhing

fpectacle

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.

I. 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.

II. 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 XI. fig.* 1.) the points *a b c* collect in the eye, 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.

III. The azure colour which we ſee in the heavens, when ſerene, is nothing elſe, then, but the reſult of all

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 becomes not ſufficiently deep and perceptible, except when they are in a very great number, and unite their rays according to the ſame direction.

IV. 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.

V. 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.

VI. As it appears probable, from this obſervation, that the minute particles of water are greeniſh, it might

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.

VII. 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 it's 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.

11th May, 1762.

LETTER

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 XI. fig. 2, repreſents the ſun; and the point

 O is

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 E O F. 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 E O F; 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

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 it's 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, *(ſee the ſame figure as before)* 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 upward of 300,000 times more faint than

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 over-clouded, 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 it's importance, merits a particular explanation, which I propoſe to attempt in my next Letter: and thus, one article in phyſics naturally runs into another.

15th May, 1762.

LETTER

LETTER CXVIII.

Refraction of Rays of Light in the Atmoſphere, and it's 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 A O B D (*plate XI. fig.* 3.) 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 H O R I, touching the earth at O, and this line H I 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 S T R, 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 *h o* R over

 our

our horizon begins to be illuminated at R, and in proportion as the fun 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 interefting, and very intimately connected with it, namely, that the atmofphere difcovers to us the body of the fun and of the other ftars, fome time before they get above the horizon, and fome time after they have fallen below it, by means of the refraction which rays of light undergo on paffing from the pure ether into the groffer air, which conftitutes our atmofphere; of this I proceed to give you the demonftration.

I. Rays of light do not continue to proceed forward in a ftraight line any longer than they move through a tranfparent medium of the fame nature. As foon as they pafs 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 confiderable length, and demonftrated that rays, on paffing from air into glafs, and reciprocally, are thus broken or refracted:

II. Now air being a different medium from ether, when a ray of light paffes from ether into air, it muft, of neceffity, undergo fome refraction.

Thus, the arch of the circle A M B (*plate XI. fig.* 4.) terminating our upper atmofphere, if a ray of light M S, from the ether, falls upon it at M, it will not proceed ftraight forward in the fame direction

tion M N, but will affume, on entering into the air, the direction M R, fomewhat different from M N, and the angle N M R is denominated the angle of refraction, or, fimply, the refraction.

III. I have already remarked, that the refraction is greater in proportion as the ray S M falls more obliquely on the furface of the atmofphere; or as the angle BMS is fmaller or more acute. For if the ray SM falls perpendicularly on the furface of the atmofphere, that is, if the angle B M S is a right angle, no refraction will take place, but the ray will purfue it's progrefs in the fame ftraight line. This rule is univerfally applicable to every kind of refraction, whatever may be the nature of the two media, through which the rays travel.

IV. Let the arch of the circle A O B (*plate XI. fig.* 5.) reprefent the furface of the earth, and the arch E M F terminate the atmofphere. If you draw at O the line O M V, touching the furface of the earth at O, it will be horizontal. And if the fun is ftill under the horizon at S, fo as to be ftill invifible (for no one of his rays can yet reach us in a ftraight line) the ray S M, being continued in a ftraight line, would pafs over us to N; but as it falls on the atmofphere at M, and in a very oblique direction, the angle F M S being very acute, it will thence undergo a very confiderable refraction; and inftead of proceeding forward to N, would affume the direction M O, fo that the fun would be actually vifible to a perfon at O, though ftill confiderably below

low the horizon at S, or, which is the fame thing, below the horizontal line O M V.

V. However, as the ray M O, which meets the eye, is horizontal, we affign that direction to the fun himfelf, and imagine him to be actually at V, that is, in the horizon, though he is ftill below it. And reciprocally, as often as we fee the fun, or any other ftar, in the horizon, we are affured they are ftill below it, according to the angle S M V, which aftronomers have obferved to be about half a degree, or, more exactly, 32 minutes.

VI. In the morning, then, we fee the fun before he has reached our horizon, that is, while he is yet an angle of 32 minutes below it; and in the evening a confiderable time after he is really fet, as we fee him till he has defcended an angle of 32 minutes. We call that the true rifing and fetting of the fun, when he is actually in the horizon; and the commencement of his appearance in the morning, and difappearing at night, we denominate the apparent rifing and fetting.

VII. This refraction of the atmofphere, which renders the apparent rifing and fetting of the fun both earlier and later than the real, procures for us the benefit of a much longer day than we fhould enjoy, did not the atmofphere produce this effect. Such is the explanation of a very important phenomenon in nature.

18th May, 1762.

LETTER

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 fingular effect of our atmofphere, by which the fun and the other heavenly bodies are rendered vifible in the horizon, though confiderably below it, whereas they would be invifible but for the refraction. For the fame reafon, the fun, and all the heavenly bodies, always appear at a greater elevation above the horizon than they really are. It is neceffary, therefore, carefully to diftinguifh the apparent elevation of a ftar, from what it would be were there no atmofphere. I fhall endeavour to fet this in the cleareft light poffible.

I. Let the arch A O B *(plate XI. fig. 6.)* be part of the furface of the earth, and O the fpot where we are, through which draw the ftraight line H O R, touching the furface, and this line H O R will reprefent the true horizon. From O let there be drawn perpendicularly the ftraight line O Z, which is the fame thing as fufpending a given weight by a cord. This line is faid to be vertical, and the point Z of the heavens, in which it terminates, is called the zenith. This line O Z, then, is perpendicular to the horizontal H O R, fo that one being known, the other muft be known likewife.

II. This being laid down, let (*plate XI. fig.* 7.) there

there be a ſtar at S: were there no atmoſphere, the ray S M O would proceed in a ſtraight line to the eye at O, and we ſhould ſee it in the ſame direction O M S, where it would actually be, that is, we ſhould ſee it in it's true place. Let us, then, meaſure the angle S O R, formed by the ray S O with the horizon O R, and this angle is named the height of the ſtar, or it's elevation above the horizon. We meaſure alſo the angle S O Z, formed by the ray S O with the vertical line O Z terminating in the zenith: and as the angle Z O R is a right angle, or 90 degrees, we have only to ſubtract the angle S O Z from 90 degrees, to have the angle S O R, which gives the true elevation of the ſtar.

III. But let us now attend to the atmoſphere, which I ſuppoſe terminated by the arch H D N M R; and, I remark, firſt, that the preceding ray S M 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 it's rays in all directions, and that all ſpace is filled with them.

IV. There will be, then, among others, ſome ray, as S N, which is broken or refracted, on entering the atmoſphere at N: ſo that it's 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

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.

V. 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 it's place S, where the ſtar would be ſeen, were there no atmoſphere.

VI. 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 ſhewed, the angle R O S.

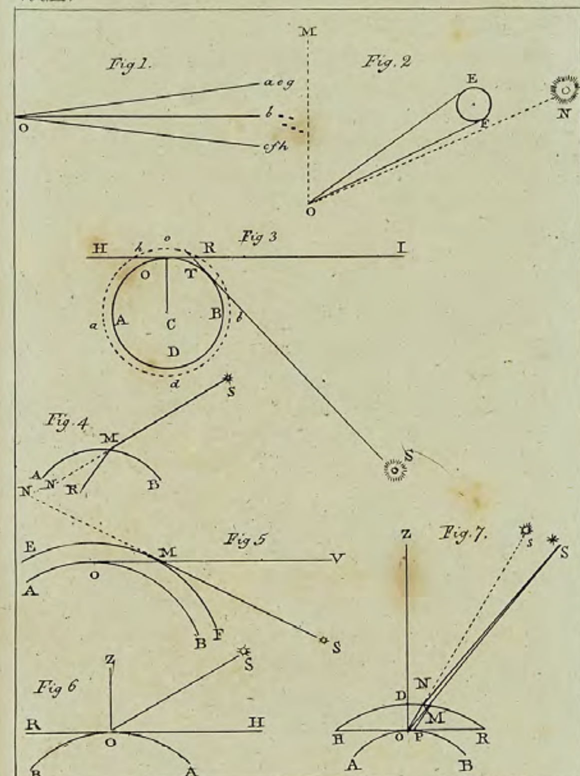
VII. Hence it is evident, that the apparent altitude R O N, is greater than the real altitude R O M, ſo that the ſtars appear to us at a greater elevation above the horizon than they really are, for the ſame reaſon they appear already in the horizon while they are ſtill below it. Now the exceſs of the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

differs not from the 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*.

VIII. 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 abated in order to reduce the apparent to the real altitude.

IX. 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 encreaſes, the refraction always becomes leſs, till, at length

Vol. II. *Plate XI*



length, it entirely diſappears, at the altitude of 90 degrees.

X. This is the caſe when a ſtar is ſeen in the very zenith; for it's 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 it's place, as at every other degree of altitude.

THE END.

GLOSSARY

OF

FOREIGN AND SCIENTIFIC TERMS.

A.

ABERRATION, in Aſtronomy a ſlight deviation of a Star from the ſtated courſe. Latin.

ABSORPTION, the act of ſucking or ſwallowing up. Latin.

ABSTRACTION, in Philoſophy, that operation of the mind, which purſues a general idea, without attending to the particulars of which it is made up. Thus, *Man*, *Tree*, are *abſtract* ideas, and may be purſued, without deſcending to any one individual perſon or plant, included in the general term. Accordingly, all qualities, ſuch as *whiteneſs*, *cruelty*, *generoſity*, are *abſtract* ideas. Latin.

ACCORD, in Muſic, the ſame with *concord*, the relation of two ſounds which are always agreeable to the ear, whether emitted at once or in ſucceſſion. Latin.

ACHROMATIC-Glaſſes, in Optics, are a recent improvement of the Teleſcope, by which the inconveniency ariſing from the confuſed tranſmiſſion of different coloured rays is prevented. The word is of Greek extraction, and ſignifies *colourleſs*.

AERIFORM, Latin, having the form or conſiſtency of *Air*.

AEROSTATION, the art of aſcending into the Atmoſphere by means of a Balloon filled with inflammable Air. Latin.

AFFIRMATIVE-propoſition, in Logic, a propoſition which aſſerts or affirms; as *Man is mortal*. Latin.

AIR-PUMP, a machine for making experiments on air, chiefly by exhauſting cloſe veſſels of that fluid.

ALGEBRA, an Arabic word; it is the Science of univerſal Arithmetic; the general proceſs of which is, by comparing ſuppoſed and unknown numbers or quantities, with ſuch as are known, to reduce ſuppoſition into certainty.

ALKALI, an Egyptian word; in Chemiſtry, any ſubſtance which, when blended with an acid, excites fermentation.

ALTITUDE, in Aſtronomy, the height of a Star above the Horizon. Latin.

AMALGAMATE, to incorporate mercury, or quickſilver, with other metals; ſometimes uſed to denote, in general, the mixture and conſolidation of ſeveral ſubſtances, ſo as to make them appear one. Greek.

ANALAGOUS, having reſemblance or agreement. Greek.

ANALYSIS, reſolution into firſt principles, whether in grammar, logic, mathematics, or chemiſtry. To give an inſtance, in Grammar, which is perhaps the moſt familiar to a young perſon's mind, an *analyſis* of this ſentence; *In the beginning God created the Heavens and the Earth*, is to indicate the various parts of ſpeech of which it is compoſed, and the grammatical rules according to which they are arranged. The child may innocently amuſe himſelf with the idea of a *Chemical analyſis*, by a ſcientific proceſs applied to a bowl of the vulgar liquor called punch. To analyze it, is to aſcertain, by ſeparation, the proportion of ſugar, lemon-juice, ſpirit, and water, of which it is compoſed. Greek.

ANATHEMA, and it's compounds; ſomething ſet apart to a ſacred uſe; generally underſtood in an ungracious ſenſe; devoted to deſtruction, accurſed. Greek.

ANATOMY, the ſcience of the ſtructure of the body, and the art of diſſecting and reaſoning upon it. Greek.

ANGLE, the meeting of two lines in a point, but ſo as not to form of both one ſtraight line. Latin.

ANTECEDENT, in Logic, the former of two propoſitions, in a ſpecies of reaſoning, which, without the intervention of any middle propoſition, leads directly to a fair concluſion; and this concluſion is termed the *Conſequent*. Thus *I reflect*; *therefore I exiſt*. *I reflect* is the *Antecedent*, *therefore I exiſt* is the *Conſequent*. Latin.

ANTIPODES, the Inhabitants of the Globe diametrically oppoſite to us, and whoſe feet preſent exactly to our feet. Greek.

APERTURE, opening. Latin.

APPROXIMATION, a coming nearer to. In Aſtronomy, the gradual approach of two ſtars toward each other: in Arithmetic, a nearer approach to a number or root ſought, without the poſſibility of arriving at it exactly. Latin.

AQUEDUCT, what conveys, or conducts *water*; a pipe, a canal. Latin.

AQUEOUS, watery, conſiſting of water. Latin.

ARITHMETIC, the ſcience of numbers. Greek.

ASTRONOMY, the ſcience of the heavenly bodies. Greek.

ASTROLOGY, the pretended ſcience of predicting future events by means of the ſtars. Greek.

ATMOSPHERE, the body of air which ſurrounds the globe on all ſides. Greek.

AXIS, in Geography, an imaginary ſtraight line paſſing through the centre of the Earth from pole to pole, round which the Globe revolves once every twenty-four hours. Latin.

B.

BAROMETER, an inſtrument of glaſs filled with quickſilver, which indicates the preſſure of the air, and which is in general uſe, as an index of the weather. The word is Greek, and ſignifies *weight-meaſurer*.

BISECT, to cut into two equal parts. Latin.

BITUMINOUS, like to, or conſiſting of *bitumen*, a fat, clammy, eaſily inflammable juice, dug out of the earth, or ſcummed off lakes. Amber, pit-coal, and ſulphur, are hard *bitumens*. Latin.

BOMB, a hollow caſt-iron globe, to be thrown from a ſpecies of great gun called "*mortar*," and intended to burſt by the force of gun-powder, at the moment of falling, and to ſcatter deſtruction all around. It is in this Work innocently employed to explain the path of all bodies forcibly thrown through the air, and the effect of gravity in bringing all heavy moving bodies down to the ground. Latin.

BOTANY, the ſcience of Plants; or that part of natural and medicinal hiſtory which has the vegetable world for it's object. Greek.

C.

CAMERA OBSCURA, an apartment darkened, all but a ſmall circular opening, to which a double-convex glaſs is fitted, and by which external objects are repreſented in their natural colours, motions, and proportions, on a white table within the apartment. Latin.

CATARACT, a body of water precipitated from a great height. Greek.

CATOPTRICKS, that branch of the ſcience of viſion which relates to reflected light. All bodies which you do not *ſee through*, but which from their poliſh and brightneſs *throw back* the light, belong to *catoptricks*, ſuch as mirrors of every kind. The word is Greek, and ſignifies *backward viſion*.

CAVITY, a hollow. Latin.

CAUSA-SUFFICIENS, *ſufficient or ſatisfying cauſe or reaſon*, a jargon employed by certain Metaphyſicians of the laſt age, who attempted to check all rational, experimental enquiry, by calling continually for the *cauſa ſufficiens*, the *adequate cauſe* of

of every fact that occurred, and of every obſervation that was made; while they were bewildering themſelves, and attempting to bewilder mankind, in a philoſophic maze, uſeleſs, reaſonleſs, and therefore unſatisfactory.

CENTRE, a point within a circle or ſphere, equally diſtant from every point of the ſurface or circumference. Latin.

CHART, a delineation on paper of part of the land or of the ſea, or both. Latin.

CHEMISTRY, or CHYMISTRY, a word of uncertain derivation; the ſcience of ſeparating compound ſolid bodies, or of compounding ſimple bodies into one maſs, by the force of fire.

CHIMERA, a vain and wild imagination. Latin.

CHORAL-muſic, a ſacred band compoſed of voices and inſtruments. Latin.

CHROMATIC; in Opticks, relating to colour; in Muſic, to a certain ſeries of ſounds. Greek.

CIRCLE, a round figure, having this eſſential property, that every point of it's ſurrounding line, called the circumference, ſhall be equally diſtant from it's middle point, called the centre. Latin.

CIRCUMAMBIENT, encompaſſing round and round: applied particularly to air and water. Latin.

CIRCUMFERENCE, the ſurrounding line of a circle, every point of which muſt have an equal diſtance from it's middle point or centre. Latin.

COHESION, clinging or ſticking together. Latin.

COLLISION, the claſhing of one ſolid body againſt another. Latin.

COMET, a ſtar with a fiery train, like flowing hair, averted from the ſun; of uncertain appearance and re-appearance, but undoubtedly forming part of our ſolar ſyſtem. Greek.

COMPLEX, made up of various qualities or ingredients. A beautiful, wiſe and good woman, is a *complex* idea, containing three diſtinct ideas, beauty, wiſdom, goodneſs; you might

Ii 3 render

render it ſtill more complex by the addition of high-born, rich, religious——but I muſt not make my idea too complex.

Compression, the act of reducing to a ſmaller ſpace by preſſure.

Concave, the hollowed ſurface of a globular body. Latin.

Concussion, mutual ſhock, by violent meeting of two ſolid bodies. Latin.

Condensation, the act of contracting air into a ſmaller ſpace, and thereby increaſing it's elaſtic force, that is, it's power of burſting out. Latin.

Congelation, the reduction of a fluid to a ſolid ſubſtance, as water to ice by cold. Latin.

Concentric Circles, one within another, having a common centre. Latin.

Conical, having the form of a *cone*, which is a figure produced by turning round a right-angled triangle about it's perpendicular ſide; a common candle extinguiſher conveys the idea of it. Greek.

Consequent. Take the trouble to look to the word *Antecedent*. They are what is called *correlative*, in other words the one cannot be underſtood but by referring to the other.

Consonance, in Muſic, the agreement of two ſounds emitted at the ſame time. Latin.

Constituent, contributing to make up or compoſe. Thus the conſtituent parts of gun-powder are ſaltpetre, ſulphur, and charcoal. Latin.

Continuity, uninterrupted connection; the unviolated union of the parts of an animal body. Latin.

Contexture, an interweaving. Latin.

Contour, the extreme bounding line of any object. Children delineate the *contours* of each other's faces by tracing, with a pencil, the line deſcribed on the wall, when the face is placed between a light and the wall. It is a French word.

Convergent,

Convergent, gradually approaching to each other. Placed at the extremity of an avenue of two rows of trees, planted in ſtraight lines, equally diſtant throughout, you perceive them apparently approaching, and at length almoſt meeting; they are apparently *convergent*.

Convex, the prominent or ſwelling ſurface of a globular body. Latin.

Cornea, the white, horny membrane of the eye. Latin.

Corporeal, belonging to body. Latin.

Corpus Callosum, in Metaphyſics and Anatomy, the part of the human brain where the ſoul is ſuppoſed to reſide. Latin, but of ludicrous derivation.

Corpuscle, a ſmall or minute body. Latin.

Couching, an operation in Surgery, by which a film obſtructing ſight is by a needle or lancet removed from the aqueous humours of the eye; the word is of French extraction. The film removed is denominated *cataract*.

Crucible, an earthen pot which can ſtand fire, employed in melting and refining metals. Low Latin.

Crystalline, the lucid, various-coloured humour of the eye, which forms a beautiful circle, incloſed by the cornea, and incloſing the pupil, or central ſpot of that precious organ. Greek.

Cube, and it's compounds; a figure ſquare and rectangular in all it's dimenſions and ſituations. A common die conveys the idea of it. A cubical room of twenty feet, is a room twenty feet long, twenty feet broad, and twenty feet high, and all in ſtraight lines, and at right angles. Greek.

Curve, a bending line. Latin.

Cylinder, a figure formed by turning a parallelogram round one of it's ſides as an axis. The barrel of a hand-organ is a cylinder. The word is derived from a Greek verb, which ſignifies to *wheel round*.

I i 4 Decompose,

D.

Decompose, to feparate things compounded: thus, in printing, to *compofe* is to arrange the types in a frame, in the order of words and fentences; and to *decompofe* is to take the frame to pieces. Latin.

Degree, in Geography, the three hundredth and fixtieth part of the circumference of the globe: it contains about 69 Englifh miles. French.

Density, thicknefs. Latin.

Dephlogistic, deprived of fiery inflammable qualities. Greek.

Detonation, the thunder-like noife produced by firing off heavy artillery. Latin.

Diagram, a figure delineated for the purpofe of mathematical demonftration. Greek.

Diameter, a ftraight line drawn through the centre of a circle or globe, from circumference to circumference. Greek.

Diaphonous body, that which eafily tranfmits the light, as glafs. Greek.

Diaphragm, in optical inftruments, a circular piece of pafteboard, or other non-tranfparent fubftance, applied to the object-glafs, to exclude part of the rays of light. Greek.

Diatonic, an epithet given to the common mufic, as it proceeds by tones, both afcending and defcending. Greek.

Dilate, to expand, to fpread over greater fpace. Latin.

Dimension, meafure. Latin.

Dioptricks, that branch of the fcience of vifion which relates to the tranfmiffion of the rays of light *through* tranfparent bodies. Greek.

Dissonance, in mufic, founds that do not harmonize, but are harfh and difagreeable to the ear. Latin.

Distraction, tendency in different directions. Latin.

Divergent,

Divergent, ftraight lines, gradually removing farther and farther from each other. See *Convergent*. Latin.

Diving-bell, a machine of wood, glafs, or metal, in form of a bell, for the purpofe of conducting down into the water, with fafety, perfons employed in certain kinds of fifhery, and in recovering goods loft by fhipwreck.

Divisibility, capability of being divided. Latin.

Double-concave, an optical glafs which has both furfaces hollowed.

Double-convex, an optical glafs which has both furfaces raifed.

Ducat, a *ducal* coin of gold, current on the continent, value about nine fhillings and fixpence.

Ductile, pliant, eafily drawn or fpread out. Latin.

E.

Effulgence, luftre, brightnefs. Latin.

Elasticity, a power in bodies of recovering their former fituation, as foon as the force is removed, which had changed it. Thus, the extremities of a bow are brought nearer by drawing the ftring, but when the ftring is relaxed, the bow, by it's *elafticity*, is reftored to it's natural ftate. It is a property of air, as well as of folid bodies. Greek.

Electricity, the difpofition which certain bodies have of acquiring, by rubbing, the quality of attracting other bodies, and of emitting fparks of fire. It is derived from a Latin word fignifying *amber*, which is one of the fubftances endowed with the electrical virtue.

Elicite, to ftrike out by force. Thus by a fharp ftroke of the fteel on flint, fire is *elicited*. Latin.

Elogium, or **Eulogium**, an oration in praife of one abfent or dead. Greek.

Elucidation,

Elucidation, the act of explaining or rendering clearer. Latin.

Emanation, an iſſuing or flowing from any ſubſtance as a ſource. Latin.

Emersion, in Aſtronomy, the re-appearance of a ſtar, after having been obſcured by it's approach to the Sun, or by the intervention of another ſtar intercepting the Sun's light. Latin.

Emission, the act of ſending out, or giving vent. Latin.

Encyclopedia, the whole circle of ſcience: an univerſal ſcientific Dictionary, deſtined to the inſtruction of the young and ignorant. Greek.

Epicurean, belonging to the doctrine or philoſophy of *Epicurus*; according to which man's duty and happineſs are made to conſiſt in ſenſual indulgence, it is accordingly become deſcriptive of refined luxury.

Equator, an imaginary great circle, equally diſtant from both Poles, ſurrounding the Globe from Eaſt to Weſt, and dividing it into the Northern and Southern Hemiſphere. On it are marked the degrees of Longitude, from 1 to 360. It is by way of diſtinction called *the* Line. Latin.

Equidistant, at equal diſtances. Latin.

Equilibrium, a Latin word, ſignifying exactneſs of balance or counter-poiſe. The Latin ablative with the prepoſition is adopted into our language, *in equilibrio*, to expreſs perfectneſs of equality in oppoſed weights.

Equinox. The equalization of day and night, which takes place twice every year about the middle of the months of March and of September, when the Sun, in his alternate progreſs from North to South, and from South to North, paſſes directly over the Equator, which is likewiſe, for this very reaſon, frequently denominated the *Equinoctial* Line. Latin.

Era, an important event or period of time, from which, as a beginning, computation of time is made. Latin.

Erudition,

Erudition, extenſive and profound learning. Latin.

Ether, the moſt ſubtile and pure of all fluids. Greek.

Evaporation, the act of flying off by the force of heat in fumes or *vapor*. Latin.

Exhalation, a word of the ſame import with the former; *evaporation* may be conſidered as the cauſe, and *exhalation* as the effect. Latin.

Expansibility, capability of being ſpread out, and of covering a larger ſurface. Latin.

Experiment, a practical trial made to aſcertain any natural fact. Latin.

Extension, ſpace over which matter is diffuſed; ſize, magnitude. Latin.

Extraneous, not belonging to. Latin.

F.

Fathom, a meaſure of length containing ſix feet. Saxon.

Fibre, a ſmall thread; in Anatomy, fibres are long, ſlender, whitiſh filaments, variouſly interwoven, which form the ſolid parts of an animal body. Latin.

Fifth, in Muſic, one of the harmonic intervals or concords, and the third in reſpect of harmony, or agreeableneſs to the ear: it is thus called becauſe it contains *five* terms, or ſounds, between it's extremes. See Vol. I. Letter VII.

Filament, the ſame with *fibre*. Latin.

Fluid, conſiſting of parts eaſily compreſſible and ſeparable, as melted metals, water, air. Latin.

Flux, in Geography, the riſing of the tide. Latin.

Focus, in Optics, the little circle in which rays of light are collected, either after paſſing through a glaſs, or on being thrown back from it, and where they exert their greateſt power of burning. Latin.

Formulæ,

FORMULE, a ſet or preſcribed ſtandard: a ſcheme for ſolving mathematical and algebraical queſtions. Latin.

FORTE, in Muſic, forcibly, in oppoſition to *piano*, ſoftly. Latin.

FOURTH, in Muſic, one of the harmonic intervals, and the fourth in reſpect of agreeableneſs to the ear. It conſiſts of two ſounds blended, in the proportion of 4 to 3; that is, of ſounds produced by chords, whoſe lengths are in the proportion of 4 to 3. See Vol. I. Letters VI. and VII.

FRICTION, the act of rubbing one ſolid body againſt another. Latin.

FUSIBLE, that may be eaſily melted. Latin.

G.

GAMUT, the ſcale of muſical notes. Italian.

GENUS, kind, general claſs containing ſeveral ſpecies, which again contains many individuals. Thus, *Dog* is the *genus*; *Greyhound* is the *ſpecies*, and *Light-foot* the individual. The Latin plural *genera* is in uſe.

GEOGRAPHY, a deſcription of the Globe. Greek.

GEOMETRY, the ſcience of quantity, magnitude or extenſion abſtractly conſidered. Greek.

GLAUCOUS, azure-coloured. Greek.

GLOBULE, ſmall globe; little particles of a ſpherical form. Latin.

GRADATION, regular progreſs from one ſtep to another. Latin.

GRAVITY, weight; in the ſyſtem of the Univerſe, that principle in all bodies which preſſes them down to, or attracts them toward, their centre. Latin.

GROOVE, a channel cut out in a hard body with a tool, fitted to another body which is deſigned to move in it.

HARMONY,

H.

HARMONY, in Muſic, a combination of ſounds perfectly adapted to each other, ſo as to produce a pleaſing effect on the ear. Greek.

HEMISPHERE, one half of a Globe. Greek.

HETEROGENEOUS, made up of diſſimilar or diſcordant parts; it is the oppoſite of *homogeneous*, which ſignifies, made up of things ſimilar. Greek.

HORIZON, the line which terminates the view. In Geography, an imaginary circle encompaſſing the Globe, and dividing it into the upper and under Hemiſpheres. To a perſon placed at either of the Poles, the *Equator* would be the real *Horizon*. The ſenſible *Horizon* is the circle viſibly ſurrounding us, where the ſky and the earth meet. Greek.

HUMIDITY, moiſture. Latin.

HYDROGRAPHY, a deſcription of that part of our Globe which conſiſts of water.

HYPOTHESIS, a propoſition or doctrine ſuppoſed to be true, but not yet confirmed by irreſiſtible argument or ſatisfying experiment. Greek.

I.

IDEALIST, a kind of Philoſopher who denies the exiſtence of matter, and reduces every thing to *idea* or mental image. Greek.

ILLIMITABLE, what admits of no bound. Latin.

ILLUMINATION, the act of diffuſing light. Latin.

ILLUSION, what deceives by a falſe appearance. Latin.

IMMATERIAL, in Philoſophy, not conſiſting of body or *matter*. Latin.

IMMERSION, in Aſtronomy, the diſappearance of a ſtar by a near approach to the Sun, or the interception of it's light by another ſtar interpoſing between the Sun and it. Latin.

IMPENETRABILITY,

IMPENETRABILITY, that property of all bodies, in virtue of which no two can occupy the ſame ſpace, at the ſame time. Latin.

IMPULSION, the agency of one body in motion upon another. Latin.

IMPUTABILITY, the quality of being charged upon, or aſcribed unto. Latin.

INCIDENCE, the direction in which one body falls upon or ſtrikes another: and the angle formed by that line, and the plane ſtruck upon, is called the angle of *incidence*. Latin.

INDEX, the fore-finger, any inſtrument that points out or *indicates*. Latin.

INDIVIDUAL, one ſeparate, diſtinct, undivided whole.

INERTIA, that quality of bodies in virtue of which they are diſpoſed to continue in a ſtate of reſt, when at reſt, or of motion, when in motion; and which can be overcome only by a power not in body itſelf. Latin.

INFINITY, boundleſſneſs, applied equally to ſpace, number, and duration: *in infinitum* without limit, without end. Latin.

INFLECTION, the act of bending or turning. Latin.

INHERENT, naturally belonging to, and inſeparable from. Latin.

INTELLECTUAL, relating to the underſtanding, mental. Latin.

INTENSITY, the ſtate of being ſtretched, heightened, affected to a very high degree. Latin.

INTERCEPTION, the cutting off or obſtruction of communication. Latin.

INTERSECT, mutually to cut or divide. Latin.

INTERSTICE, the ſpace between one thing and another.

INVERSE, having changed places, indirect, turned upſide down. Latin.

IRIS, the circle round the pupil of the eye. Latin.

LABYRINTH,

L.

LABYRINTH, maze, inextricable difficulty or perplexity. Latin.

LATITUDE, in Geography, meaſurement of the Globe from the *Equator*, Northward and Southward to the *Poles*, in degrees and minutes. The degree contains about 69 Engliſh miles, and a minute is the ſixtieth part of a degree. The higheſt poſſible degree of *Latitude* is at the *Poles*, each being 90 degrees from the *Equator*. Latin.

LENS, a round glaſs, double-convex, for aſſiſting viſion, or deriving fire from the collected rays of the Sun. *Lenticular*, having the form of a *lens*.

LEVEL, riſing or falling to the ſame height. Saxon.

LITERATI, the learned; the plural of the Latin word *literatus* a learned man.

LOGIC, the art of right reaſoning, for the purpoſe of inveſtigating, and communicating uſeful truth. Greek.

LONGITUDE, in Geography, meaſurement of the Globe in degrees and minutes, round and round, from Eaſt to Weſt. Latin.

LUNAR-TIDE, the flowing and ebbing of the tide relatively to the Moon. Latin.

LYMPHATIC, veſſels, ſlender, tranſparent tubes through which *lymph*, or a clear colourleſs fluid is conveyed.

M.

MAGNET, and it's compounds, a ſtone which attracts iron and ſteel; and gives a northerly direction to the needle of the Mariner's Compaſs. Art has been enabled, by means of bars of ſteel, ſucceſsfully to imitate the natural *magnet* or loadſtone. Latin.

MAGNITUDE, greatneſs, bulk, extenſion. Latin.

MANICHEAN,

MANICHEAN, one of a ſect who maintained the exiſtence of a ſupreme evil ſpirit.

MAJOR, in Logic, the firſt propoſition of a ſyllogiſm, containing ſome general aſſertion or denial; as, *all men are mortal; no man is perfect*. Latin.

MATERIALIST, one who denies the exiſtence of ſpiritual ſubſtances. Latin.

MATHEMATICS, the Science which has for its object every thing capable of being meaſured or numbered. Greek.

MEAN, or *Medium*, in Phyſics, ſomewhat intervening between one ſubſtance and another: in Logic, an intermediate propoſition employed to lead to a fair and juſt concluſion. Latin.

MECHANICS, the Geometry of motion; the Science of conſtructing moving machinery. Greek.

MEMBRANE, a web of various fibres interwoven, for wrapping up certain parts of vegetable and animal bodies. Latin.

MENISCUS-lens, in Optics, a glaſs which is convex on one ſurface, and concave on the other.

MEPHITES, poiſonous, ill-ſcented vapor. Latin.

MERCURY, the chemical name of the fluid commonly called *quickſilver*. Latin.

MERIDIAN, in Geography, a great circle encompaſſing the Globe in the direction of South and North, and dividing it into the eaſtern and weſtern Hemiſpheres. The degrees of Latitude, from the Equator to both Poles, are marked on this circle. Every ſpot of the Globe comes to it's *meridian* once in every twenty-four hours, that is, has it's inſtant of *noon*. Latin.

METAPHYSICS, otherwiſe called *Ontology*, the Science of the affections of being in general. It employs *abſtract* reaſoning. Turn to the word ABSTRACT. Greek.

METEOROLOGY, the Science of Meteors, that is, of bodies floating in the air, and quickly paſſing away. Greek.

MICROSCOPE, an optical inſtrument, which, by means of a greatly-magnifying glaſs, renders diſtinctly viſible objects too minute for the unaſſiſted eye. Greek.

MINOR, in Logic, the ſecond, or particular propoſition of a ſyllogiſm: for example, in this Syllogiſm,

All men are mortal:
But, The King is a man;
Therefore, The King is mortal.

The firſt propoſition, *All men are mortal* is the *Major*; the ſecond, *the King is a man*, is the *Minor*, and theſe two are called the *premiſes*; the third, *the King is mortal*, is the concluſion. Latin.

MOBILITY, eaſineſs of being moved. Latin.

MODE, in Logic, particular form or ſtructure of argument. Latin.

MONAD, a minute particle of matter which admits of no farther ſubdiviſion. Greek.

MONOCHORD, a muſical inſtrument of one ſtring. Greek.

MYOPS, ſhort-ſighted. Greek.

N.

NADIR, the Point in the heavens directly under foot. Arabic.

NAVIGATION, the art of ſailing. Latin.

NEGATION, denial, the oppoſite of *affirmation*. Latin.

NOTION, thought; repreſentation of any thing formed by the mind. Latin.

O.

OBJECTIVE-lens, in Optics, that glaſs of a teleſcope which is turned to the *object* or thing looked at. Latin.

OBLIQUE, not direct, not perpendicular, not parallel. Latin.

OBSERVATORY, an edifice reared for the purpoſe of aſtronomical *obſervations*. Latin.

OCCULT, ſecret, unknown, undiſcoverable. Latin.

OCTAVE, in Muſic, a regular ſucceſſion of notes from one to eight; the firſt and the eighth having the ſame name and emitting the ſame ſound. Latin.

OCULAR-lens, in Optics, that glaſs of a teleſcope which is applied to the eye. Latin.

OPAQUE, what does not tranſmit the rays of light, not tranſparent. Latin.

OPTICS, the Science of the nature and laws of viſion, or ſight. Greek.

ORB, ſphere, heavenly globular body. Latin.

ORBIT, the circular path in which a planet moves round the Sun. Latin.

OSCILLATION, alternate moving backward and forward like the pendulum of a clock. Latin.

P.

PARADOX, a tenet which exceeds or contradicts received opinion, affirmation contrary to appearance. Greek.

PARALLEL-lines, in Geometry, lines which through the whole of their length maintain the ſame diſtance: they are the oppoſite of *convergent* and *divergent*. Greek.

PARALLELISM, ſtate of being parallel.

PARALLELOGRAM, a geometrical figure of four ſides, having this property, that the oppoſite ſides are equal and parallel, and the oppoſite angles equal. Greek.

PELLUCID, what tranſmits the rays of light: tranſparent. Latin.

PENDULUM, a heavy body ſuſpended, ſo as to ſwing backward and forward without obſtruction, for the purpoſe of meaſuring

time:

time: the great perfection of ſuch an inſtrument is, that every vibration or ſwing ſhall be performed in exactly the ſame quantity of time. Latin.

PERCEPTION, the power of perceiving, knowledge, conſciouſneſs. Latin.

PERMEABLE, what may be paſſed through. Latin.

PERPENDICULAR, in Geometry, one line ſtanding on another, or on a horizontal plane, without the ſlighteſt inclination to one ſide more than another, and forming right angles with the horizontal line or plane. Latin.

PHALANX, a military force cloſely embodied. Latin.

PHASIS, appearance preſented by the changes of a heavenly body, particularly thoſe of the Moon. The Greek and Latin plural *phaſes* is adopted in our language.

PHENOMENON, ſtriking appearance of Nature. The Greek plural *phenomena* is in common uſe.

PHILOSOPHY, knowledge natural or moral: Syſtem in correſpondence to which important truths are explained: Academical courſe of Science. Greek.

PHYSICS, the Science of Nature; natural Philoſophy. Greek.

PIANO, in Muſic, ſoftly, delicately, oppoſite to fortè. Italian.

PISTON, the moveable circular ſubſtance fitted to the cavity of a tube, ſuch as a pump or ſyringe, for the purpoſe of ſuction, expulſion, or condenſing of fluids. French.

PLANET, a wandering ſtar; thoſe heavenly bodies, our globe being one, which perform a regularly irregular courſe round the Sun, are called *planets*. Greek.

PLANO-CONCAVE, in Optics, a glaſs which has one ſurface plane, and the other hollow. Latin.

PLANO-CONVEX, an optical glaſs which has one ſurface plane, and the other raiſed. Latin.

PLENUM, ſpace filled with ſubſtance. Latin.

PLUMB-LINE, a weight appended to a ftring, for the purpofe of afcertaining perpendicularity.

POLAR-CIRCLES, circles parallel to the Equator and the Tropics, at the diftance of twenty three degrees and a half each from it's refpective Pole. Latin.

POLARITY, tendency toward the Pole. Latin.

POLYGON, a figure having many fides and angles. Greek.

POLYTHEISM, the doctrine of a plurality of Gods. Greek.

POROUS, full of fmall minute paffages. Greek.

PRESBYTES, far-fighted. Greek.

PRESCIENCE, foreknowledge. Latin.

PREDICATE, in Logic, what is affirmed of the fubject, as, *man is rational*. Latin.

PREDILECTION, preference given from pre-conceived affection. Latin.

PRE-ESTABLISHED HARMONY, the metaphyfical doctrine of an original adaptation of mind to matter, by a creative act of the Supreme Will, in virtue of which every human action is performed.

PRISM, a triangular optical inftrument of glafs, contrived for the purpofe of making experiments with the rays of light. Greek.

PROBLEM, a propofition announcing fomething to be firft performed and then demonftrated. Greek.

PROBOSCIS, the fnout or trunk of an elephant or other animal. Latin.

PROMINENT, jutting out, projecting forward. Latin.

PROPOSITION, a point advanced or affirmed with a view to proof. Latin.

PROXIMITY, nearnefs. Latin.

PUPIL, in Optics, the apple of the eye. Latin.

PYROMETER, a machine contrived to afcertain the degree of the expanfion of folid bodies, by the force of fire. Greek.

PYRRHONIST,

PYRRHONIST, an univerfal doubter and unbeliever; derived from the name of the Man.

Q.

QUADRANT, the fourth part of a circle; an inftrument of that form, contrived to meafure and afcertain Latitude. Latin.

QUADRILATERAL, confifting of four fides. Latin.

QUOTIENT, in Arithmetic, the number refulting from the divifion of two numbers which meafure each other. Thus on dividing 36 by 4, we have a *quotient* of 9.

R.

RADIUS, in Englifh *ray*, a ftraight line drawn from the centre of a circle or fphere to the circumference. The Latin plural *radii* is in ufe.

RAREFACTION, the rendering of a fubftance thinner, more tranfparent, it is the oppofite of condenfation. Latin.

RATIO, proportion. Latin.

RATIOCINATION, a procefs of reafoning, a deduction of fair conclufions from admitted premifes. Latin.

RECIPIENT, that which receives and contains. Latin.

RECIPROCALLY, mutually, interchangeably. Latin.

RECTANGULAR, containing one or more right angles. A right angle confifts of 90 degrees. Latin.

RECTILINEAR, confifting of ftraight lines. Latin.

REFLECTION, in Catoptricks, the fending back of the rays of light from an illuminated body. Latin.

REFLUX, the ebbing, or flowing back, of the tide. Latin.

REFRACTION, in Dioptricks, the deviation or broken off courfe of a ray of light on paffing obliquely from one medium

 through

through another, as from air through water or glaſs. Latin.

REFRANGIBILITY, diſpoſition to leave the direct courſe, capability of being broken or refracted. Latin.

REFRINGENT-medium, that which alters, or breaks off, the courſe of rays. Latin.

REMINISCENCE, the power of recollection, memory. Latin.

REPULSION, the act or power of driving back. Latin.

RESINOUS, conſiſting of, or ſimilar to reſin, the fat, ſulphureous emanation from certain vegetables. Latin.

RESONANCE, ſound repeated. Latin.

RESPIRATION, the act of breathing. Latin.

RETICULATED, formed like a net. Latin.

RETINA, the delicate, net-like membrane at the bottom of the eye, on which are painted the images of the objects which we contemplate. Latin.

RETROGRADE, moving in a backward direction. Latin.

REVERBERATION, the act of beating or driving back. Latin.

REVERY, looſe, wild, irregular meditation.

S.

SATELLITE, an inferior, attendant planet revolving round a greater. Latin.

SCALPEL, a chirurgical inſtrument uſed for ſcraping a bone. Latin.

SCIENCE, knowledge: in the plural, the ſeven liberal arts, namely, Grammar, Rhetoric, Logic, Arithmetic, Muſic, Geometry, Aſtronomy.

SEGMENT, in Geometry, part of a circle formed by a ſtraight line drawn from one extremity of any arch to the other, and the part of the circumference which conſtitutes that arch. The ſtraight line is denominated the chord of the arch, from it's reſemblance to a bow-ſtring. Latin.

SEMICIRCLE,

SEMICIRCLE, the half of a circle; the ſegment formed by a diameter as the chord, and one half the circumference as the arch. Latin.

SEMITONE, in Muſic, half a tone, the leaſt of all intervals admitted into modern muſic. The *ſemitone major* is the difference between the *greater third* and the fourth, it's relation is as 15 to 16: the *ſemitone minor* is the difference of the *greater third* and the *leſſer third*, and it's relation is as 24 to 25. Latin.

SENSATION, perception by means of the ſenſes. Latin.

SERIES, regular, ſettled, proportional order or progreſſion, as, in numbers, 9, 18, 27, 36, 45, 54, 63 are in a *ſeries*. The word is the ſame ſingular and plural. Latin.

SEVENTH, in Muſic, the inverted diſcordant interval of the *Second*, called by the Ancients *Heptachordon*, becauſe it is formed of ſeven ſounds. There are four ſorts of the *ſeventh*, of which the following are the proportions in numbers; as 5 to 9: as 8 to 15: as 75 to 128: as 81 to 160: it is harſh and unharmonious.

SOLAR-TIDE, the flux and reflux of the tide relatively to the Sun. Latin.

SOLUTION, demonſtration, clearing up of intricacy or difficulty. Latin.

SONOROUS, emitting loud or ſhrill ſounds. Latin.

SPECIES, kind, ſort, claſs: ſee *Genus*. It is the ſame in ſingular and plural. Latin.

SPECTRUM, an image; a viſible form. Latin.

SPHERE, Globe. Greek.

SPHEROID, approaching to the form of a ſphere, but ſomewhat lengthened. Greek.

SPIRITUAL, not conſiſting of, diſtinct from matter or body. Latin.

SUBLIME, elevated in place; in Chymiſtry, raiſed by the force of fire. Latin.

SUBTERFUGE,

SUBTERFUGE, mean, paltry eſcape or evaſion. Latin.

SUBTERRANEOUS, under the ſurface of the ground. Latin.

SUBTILE, thin, not denſe, not groſs. Latin.

SUPERFICIAL, external, extended along the ſurface. Latin.

SUPERNATURAL, what is above or beyond the powers of *Nature*. Latin.

SURFACE, in Geometry, length and breadth without thickneſs. French.

SYLLOGISM, in Logic, an argument conſiſting of three propoſitions: for example, *Every virtue is commendable: honeſty is a virtue; therefore honeſty is commendable.* See *Major* and *Minor*. Greek.

SYSTEM, a ſcheme of combination and arrangement, which reduces many things to a regular connection, dependance and co-operation. Greek.

T.

TANGENT, in Geometry, a ſtraight line touching a circle externally in a ſingle point. Latin.

TELESCOPE, an optical inſtrument deſigned, by the magnifying power of glaſſes, to repreſent diſtant bodies as much nearer. Greek.

TEMPERAMENT, ſtate of body or mind as produced by, or depending upon, the predominancy of a particular quality. Latin.

TENSION, the ſtate of being ſtretched out, wound up, diſtended. Latin.

TENUITY, thinneſs, delicate fineneſs. Latin.

TERM, deſcriptive name, or phraſe; component part, condition. Latin.

TERRAQUEOUS, conſiſting of land and water. Latin.

THEOLOGY, ſyſtematic Divinity. Greek.

THEOREM, a propoſition announced for demonſtration. Greek.

THEORY, a doctrine contemplated and conceived in the mind, but not yet confirmed by irreſiſtible argument, or ſatiſfying experiment. Greek.

THERMOMETER, an inſtrument contrived to meaſure the heat of the air or other body by means of the riſing or falling of a ſpirituous fluid. Greek.

THIRD, in Muſic, the firſt of the two imperfect concords, ſo called becauſe it's interval is always compoſed of two degrees or of three diatonic ſounds. The *tierce major* or *greater third*, is repreſented in numbers by the ratio of 4 to 5: and the *leſſer*, by the relation of 5 to 6. See Vol. II. Let. VI. and VII.

TIDE, the alternate riſing and falling of the Water in rivers, and along the ſhores of the Sea. Saxon and Dutch.

TONE, in Muſic, the degree of elevation which the voice aſſumes, and to which inſtruments are adapted, in order to the harmonious execution of a muſical compoſition: a pitch pipe. Latin and Greek.

TRANSIT, in Aſtronomy, the paſſing of one heavenly body over the diſk of another. Latin.

TRANSMISSION, permiſſion to paſs through. Latin.

TRANSPARENT, clear, what may be ſeen through, as air, water, glaſs. Latin.

TRANSVERSE, in a croſs direction. Latin.

TRIANGLE, a geometrical figure conſiſting of three ſides and three angles. Latin.

TUBE, a pipe; a long hollow body. Latin.

TUNICLE, a ſmall coat or covering. Latin.

V.

Vacuum, empty ſpace. Latin.

Valve, a moveable membrane in the veſſels of an animal body, and imitated by art in the conſtruction of various machines, which opens for giving paſſage to fluids in one direction, but ſhuts to oppoſe their return through the ſame paſſage. Latin.

Velocity, ſpeed, ſwiftneſs of motion. Latin.

Vertical, perpendicularly over head. Vertical angles, in Geometry, are thoſe formed by the interſection of two ſtraight lines, in whatever direction, making four in all at the point of interſection, and of which the mutual two and two are equal. Latin.

Vibration, rapid, tremulous motion backward and forward. Latin.

Visual, relating to viſion or ſight; belonging to the eye. Latin.

Vitreous, compoſed of, or reſembling glaſs. Latin.

Vivid, lively, briſk, ſprightly. Latin.

U.

Ultimate, final, beyond which there is no farther progreſs. Latin.

Unison, emiſſion of the ſame or harmonious ſounds. Latin.

Untenable, what cannot be maintained or ſupported.

W.

Waning, gradual diminution of apparent magnitude and light. Saxon.

Waxing, gradual increaſe of apparent magnitude and light; particularly of the Moon. Saxon and Daniſh.

Wind-gun, a gun which forcibly emits a ball by means of compreſſed air or wind.

Z.

Zenith, the point in the heavens directly perpendicular or vertical: exactly over head: the oppoſite of *Nadir*. Arabic.

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