## LETTER XXXII.

### *Of the Azure-colour of the Heavens.*

YOU have juſt ſeen, that the cauſe of the viſibility of objects, is a motion of vibration extremely rapid, by which the minuter particles of their ſurfaces are agitated, and that the frequency of theſe vibrations determines the colour.

It is the ſame thing, whether theſe particles be agitated by an intrinſic force, as in luminous bodies, or whether they receive their agitation from illumination, or from foreign rays, by which they are illumined, as in opaque bodies. The frequency or rapidity of the vibrations depends on the groſſneſs of theſe particles, and on their elaſticity, as that of the vibrations of a muſical ſtring depends on it's thickneſs, and degree of tenſion; thus, as long as the particles of a body preſerve the ſame elaſticity, they repreſent the ſame colour; as the leaves of a plant preſerve a green colour, as long as they are freſh; but when they begin to dry, the difference of elaſticity, which then takes place, produces, likewiſe, a different colour. This ſubject I have already diſcuſſed. I now proceed to explain, Why the heavens appear to us of a blue colour in the day-time.

On obſerving this phenomenon with a vulgar eye, it would appear, that we are ſurrounded by a prodigious vault of azure, as painters repreſent the ſky on a ceiling. I have no occaſion to undeceive you reſpecting



reſpecting this prejudice: a ſmall degree of reflection is ſufficient to make you comprehend, that the heavens are not an azure vault to which the ſtars are affixed, like ſo many luminous ſtuds. You are perfectly convinced, that the ſtars are immenſe bodies, at inconceiveable diſtances from us, and which move freely through a ſpace almoſt void, or which is filled only by that ſubtile matter called ether. And I will ſhew you, that this phenomenon is to be aſcribed to our atmoſphere, which is not perfectly tranſparent.

Were it poſſible to riſe higher and higher above the ſurface of the earth, the air would become gradually more and more rare, till it ceaſed to aſſiſt reſpiration; and would, at length, entirely ceaſe; we ſhould then have reached the region of pure ether. Accordingly, in proportion as we aſcend on mountains, the mercury in the barometer continues to fall, becauſe the atmoſphere becomes lighter and lighter: and then, likewiſe, it is remarked, that the azure colour of the heavens becomes fainter; and were it poſſible to mount into pure ether, it would entirely diſappear; on looking upward, we ſhould ſee nothing at all, and the heavens would appear black as night; for where no ray of light can reach us, every thing wears the appearance of black.

There is good reaſon, then, for aſking, Why the heavens appear to be blue? This phenomenon could not exiſt, were air a perfectly tranſparent medium, as ether is: in that caſe, we ſhould receive from above no other rays but thoſe of the ſtars: but the luſtre of day-light is ſo great, that the feeble light of of the ſtars is abſorbed by it. You could not perceive the flame of a taper in the day-time, at any conſiderable diſtance; but that ſame flame, in the night, would appear very brilliant at much greater diſtances. This clearly proves, that we muſt look for the cauſe of the azure-colour of the heavens, in the want of tranſparency in the air. The air is loaded with a great quantity of ſmall particles, which are not perfectly tranſparent, but which, being illuminated by the rays of the ſun, receive from them a motion of vibration, which produces new rays proper to theſe particles; or elſe they are opaque, and become viſible to us from being illumined.

Now, the colour of theſe particles is blue; and this explains the phenomenon: the air contains a great quantity of ſmall blue particles: or it may be ſaid, that it's minuter particles are bluiſh, but of a colour extremely delicate, and which becomes ſenſible to us only in an enormous maſs of air. Thus, in a room, we perceive nothing of this blue; but when the bluiſh rays of the whole atmoſphere penetrate our eyes at once, however delicate the colour of each ſingly, their totality may produce a very deep colour.

This is confirmed by another phenomenon, with which you muſt be well acquainted. If you look at a foreſt, from a moderate diſtance, it appears quite green; but in proportion as your diſtance increaſes, it acquires a bluiſh caſt, and this gradually becomes deeper and deeper. The foreſts on the mountains of Hartz, which may be ſeen from Magdeburg, appear

thence



thence to be blue, but viewed from Halberſtadt, they are green. The great extent of air between Magdeburg and theſe mountains, is the reaſon of it. However delicate or rare the bluiſh particles of the air may be, there is ſuch a prodigious quantity of them in that interval, the rays of which enter into the eye at once, that they repreſent a tolerable deep blue.*

* This explanation of the blueneſs of the ſky is ſtrained and unſatisfactory. The air is, like water, perfectly colourleſs, otherwiſe any portion of it might be diſtinguiſhed by the ſight. Beſides, the blueneſs of the ſky, even in clear weather, is not uniformly the ſame, but acquires different degrees of intenſity, and different ſhades, from a variety of circumſtances, the climate, the ſeaſon, and the elevation of the place. The true explanation of the phenomenon muſt be ſought from other principles. The moſt refrangible rays are, at minute diſtances, attracted or repelled, by colourleſs ſubſtances, with the greateſt force. A ſunbeam, therefore, in it's paſſage through the atmoſphere, will firſt loſe it's violet rays moſt profuſely, next the indigo, then the blue, and if the track be of ſufficient length, perhaps a few of the green. The rays, thus ſeparated, are either abſorbed by the air, or they are reflected, and cauſe the blue appearance. Hence, on the ſummits of lofty mountains, the colour of the heavens ſeems faint and dark, and inclined ſomewhat to violet. On the contrary, in denſe humid air, the colour is a light milky blue. Hence, alſo, the bright azure which paints the ſky of the ſouthern regions, owing to the dryneſs of the air, and the ſhortneſs of the light's tract. For the ſame reaſon, not only the quantity, but even the quality, of the light which we receive from the ſun, depends on his altitude. At riſing, and ſetting, thoſe rays which reach the ſurface, and even the lower range of clouds, are chiefly the reddiſh; at a greater elevation of the ſun, the prevailing colour of his beams is ſomewhat orange; and when ſtill higher, it is a dilute yellow.

The ſame principles will account for the colour of the ocean,



which

We remark a ſimilar phenomenon in a fog, when the air is loaded with a great quantity of opaque particles of a whitiſh colour. On looking to only a ſmall diſtance, you ſcarcely perceive the fog; but when the diſtance is conſiderable, the whitiſh colour becomes very perceptible; to ſuch a degree, that it is impoſſible to ſee through it. The water of the ſea appears green at a certain depth; but when you take up a ſmall quantity, as much, for inſtance, as a glaſs will contain, it is ſufficiently diaphonous, and has no ſenſible colour: but in a great extent, when you look toward the bottom, ſo many greeniſh rays collected produce a deep colour.

*27th July*, 1760.

which is dark blue. It is only in ſeas, not exceeding one hundred fathoms in depth, that the reflection from the white bottom dilutes the proper colour, and forms a glaucous hue. This appearance is an invariable ſign of the ſhallowneſs of the water, which is often a token of the proximity of the land. Dr. Hally relates an obſervation that he made in a diving-bell, which confirms theſe reaſonings; after deſcending to a great depth in the ſea, he ſtretched out his hand, on which the ſun ſhone through the water, and painted a beautiful crimſon. The ſame obſervation may be extended, even to ſubſtances that are reckoned opaque. Hold an ivory knife in the focus of a burning glaſs, perpendicular to the pencil of light, and a bright yellowiſh ſpot will be perceived on the back. Incline the knife gradually, and the colour of the ſpot will paſs through all the intermediate ſhades, and terminate in a fine red. It is ſcarce neceſſary to remark, that this experiment muſt be performed expeditiouſly, leſt the ivory be ſcorched.—*E.E.*

LETTER



## LETTER XXXIII.

*Of Rays iſſuing from a diſtant luminous Point, and of the viſual Angle.*

AS long as the rays produced by the rapid vibration of the minuter particles of a body, move in the ſame tranſparent medium, they preſerve the ſame direction, or diffuſe themſelves in all directions, in ſtraight lines. Theſe rays may be repreſented by the radii of a circle, or rather of a ſphere, which, iſſuing from a centre, proceed in ſtraight lines to the circumference; and it is on account of this reſemblance, that we employ the ſame term *radius*, or ray, to expreſs them, though, properly ſpeaking, the light does not conſiſt of lines, but of very rapid vibrations, going continually forward, in the direction of ſtraight lines: and, for this reaſon, light may be conſidered as ſtraight lines, iſſuing from a luminous point, in all directions.

Let C (*plate* I. *fig.* 11.) be a luminous point, from which rays iſſue in all directions. Let two ſpheres be deſcribed round C, as a centre, of the one of which, let the great circle be *a b d e*, and of the other A B D E. The light diffuſed over the ſurface of the ſmaller ſphere *a b d e*, will likewiſe occupy that of the greater ſphere A B D E. The light, then, muſt be more faint and weak at the ſurface of this laſt, than on that of the ſmaller ſphere *a b d e*. Hence it may be concluded, that the effect of light muſt be ſmaller,

 in

in proportion to the diftance from the luminous point. If we fuppofe, that the radius of the greater fphere is double that of the fmaller, the furface of the greater fphere will be four times as great. Since, therefore, the fame quantity of light is diffufed over the furface of the greater fphere, and over that of the fmaller, it muft follow, that light, at double the diftance, is four times more faint; at thrice the diftance, nine times; at a quadruple diftance, fixteen times; and fo on.*

On applying this rule to the light of the fun, it will appear, that if the earth were removed to double the diftance from the fun, the light derived from him would be rendered four times more faint; and if the fun were a hundred times farther from us, his brightnefs would be a hundred times a hundred, that is, ten thoufand times lefs. Suppofing, then, a fixed ftar to be as great, and as luminous as the fun, but that it was 400,000 times farther from us, it's light will be 400,000 times 400,000, that is, 160,000,000,000 times more faint than that of the fun. Hence we fee, that the light of a fixed ftar is nothing, compared to that of the fun; and this is the reafon that we do not fee the ftars in the day time; a feebler light

* As the furfaces of fpheres are to one another as the fquares of their radii, it muft be concluded, from what the Author has just now faid, that the intenfity of light, at different diftances from the point which produces it, is in the inverfe ratio of the fquare of thefe diftances. It muft be recollected, that the fquare of a number is the product which refults from the multiplication of that number by itfelf.—*F. E.*





always difappears in prefence of one much more bright. The fame thing holds good with refpect to candles, and all other luminous bodies, which adminifter lefs light, in proportion to their diftance from us; and you muft have frequently remarked, that however ftrong a light may be, it is infufficient to affift us in reading a printed book, if you remove from it to any confiderable diftance.

There is ftill another circumftance, clofely connected with what I have juft obferved; namely, that the fame object appears fmaller to us, in proportion to it's diftance. A giant, at a great diftance, does not appear taller than a dwarf near us. To form a clearer judgment of this, it is neceffary to attend to the angles at which thefe objects are feen by us.

Let us fuppofe, then, (*plate* I. *fig.* 12,) A B to be an object, fay a man, and that the eye looks at it from the point C. Draw from that point the ftraight lines, A C and B C, which reprefent the extreme rays proceeding from the object to the eye; we call the angle formed at C, the vifual angle of that object for the point C. If we look at the fame object from a fmaller diftance, at D, the vifual angle D will be, undoubtedly, greater: hence it is clear, that the more diftant the fame object is, the fmaller is it's vifual angle; and the nearer it approaches, it's vifual angle becomes greater.

Aftronomers meafure very accurately the angles under which we fee the heavenly bodies, and they have found, that the vifual angle of the fun is fomewhat more than half a degree. If the fun were twice farther from us, this angle would be reduced to the half; and then it will not feem furprizing that it fhould furnifh us four times lefs light. And if the fun were 400 times farther off, his vifual angle would become fo many times lefs, and then that luminary would appear no greater than a ftar. We muft, therefore, carefully diftinguifh the apparent greatnefs of any object from it's real greatnefs. The firft is always an angle greater or lefs, according as the object is nearer or more diftant. Thus the apparent greatnefs of the fun, is an angle of about half a degree, whereas his real magnitude far furpaffes that of the earth; for the fun being a globe, his diameter is eftimated to be 172,000 German miles,* while the diameter of the earth is only 1720† miles.‡

*29th July*, 1760.

* 790,000 miles Englifh. † 7,920 miles Englifh.

‡ Aftronomers likewife call the apparent diameter of a ftar the angle under which it is feen. Thus, they fay, that the mean diameter of the fun is 31′ 58″; that of the earth, viewed from the fun, would be 17″. Hence it follows, that the diameter of the earth being 2865 leagues, that of the fun is 323,000 leagues. The German mile contains 4000 fathoms, or 24,000 feet. The league of France contains 2282 fathoms. Hence it is eafy to reduce the one meafurement into the other.—*F. E.*

LETTER



## LETTER XXXIV.

*Of the Supplement which Judgment lends to Vifion.*

WHAT I have now fubmitted to you on the phenomenon of vifion, belongs to optics, which is a branch of mixed mathematics, and which, likewife, holds a confiderable rank in phyfics. Befide colours, the nature of which I have endeavoured to explain, it is the bufinefs of optics to treat of the manner in which vifion acts, and of the different angles under which objects are feen.

You muft have already remarked, that the fame object may be viewed, fometimes under a greater vifual angle, fometimes under a fmaller, as it is lefs or more diftant from us. I fay farther, That a fmall object may be viewed under the fame angle as a great one, when the former is very near, and the latter very diftant. A fmall difh may be placed before the eye in fuch a manner, as to cover the whole body of the fun; and, in effect, a plate of half a foot diameter, at the diftance of 54 feet, exactly covers the fun, and is feen under the fame angle: and yet what a prodigious difference between the fize of a plate and that of the fun: The full moon appears to us under nearly the fame vifual angle as the fun, and, of confequence, nearly as great, though in reality much fmaller; but it is to be confidered, that the fun is almoft 400 times more remote from us than the moon.

The

The viſual angle is a point of ſo much the more importance in optics, that the images of the objects, which paint themſelves on the bottom of the eye, depend upon it. The greater or leſs the viſual angle is, the greater or leſs they (the objects) are great or little. And as we ſee objects out of ourſelves, only ſo far as their images are painted on the bottom of the eye, they conſtitute the immediate object of viſion or ſenſation. One of theſe images, therefore, leads us to the knowledge only of three things. Firſt, it's figure and it's colours conduct to the concluſion, That there is, out of us, a ſimilar object, of ſuch a figure, and ſuch a colour. Secondly, it's magnitude diſcovers the viſual angle under which the object appears to us: and, finally, it's place on the bottom of the eye makes us ſenſible of the direction of the external object, relatively to us, or that in which the rays emitted from it reach our eyes.

In theſe three particulars conſiſts the phenomenon of viſion; and we only perceive, 1ſt, the figure and colours; 2dly, the viſual angle, or the apparent magnitude; and, 3dly, the direction, or the place in which we conclude that the object exiſts. Viſion, then, diſcovers to us nothing reſpecting either the real magnitude of objects, or their diſtances. Though we frequently imagine, that we can determine by the eye the magnitude and diſtance of an object, this is not an act of viſion, but of the underſtanding. The other ſenſes, and habits of long ſtanding, enable us to calculate at what diſtance an object is from us. But this faculty extends only to objects at no great

 diſtance.



diſtance. Whenever their diſtance becomes conſiderable, our judgment cannot exerciſe itſelf with certainty; and if ſometimes we venture to hazard a deciſion, it is generally very remote from the truth. Thus, no one can pretend to ſay that he ſees the magnitude or the diſtance of the moon; and when the vulgar imagine they can judge of the firſt, by conſidering it as equal to that of the terreſtrial bodies which are ſeen under the ſame angle, it is not by viſion they are deceived, but by their judgment, which they want to apply to an object far beyond their reach. It is certain, therefore, that the eyes alone can determine nothing reſpecting the diſtance and magnitude of objects.

To this ſubject may be referred the very remarkable caſe of a man born blind, who obtained ſight, by means of an operation, at an advanced period of life:* This perſon was at firſt dazzled: he could diſtinguiſh nothing as to the magnitude and diſtance of objects. Every thing appeared ſo near, that he wanted to handle them. A conſiderable time, and long practice, were requiſite to bring him to the real uſe of ſight. He was under the neceſity of ſerving a long apprenticeſhip, ſuch as we perform during the term of childhood, and of which we afterwards preſerve no recollection.

This it is which inſtructed us, that an object appears to us ſo much the more clear and diſtinct as it

* This was the blind man, on whom the famous *Cheſſelden* performed the operation of the couching cataract.—*F. E.*

is

is nearer; and reciprocally, that an object which appears clear and diftinct is near; and when it appears obfcure and indiftinct, that it is at a diftance. It is thus that painters, by weakening the tints of the objects which they wifh to appear remote, and ftrengthening thofe which they would reprefent as nearer, are enabled to determine our judgment, conformably to the effect which they mean to produce. And they fucceed fo perfectly, that we confider fome of the objects reprefented in painting as more diftant than others: an illufion which could not take place, if vifion difcovered to us the real diftance and magnitude of objects.

*1ft Auguft*, 1760.

## LETTER XXXV.

*Explanation of certain Phenomena relative to Optics.*

YOU have juft feen, that vifion alone difcovers to us nothing, refpecting either the real magnitude or the diftance of objects; and that all we imagine we fee, whether as to the diftance or magnitude of any object, is the effect of judgment. We muft carefully diftinguifh that which the fenfes reprefent to us, from what judgment adds, in which we frequently deceive ourfelves. Many philofophers, who have declaimed againft the accuracy of the fenfes, and who meant thence to infer the uncertainty

tainty



tainty of all human knowledge,* have confounded the proper reprefentations of our fenfes with judgment.

This is their mode of reafoning: We fee the fun no bigger than a trencher, though it be infinitely greater; therefore the fenfe of feeing deceives us; therefore all our fenfes deceive us; at leaft, we cannot depend on them: therefore, all the knowledge we acquire by means of the fenfes, is uncertain, and probably falfe: We, therefore, know nothing. Such is the reafoning of thefe fceptics, who boaft, fo vain gloriouſly, of their ingenuity; though there be nothing fo eafy as to fay, that every thing is uncertain; and the greateft dunce may make a fhining figure in this fublime philofophy. But it is abfolutely falfe, that the fight reprefents to us the fun no bigger than a pewter plate; it determines nothing whatever refpecting his magnitude; it is our judgment alone that deceives us. When the objects, however, are not very diftant we can pronounce with tolerable exactnefs on their dimenfions and diftances; and the other fenfes, joined to the degree of clearnefs with which we fee thefe fame objects, render our judgments fufficiently certain. Now, as foon as we have the idea of the diftance of an object, we form to ourfelves, likewife, that of it's real magnitude, knowing that it depends on that diftance.

* Such were the Pyrrhonifts. We ftill give the name of *fcepticifm*, or Pyrrhonifm, to this ftate of univerfal doubt or uncertainty.—*F. E.*

Hence

Hence, the more diſtant we reckon an object to be, the greater we conclude is it's magnitude; and reciprocally, the nearer we conclude it is, the ſmaller we ſuppoſe it. We, of courſe, frequently take one body for another of much greater magnitude, when a ſuſpenſion of judgment prevents our taking diſtance into the account. The reaſon is that a very large body may be ſeen at a great diſtance, under the ſame angle as a ſmall object placed near us.

There is another phenomenon, well known to every one, and which has given occaſion to many diſputes among the learned, and which it is now perfectly eaſy to explain. The full moon appears to every eye at the time of her riſing to be much greater than when ſhe has got to a conſiderable height above the horizon, though the viſual angle of the apparent magnitude be the ſame. The ſun, too, at the time of riſing and ſetting, appears to every one greater than at noon. What then is the foundation of this judgment, ſo univerſal, and ſo falſe? It is undoubtedly becauſe we judge the ſun and the moon in the horizon to be at a greater diſtance from us than when they have got to a conſiderable height.

But how come we to form ſuch a judgment? The common anſwer is, that when the ſun and the moon are in the horizon, we perceive a great many objects between them and us which ſeem to increaſe their diſtance; whereas when the ſun and moon have riſen to a great height, we perceive nothing between them and us, and therefore conclude that they are

nearer.



nearer. I know not whether this explanation will be ſatisfactory. It may be objected that an empty apartment appears greater than one completely furniſhed, though the ſize be exactly the ſame; ſeveral intervening objects, therefore, do not always lead us to imagine that one more remote is at a greater diſtance than is really the caſe. I flatter myſelf that the following ſolution will be deemed more natural, and better founded.

Let the circle A (*plate* I. *fig.* 13.) repreſent the earth, and the dotted circle the atmoſphere, or air with which the earth is ſurrounded; ſuppoſe yourſelf ſtationed at the point A, if the moon is in the horizon, the rays will reach you in the direction of the line B A; but in her extreme height, the rays will deſcend in the line C A. In the firſt caſe the rays paſs through the greater ſpace B A; and in the ſecond caſe through the ſmaller ſpace C A. Now, you will pleaſe to recollect, that the rays of light which paſs through a tranſparent medium have their force diminiſhed in proportion to the length of the paſſage. The atmoſphere or air, then, being a tranſparent medium, the ray B A muſt in it's paſſage loſe much more of it's force than the ray C A. Hence it follows, in general, that all the celeſtial bodies appear much leſs brilliant in the horizon than when fully riſen and elevated. We are able to look directly even at the ſun, when he is in the horizon; but when once he has gained a certain height, the eye is conſtrained to ſhrink from his luſtre.

I conclude from this that the moon, too, appears

leſs

leſs brilliant in the horizon than when elevated.* Now, you will recollect what I ſaid a little above, in ſpeaking of effect in painting, that the ſame object appears to us more diſtant when it's light is weakened: the moon, then, being in the horizon, muſt appear more diſtant than at any point of elevation.

* This explanation of the appearance of the horizontal moon was offered, in the beginning of the preſent century, by the acute Dr. Berkeley, Biſhop of Cloyne. It has ſince been refuted by that excellent optician, Dr. Smith, who was the firſt that completely inveſtigated this curious ſubject. The following is an abſtract of the theory, from Dr. Prieſtley's "Hiſtory of Viſion, Light, and Colours."

"If the ſurface of the earth were perfectly plane," ſays Dr. Smith, "the diſtance of the viſible horizon would ſcarce exceed 5000 times the height of the eye above the ground, or the diſtance of miles (ſuppoſing the height of the eye to be between five and ſix feet) and all objects placed beyond that diſtance would appear in the viſible horizon. All objects and clouds, likewiſe, placed at any diſtance beyond this, muſt conſequently, if they be viſible at all, appear to be in the horizon. "Hence," he ſays, "if we ſuppoſe a vaſt wall to be built at the extremity of the plane, beyond the point of viſible diſtance, it will not appear ſtraight, but circular, as if built upon the circumference of the horizon; and, if continued infinitely, would make a perfect ſemi-circle. If now this round plane, with the wall upon it, be imagined to be raiſed, till it come perpendicular to the reſt of the plane, on which a perſon ſtands, the wall will appear like the concave figure of the clouds over his head. But though the wall in the horizon appear in the ſhape of a ſemi-circle, yet the cieling will not, but much flatter; becauſe the horizontal plane was a viſible ſurface, which ſuggeſted the idea of the ſame diſtances quite round the eye; but in the vertical plane, extended between the eye and the cieling, there is nothing that affects the ſenſe with an idea of it's parts. Conſequently the apparent diſtances of the higher parts of the cieling will be gradually diminiſhed. Now, when the ſky is quite overcaſt with clouds of equal gravities, they will all float in the air at equal heights above the earth, and conſequently will compoſe a ſurface reſembling a large cieling, as flat as the viſible ſurface of the earth. It's concavity, therefore, is not real, but apparent; and when the heights of the clouds are unequal, ſince their real ſhapes and magnitudes are all unknown, the eye can ſeldom diſtinguiſh the unequal diſtances of thoſe clouds which appear in the ſame directions, unleſs when they are very near us, or are driven by contrary currents of the air. So that the viſible ſhape of the whole ſurface remains alike in both caſes. And when the ſky is either partly overcaſt, or perfectly free from clouds, it is a fact that we ſtill retain much the ſame idea of it's concavity, as when it was quite overcaſt. But if any one thinks that the reflexion of light from the air is alone ſufficient to ſuggeſt that idea, he would not diſpute it."

"The concavity of the heavens appears to the eye, which is the only judge of an apparent figure, to be a leſs portion of a ſpherical ſurface than an hemiſphere. In other words," he ſays, "the center of the concavity is much below the eye; and, by taking a medium among ſeveral obſervations, he found the apparent diſtance of it's parts, at the horizon, was generally between three and four times greater than the apparent diſtance of it's parts over head."

"This he determined by meaſuring the actual height of ſome of the heavenly bodies, when, to his eye, they ſeemed to be half way between the horizon and the zenith. In this caſe their real altitude was only 23 degrees."

Upon theſe principles Dr. Smith conſtructed the following table:

| Sun or Moon's altitude, in degrees. | Apparent Diameters, or diſtances. |
|---|---|
| 00 | 100 |
| 15 | 68 |
| 30 | 50 |
| 45 | 40 |
| 60 | 34 |
| 75 | 31 |
| 90 | 30 |

E. E.



The

The conſequence is obvious; as we judge the diſtance of the moon greater in the horizon, we muſt likewiſe judge her magnitude greater. And in general all the ſtars, when near the horizon, appear to us greater, becauſe their apparent diſtance is greater.

*3d Auguſt*, 1760.

## LETTER XXXVI.

### *Of Shade.*

I HAVE endeavoured to explain almoſt all that is uſually treated of in optics. All that remains is to ſpeak of ſhade. You already know too well what is meant by ſhade to render it neceſſary for me to dwell long on the ſubject. Shade always ſuppoſes two things: a luminous body, and an opaque body, which does not tranſmit the rays of light. The opaque body, then, prevents the rays of a luminous body from getting behind it, and the ſpace which the rays cannot reach, from this interception, is called the ſhade of the opaque body, or, what comes to the ſame thing, ſhade includes all that ſpace in which the luminous body is not to be ſeen, becauſe the opaque body obſtructs it's rays.

Let A (*plate* I. *fig.* 14.) be a luminous point, and B C D E an opaque body. Draw the extreme rays A B M, A D N, touching the opaque body. It is evident that no ray of light proceeding from A, can penetrate into the ſpace M B E D N; and in whatever point within that ſpace the eye may be placed, at O for example, it will not ſee the luminous body. This ſpace is the ſhade of the opaque body, and we ſee that it is continually increaſing, and may extend to infinity. But if the body from which the rays proceed be itſelf of great magnitude, the determination of the ſhade is ſomewhat different. There are three caſes which demand conſideration; the firſt is, when the luminous body is leſs than the opaque; the ſecond, when they are equal; and the third, when the luminous body is the greater. The firſt caſe is that which we have now been conſidering, in which the light is ſmaller than the opaque body.



The ſecond is repreſented, (*plate* I. *fig.* 15.) in which the luminous body A is of the ſame magnitude with the opaque body B C E D. If you draw the extreme rays A B M, A E N, the ſpace M B E N will be ſhaded, and through the whole of that ſpace it will be impoſſible to ſee the luminous body. You ſee, likewiſe, that the lines B M and E N are parallel, and that the ſhade extends to infinity, always preſerving the ſame breadth.

The third caſe is exhibited, (*plate* I. *fig.* 16.) in which the luminous body A A is greater than the opaque body B C E D. The extreme rays, touching the opaque body in B and E, if produced, will meet in the point O, and the ſpace of the ſhade B O E becomes finite, and terminates in O. The ſhade, in this caſe, is termed conical. It is only into this ſpace that the light has no admiſſion, and in which it is impoſſible

impoſſible to ſee the luminous body. To this third caſe belong the ſhades of the celeſtial bodies, which are much ſmaller than the luminous body which enlightens them, namely the ſun.

We have here, then, another diſplay of the Creator's wiſdom. For if the ſun were ſmaller than the planets, their ſhades would not be terminated, but extend to infinity, which would deprive immenſe ſpaces of the benefit of the ſun's light. But the magnitude of that luminary ſurpaſſing by ſo many times that of the planets, their ſhades are contracted to very narrow bounds, from which alone the light of the ſun is excluded.

It is thus that the earth and the moon project their conical ſhades; and the moon may occaſionally plunge into the ſhade of the earth either partially or totally. When this takes place, we ſay the moon is eclipſed, either wholly or in part. In the former caſe we call it a total eclipſe of the moon; in the other, a partial eclipſe. The moon, likewiſe, projects her ſhade, but it is ſmaller than that of the earth. It may happen, however, that the ſhade of the moon ſhould extend as far as to the earth; and then thoſe who are involved in that ſhade, undergo an eclipſe of the ſun. An eclipſe of the ſun, then, takes place when the moon, interpoſing, prevents our ſeeing the ſun wholly, or in part. We ſee not the ſun by night, though there be no eclipſe; but we are then in the ſhade of the earth, which cauſes our greateſt obſcurity.





Hitherto we have conſidered only the caſes in which the rays of light are tranſmitted in ſtraight lines, which is the profeſſed object of optics. But it has been already remarked, that the rays of light are ſometimes reflected, and ſometimes broken, or refracted. You will recollect, that when the rays fall on a well-poliſhed ſurface, ſuch as a mirror, they are reflected from that ſurface; and when they paſs from one tranſparent medium to another, they undergo refraction, and are in ſome ſenſe broken. Hence ariſe two other ſciences. That which conſiders viſion in reference to reflected rays is called catoptrics; and that which has for it's object viſion, in reference to broken or refracted rays, is termed dioptrics. Optics treat of viſion relatively to direct rays of light. I ſhall preſent you with a ſummary of theſe two ſciences, catoptrics and dioptrics, as they diſcloſe phenomena which are every day preſenting themſelves, and of which it is of importance to inveſtigate the cauſes and the properties. Every thing relating to the ſubject of viſion is, beyond contradiction, an object highly worthy of exciting curioſity, and of engaging attention.

*5th Auguſt, 1760.*

## LETTER XXXVII.

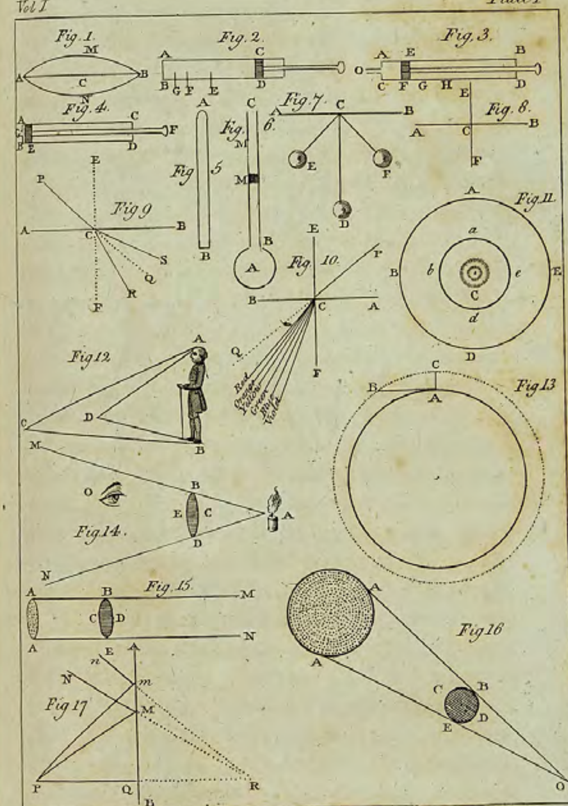
*Of Catoptrics, and the Reflection of Rays from plain Mirrors.*

CATOPTRICS treat of viſion relatively to reflected rays. When rays of light fall on a well poliſhed ſurface, they are reflected in ſuch a manner that the angles on all ſides are equal among themſelves.

To ſet this in a clear light, let A B (*plate* I. *fig.* 17.) be the ſurface of a common mirror, and P a luminous point, whoſe rays P Q, P M, P *m*, fall upon the mirror. Of all theſe rays, let P Q be that which falls perpendicularly on the mirror, and which has this particular and remarkable property, that it is reflected upon itſelf in the direction of Q P; juſt as on a billiard table, when the ball is ſtruck perpendicularly againſt the ledge, it is repelled in the ſelf-ſame direction. But every other ray, as P M, is reflected in the line M N, in ſuch a manner as to make the angle A M N equal to the angle B M P; in which it is to be remarked, that the ray P M is named the incident ray, and M N the reflected ray. In like manner, to the incident ray P *m*, will correſpond the reflected ray *m n*; and, conſequently, becauſe of the reflection, the ray P M is continued in the direction of the line M N, and the ray P *m* in the direction of *m n*, ſo that we have the angle A M N, equal to B M P, and the angle A *m n*, equal to the angle B *m* P.

This

Vol. I. Plate I.



This property is thus enounced: *The angle of reflection is always equal to the angle of incidence.*

I have already taken notice of this ſtriking property; but my deſign, at preſent, is to ſhew what the phenomema in viſion are which reſult from it. Firſt, it is evident, that an eye, placed at N, will receive from the luminous point P, the reflected ray M N; thus the ray which excites in that eye the ſenſation of the body from whence it proceeded, comes in the direction M N, juſt as if the object P were in ſome point of that line; hence it follows that the eye muſt ſee the object P in the direction N M.

In order the more clearly to elucidate this fact, we muſt have recourſe to geometry; and you will recollect with pleaſure the propoſitions on which the following reaſoning is founded. Let the perpendicular ray P Q be produced on the other ſide the mirror to R, ſo that Q R ſhall be equal to P Q; I will ſhew you that all the reflected rays, M N, and *m n* being produced behind the mirror, muſt meet in that point. For, taking the two triangles P Q M and R Q M, they have firſt the ſide M Q common to both; then the ſide Q R was made equal to the ſide P Q; and, finally, the angle P Q M being a right angle, it's adjacent angle R Q M muſt likewiſe be a right angle.* Therefore theſe two triangles, having each an equal angle contained by two equal ſides, ſhall be every way equal,† and conſequently the angle

* Euclid's Elements, book I. Prop. 13.

† Euclid, book I. Prop. 4.

P M Q equal to the angle R M Q. But the angle A M N, and the angle R M Q, being vertical, are equal to each other,* therefore alſo the angle A M N ſhall be equal to the angle P M Q; that is, the angle of reflection ſhall be equal to the angle of incidence.

In the ſame manner it is demonſtrated that the reflected ray *m n* being produced, would likewiſe paſs through the point R, and conſequently produce in the eye the ſame effect as if the object P were actually placed behind the mirror at R, this point being in the perpendicular P Q R, at the ſame diſtance as P from the ſurface of the mirror, but on different ſides. This will enable you to comprehend clearly why mirrors repreſent objects as if they were behind them; and why we judge that theſe objects are placed as far behind the ſurface of the mirror as they really are before it. It is thus the mirror tranſports objects into another place, without changing their appearance. To diſtinguiſh in the mirror that apparent object from the real, we name the apparent object the image, and we ſay that the images repreſented by reflected rays are behind the mirror. This denomination ſerves to diſtinguiſh real objects from the images of them repreſented in mirrors; and the images which we ſee in mirrors are perfectly equal and ſimilar to the objects, with this exception, that what in the object is on the left appears in the image on the right, and reciprocally. Thus a perſon wearing his ſword on the left ſide, appears with it in the mirror on his right.

* Euclid, book I. Prop. 15.

From



From what has been ſaid, it is always eaſy to ſettle the image of any object whatever behind the mirror.

For A B (*plate* II. *fig.* 1.) being a mirror, and E F an object, ſay an arrow: draw from the points E and F the perpendiculars E G and F H, to the ſurface of the mirror, and produce theſe to *e* and *f*, ſo that E G ſhall be equal to *e* G, and F H to *f* H, *e f* will be the image ſought, which will be equal to the object E F, becauſe the quadrilateral figure G *e f* H is in all reſpects equal to the quadrilateral figure G E F H. It muſt be ſtill farther remarked, that were you even to cut off from the mirror a part, as C B, and A C was the mirror, the image *e f* would not be changed. And conſequently when the mirror is not ſufficiently large to admit the falling of the perpendiculars E G and F H upon it, we muſt ſuppoſe the plane of the mirror to be extended, as we produce lines in geometry when we want to let fall perpendiculars upon them. What I have ſaid reſpects only common mirrors, whoſe ſurface is perfectly plain. Convex and concave mirrors produce different effects.

*7th Auguſt*, 1760.

## LETTER XXXVIII.

*Reflection of Rays from convex and concave Mirrors. Burning Mirrors.*

EVERY thing relating to the reflection of rays is reduced, as you have ſeen, to two things; the one of which is the place of the image which the reflected rays repreſent; and the other the relation of

2 the

the image to the object. In ordinary or plain mirrors, the image of the object is behind the mirror, at a diftance equal to that of the object before the mirror, and it is equal and fimilar to the object. To both of thefe circumftances we muft attend when the mirror is not plain; but when it's furface is convex or concave; for in either cafe the image is, for the moft part, ftrangely disfigured. You muft frequently have remarked that on prefenting any object before a fpoon very highly polifhed, you fee it's image greatly disfigured, whether reflected from it's interior furface, which is concave, or from it's exterior, which is convex.

A globe of filver, finely polifhed, reprefents objects with fufficient accuracy, but in miniature. If the interior furface of the globe is well polifhed, objects appear upon it magnified; provided always that they are not too diftant. For the fame objects may likewife appear fmaller and inverted, if they are removed far from the mirror. There is no occafion to take a whole globe; any part of it's furface whatever produces the fame effect. Thefe mirrors are denominated fpherical; and there are two forts of them. The one is convex and the other concave, according as they are taken on the exterior or interior furface of the fphere. They are compounded of various metals, fufceptible of a fine polifh; whereas plain mirrors are made of a plate of glafs, and covered on one fide with a preparation of mercury, defigned to ftop the paffage of the rays, and to reflect them. I begin with convex mirrors.

Let



Let A C B (*plate* II. *fig.* 2.) be a mirror, the fegment of a fphere, whofe centre is G. If you place before this mirror an object E, at a great diftance, it's image will appear behind the mirror, at the point D, the middle point of the radius of the fphere C G; and the magnitude of this image will be to that of the object, in the relation of the lines C D and C E: it will, therefore, be in this cafe much fmaller than the object, as the line C D is, in effect, much fmaller than the line C E. If the object E approaches to the mirror, fo likewife will it's image. This is all demonftrable on geometrical principles, by fuppofing that any incident ray whatever, fay E M, is reflected in the direction of M N, fo that the angle B M N may be equal to the angle C M E. Thus, when the eye is at N, receiving the reflected ray M N, it will fee the object E, according to that direction, and will obferve it in the mirror, at the point D: or, in other words, D will be the image of the object placed at E, but fmaller. It is likewife eafy to fee, that the fmaller the fphere is, of which the mirror is a fegment, the more, likewife, is the image diminifhed.

I proceed to concave mirrors, the ufe of which is very common on many occafions. Let A C B (*plate* II. *fig.* 3.) be a mirror, forming part of a fphere, whofe centre is G, and G C a radius. Let us fuppofe an object E, very diftant from the mirror, it's image will appear before the mirror at D, the middle point of the radius C G: for any ray of light whatever, E M, from the object E, falling on the furface of the mirror, at the point M, will be reflected

thence,

thence, in ſuch a manner, as to paſs through the point D; and when the eye is placed at N, it will ſee the object at D; but this image will be to the object in the ratio of C D to C E, and conſequently in this caſe ſmaller than it. And when you bring the object nearer to the mirror, the image retires; the object being placed even at the centre G, the image is there likewiſe. If you bring the object ſtill forward to D, the image will retire infinitely beyond E. But if the object be placed ſtill farther forward, between C and D, the image will fall behind the mirror, and appear greater than the object.

When you look at yourſelf in ſuch a mirror, at ſome point between D and C, your face will appear frightfully large. This is explained by the nature of reflection, in virtue of which the angle of incidence, E M A, is always equal to the angle of reflection, C M N. To this ſpecies muſt be referred burning mirrors, and every concave mirror may be employed to burn. This remarkable property merits a more particular explanation.

Let A B C (*plate* II. *fig*. 4.) be a concave mirror, whoſe centre is G, and inſtead of the object, let the ſun be at E; his reflected rays will repreſent the image of the ſun at D, the middle point between C and G. Now, the magnitude of this image will be determined by the extreme rays S C, S C. This image of the ſun will be, accordingly, very ſmall, and as all the rays of the ſun which fall on the mirror A C B are reflected in this image, they will be collected there, and will have ſo much more force, as the



the image D is ſmaller than the ſurface of the mirror. But the rays of the ſun are endowed with the property of heating the bodies on which they fall, as well as that of illuminating them; hence it follows, that there muſt be at D a great degree of heat; and when the mirror is ſufficiently large, this heat may become ſtronger than the moſt ardent fire. In fact, by means of ſuch a mirror, you may burn in an inſtant any combuſtible body, and even melt metals of every kind. It is the image of the ſun alone which produces theſe ſurpriſing effects. This image is uſually denominated the focus of the mirror; it falls always in the middle point of the radius C G; between the mirror and it's centre G.

You muſt carefully diſtinguiſh burning mirrors from burning glaſſes, of which I ſhall give ſome account in my next letter.

*9th Auguſt*, 1760.

## LETTER XXXIX.

### *Of Dioptrics.*

HAVING explained the principal phenomena of catoptrics, which reſult from the reflection of the rays of light; I proceed to treat of dioptrics, whoſe object is to unfold the phenomena of the refraction of rays, which takes place when they paſs through different tranſparent mediums. A ray of light does not purſue the ſame ſtraight line unleſs it continues

continues it's progrefs through the fame medium. As foon as it enters another tranfparent medium, it changes it's direction more or lefs, according as it falls upon it more or lefs obliquely. There is only one cafe in which it purfues a rectilinear courfe, namely, when it enters the other medium perpendicularly.

The inftruments principally to be confidered in dioptrics are the glaffes employed in the conftruction of telefcopes and microfcopes. Thefe glaffes are of a circular form, but with two faces. Every thing relating to them is reducible to the figure of thefe two faces, which may be plain, or convex, or concave. Their convexity, or concavity, is always equal to that of a fphere, of which the radius muft be known, it being confidered as the meafure of the curve of thofe furfaces. This being laid down, we fhall have feveral kinds of dioptric glaffes.

The firft fpecies, No. I. (*plate* II. *fig.* 5.) is that whofe two faces are plain. By cutting a circular piece out of a plate of glafs, of equal thicknefs, we fhall have one of this fpecies, which makes no change on objects either as to magnitude or diftance. Glafs No. II. has one of its furfaces plain, and the other convex; and fuch are termed *plano-convex*. The third fpecies, No. III. has one face plain, and the other concave, and thefe are called *plano-concave*. The fourth, No. IV. has two convex furfaces, and is called *double-convex*. No. V. has two concave furfaces, and is called *double-concave*. The fpecies Nos. VI. and VII. have one furface convex and the other concave; and we



give them the name of *menifcus*. All thefe lenfes are reducible to two claffes; the one containing thofe in which convexity prevails, as Nos. II. IV. VI.; in the other, concavity is predominant, namely, Nos. III. V. VII. The former clafs is fimply denominated convex, and the latter concave. Thefe two claffes are diftinguifhed by the following property.

Let A B (*plate* II. *fig.* 6.) be a convex glafs, expofed to a very diftant object, E F, whofe rays G A, G C, G B, fall on the glafs, and, paffing through it, undergo a refraction, which will take place in fuch a manner, that the rays proceeding from the point G fhall meet on the other fide of the glafs in the point *g*. The fame thing will happen to the rays which proceed from every point of the object. By this alteration all the refracted rays A *l*, B *m*, C *n*, will purfue the fame direction as if the object were at *e*, *g*, *f*, and inverted; and it will appear as many times fmaller as the diftance C *g* fhall be contained in the diftance C G. We fay, then, that fuch a glafs reprefents the object E F behind it at *e f*, and this reprefentation is called the *image*, which is confequently inverted, and is, with the object itfelf, in the ratio of the diftances of the glafs from the image, and of the glafs from the object.

It is clear, then, that if the fun were the object, the image reprefented at *e f* would be that of the fun; though very fmall, it will be fo brilliant, as to dazzle the eye, for all the rays which pafs through the glafs meet in this image, and there exercife their double power of giving light and heat. The heat there

there is nearly as many times greater, as the furface of the glafs exceeds in magnitude the image of the fun, named it's focus, from which, if the glafs be very great, you may produce the greateft effects of heat. Combuftible fubftances, placed in the focus of fuch a glafs, are inftantly confumed. Metals are melted, and even vitrified by it; and other effects are produced far beyond the reach of the moft active and intenfe fire.

The reafon is the fame as in the cafe of burning mirrors. In both the rays of the fun, diffufed over the whole furface of the mirror, or glafs, are collected in the fmall fpace of the fun's image. The only difference is, that in mirrors the rays are collected by reflection, and in glaffes by refraction. Such is the effect of convex glaffes, which are thicker in the middle than at the extremities, and which I have reprefented in Nos. II. IV. and VI. Thofe reprefented in Nos. III. V. and VII. are thicker at the extremities than at the middle, and being all comprehended under the term concave, produce a contrary effect.

Let A C B (*plate* II. *fig.* 7.) be a glafs of this form. If you expofe to it, at a great diftance, the object E G F, the rays G A, G C, G B, proceeding from the point G, will undergo a refraction, on leaving the glafs, in the direction of A *l*, C *m*, and B *n*, as if they had iffued from the point *g*; and an eye placed behind the glafs, at *m*, for example, will fee the object juft as if it were placed at *e g f*, and in a fituation fimilar to that in which it is at the point G, but as many times fmaller as the diftance C G exceeds the diftance



diftance G *g*. Convex glaffes, then, reprefent the image of a very diftant object behind them; concave glaffes reprefent it before them; the former reprefent it inverted, and the latter in it's real fituation. In both, the image is as many times fmaller as the diftance of the object from the glafs exceeds that of the glafs from the image. On this property of glaffes is founded the conftruction of telefcopes, fpectacles, and microfcopes.

*11th Auguft*, 1760.

## LETTER XL.

*Continuation. Of burning Glaffes and their Focus.*

CONVEX glaffes furnifh fome farther remarks, which I beg leave to lay before you. I fpeak here of thofe glaffes in general which are thicker in the middle than at the extremities; whether both furfaces be convex, or one plane and the other convex; or, finally, one concave and the other convex, provided, however, that the convexity exceed the concavity, or that the thicknefs be greater at the middle than at the extremities. It is farther fuppofed that the glaffes have a fpherical figure.

They have firft this property, that being expofed to the fun, they prefent behind them a focus, which is the image of that luminary, and which is endowed, like it, with the property of illuminating and burning. The reafon is that all the rays iffuing from the

the ſun, and falling on this ſurface, are collected by the refraction of the glaſs into a ſingle point. The ſame thing happens whatever be the object expoſed to ſuch a glaſs; it always preſents the image of it, which you ſee inſtead of the object itſelf. The following figure will render what I have ſaid more intelligible.

Let A B C D (*plate* II. *fig.* 8.) be a convex glaſs, before which is placed an object E G F, of which it will be ſufficient to conſider the three points E, G, F. The rays which, from the point E, fall upon the glaſs, are contained in the ſpace A E B; and are all collected in the ſpace A *e* B by refraction, ſo as to meet in the point *e*. In the ſame manner the rays from the point G, which fall on the glaſs, and which fill the ſpace A G B, are comprehended, by means of refraction, in the ſpace A *g* B, and meet in the point *g*. Finally, the rays from the point F, which fall on the glaſs in the angle A F B, are refracted ſo as to meet in the point *f*. Thus we ſhall have the image *e g f* in an inverted poſition behind the glaſs; and an eye placed at O, behind the image, will be affected in the ſame manner as if the object were at *e g f*, inverted, and as many times ſmaller as the diſtance D *g* is ſmaller than the diſtance C G.

In order to determine the place of the image *e g f*, we muſt attend as well to the form of the glaſs as to the diſtance of the object. As to the firſt, it may be remarked, that the more convex the glaſs is, in other words, the more that the thickneſs of the middle C D exceeds that of the extremities, the nearer the image





image will be to it's ſurface. With regard to the diſtance, if you bring the object E F nearer to the glaſs, it's image *e f* retires from it, and reciprocally. The image cannot be nearer to the glaſs than when the object is at a very great diſtance from it; it is then at the ſame diſtance as that of the ſun would be, which is denominated the focus of the lens. When the object, then, is very diſtant, the image falls in the very focus, and the nearer you bring the object to the glaſs the farther the image retires from it, and that in conformity to a law in dioptrics, by means of which you can always determine the place of the image, for every diſtance of the object, provided you know the focus of the glaſs, that is, the diſtance at which it collects the rays of the ſun, in a ſpace ſufficiently ſmall to ſet on fire a body expoſed to it.

The point where the rays meet is, as has been ſaid, the place of the image. Now, this point is eaſily found by experience. The different denominations of glaſſes are derived from it, as when we ſay, ſuch a glaſs has it's focus at the diſtance of an inch, another at the diſtance of a foot, another at the diſtance of ten feet, and ſo on; or, more conciſely, a glaſs of an inch, a foot, or ten feet focus. Long teleſcopes require glaſſes of a very diſtant focus, and it is extremely difficult to make them exact. I once paid 150 crowns for one lens, which I ſent to the academy of Peterſburg; it has it's focus at the diſtance of 600 feet: I am convinced it was of no great value; but they would have it on account of it's rarity.

To be satisfied that the representation of the image *e g f*, in the preceding figure, is real, you have only to hold at that place a piece of white paper, the particles of which are susceptible of the different kinds of vibrations on which colours depend. Then all the rays from the point E of the object, on meeting at the point *e*, will put the particles of the paper into a movement of vibration similar to that which the point E has, and consequently you will see the point *e* of the same colour as the point E. In like manner the points *g* and *f* will have the same colours as the points G and F of the object; and you will likewise see on the paper all the points of the object expressed in their natural colours; which will represent the most exact and the most beautiful picture of the object. This will succeed perfectly well in a dark room by applying a convex lens to a hole made in the shutter. You will then see on a sheet of white paper, placed opposite to the aperture in the shutter, all the external objects so exactly painted, that you may trace them with a pencil. Painters make use of such a machine for designing landscapes and other views.*

13th *August*, 1760.

* The hypothesis of light, contained in the preceding letters, was first proposed in the middle of last century by the ingenious Mr. Huggens; but after the brilliant discoveries of Sir Isaac Newton, it fell into oblivion, where it ought ever to have remained. What induced Mr. Euler to revive it, it is difficult to conceive. This hypothesis is not likely to have many abettors in the present age. As it appeals wholly to the imagination, it requires not any formal refutation. I shall mention a single objection, which seems to be conclusive: If ether were the vehicle of light, as air and water are of sound, the ear would likewise be, in some degree, an organ of vision.



## LETTER XLI.

*Of Vision, and the Structure of the Eye.*

I AM now enabled to explain the phenomena of vision, which is undoubtedly one of the greatest operations of nature that the human mind can contemplate. Though we are very far short of a perfect knowledge of the subject, the little we do know of it is more than sufficient to convince us of the power and wisdom of the Creator. We discover in the structure of the eye perfections which the most exalted genius could never have imagined.

I shall not detain you at present with an anatomical description of the eye. It is sufficient to remark, that the exterior membrane *a* A *b* (*plate* II. *fig.* 9.) is transparent, and is called the *cornea* of the eye; behind this, on the inside, is another membrane *a m*, *b m*, circular and coloured, which we call the *iris*, in the middle of which is an aperture *m m*, called the *pupil*, which appears to us to be black. We find behind this aperture, the *crystalline* humour *b* B C *a*, which is a body somewhat like in form to a small burning glass; it it perfectly transparent, and of a membranous substance. Behind the crystalline humour the cavity of the eye is filled with a transparent jelly, called the *vitreous humour*. The anterior space between the horny tunicle *a* A *b*, and the crystalline *a b* contains a liquor fluid as water, which, for that reaſon, is called the *aqueous humour*.

Here, then, are four tranſparent ſubſtances, through which the rays of light, that enter into the eye, muſt paſs: 1. the horny tunicle, or *cornea*; 2. the aqueous humour, between A and B; 3. the cryſtalline *b* B C *a*; 4. the vitreous humour. Theſe four ſubſtances differ as to denſity; and the rays paſſing from one to another, undergo a particular refraction; and they are ſo arranged, that the rays coming from a point of any object, are ſtill collected within the eye in a point, and there preſent an image.

The bottom of the eye at E G F, or the *retina*, is furniſhed with a whitiſh tiſſue, adapted to the reception of images; and it is thus, you will pleaſe to recollect, that the images of objects may be repreſented on a white ground. Conformably to the ſame principle, all the objects, whoſe rays enter into the eye, are found painted on the retina. Take the eye of an ox, and having removed the exterior parts which cover the retina, you will ſee all the objects painted there ſo exactly, that no artiſt could exceed it, or even arrive at ſuch a degree of perfection. And in order to ſee any object whatever, the object muſt always be painted on the retina; and when, unfortunately, any of the parts of the eye are injured, or loſe their tranſparency, the perſon becomes blind.

But it is not ſufficient, in order to our ſeeing objects, that their images ſhould be painted on the retina; ſome are blind, though this takes place. Hence we





we ſee that images painted on the retina are not, after all, the immediate object of viſion, and that the perception of the ſoul is communicated ſome other way. The retina is a reticulated contexture of nerves the moſt ſubtile, communicating with a great nerve, which, coming from the brain, enters the eye at O, and is denominated the optic nerve. Theſe ſmall nerves of the retina are agitated by the rays of light which form the image at the bottom of the eye; and this agitation is tranſmitted by the optic nerve to the brain. It is there, undoubtedly, that mental perception is formed: but the moſt dextrous anatomiſt is unable to purſue theſe nerves to their ſource: the union of the ſoul with the body muſt for ever remain a myſtery.

*15th Auguſt*, 1760.

## LETTER XLII.

*Continuation. Wonders diſcoverable in the Structure of the Eye.*

IT will not be diſagreeable to you, I hope, to contemplate with me, ſomewhat more attentively, the wonders diſcoverable in the ſtructure of the eye.

And firſt the pupil preſents an object highly worthy of admiration. It is that aperture which we find in the middle of the iris or ſtar, by which the rays paſs into the inſide of the eye, and which appears black. The larger it is, the greater quantity of rays can

can enter into the eye, to form on the retina the image which appears painted there; thus, the more the pupil is opened, the more brilliant this image will be.

On carefully examining the human eye, we obſerve, that the aperture of the pupil is ſometimes greater and ſometimes ſmaller. It is generally remarked, that the pupil is contracted when expoſed to a very ſtrong light; and, on the contrary, very much dilated where the light is faint. This variation is abſolutely neceſſary to the perfection of viſion. When we are in a very ſtrong light, the rays being more powerful, fewer of them are wanted to agitate the nerves of the retina; the pupil, accordingly, is then more contracted. Were it more dilated, and conſequently admitted more rays, their force would agitate the nerves too violently, and occaſion pain. It is for this reaſon we are unable to look upon the ſun without being dazzled, and without ſenſible pain in the bottom of the eye.

Were it poſſible for us to contract the pupil ſtill more, ſo as to admit only a very ſmall quantity of rays, we ſhould not be very greatly incommoded by it; but the contraction of the pupil is not in our own power. Eagles poſſeſs this advantage, and are able to look directly at the ſun; it is accordingly remarked, that their pupil is then ſo much contracted, as to appear reduced to a point. A clear light, requiring a very ſmall dilatation of the pupil, in proportion as the light decreaſes, the pupil dilates, and in the dark is ſo enlarged, as almoſt to occupy the

whole



whole of the iris. If it remained in the ſame ſtate of contraction as in the light, the rays which enter into it would be too weak to agitate the nerves as much as is neceſſary to perception; the rays muſt, therefore, be then admitted in greater abundance, in order to produce a ſenſible effect.

Were it in our power to open the pupil ſtill more, we ſhould be able to ſee in a greater degree of darkneſs. To this purpoſe we are told of a perſon, who, having received a blow on his eye, the pupil was ſo dilated by it, that he could read, and diſtinguiſh the minuteſt objects in the dark. Cats and ſeveral other animals which roam in the dark, have the faculty of enlarging the pupil much more than the human ſpecies; and owls have theirs at all times too much dilated to bear even a moderate degree of light.

Now, when the pupil of the human eye dilates or contracts, it is not by an act of the will; man not having the power of dilating or contracting the pupil at pleaſure. As ſoon as he enters into a luminous ſituation, it ſpontaneouſly contracts and dilates on his return to darkneſs. But this change is not produced in an inſtant; it requires a little time for this organ to accommodate itſelf to circumſtances.

You muſt, no doubt, have remarked, that as often as you make a very ſudden tranſition from a clear light to a dark place, as in the theatre of *Schuck*, you could not at firſt diſtinguiſh the company. The pupil was ſtill too narrow to permit the few feeble rays which it admitted to make a ſenſible impreſſion; but it gradually dilated to receive a ſufficiency of rays.

The

The contrary happens, when you paſs ſuddenly from darkneſs to a clear light. The pupil being then very much expanded, the retina is ſtruck in a lively manner, you are quite dazzled, and under the neceſſity of ſhutting your eyes.

It is then a very remarkable circumſtance that the pupil ſhould dilate and contract according as viſion requires, and that this change ſhould take place almoſt ſpontaneouſly and independently of any act of the will. Philoſophers who examine the ſtructure and the functions of the human body, are greatly divided in opinion as to this ſubject, and there is little appearance that we ſhall ever have a ſatisfying ſolution of this wonderful phenomenon. The variability of the pupil is, however, an object eſſentially neceſſary to viſion; and without which it would be very imperfect. But various other particulars are diſcoverable, equally entitled to admiration.

*17th Auguſt*, 1760.

## LETTER XLIII.

*Farther Continuation. Aſtoniſhing Difference between the Eye of an Animal, and the artifical Eye*, or camera obſcura.

THE principle on which the ſtructure of the eye is founded, is, in general, the ſame as that according to which I explained the repreſentation of objects on white paper by means of a convex lens. Both



Both of them muſt be reſolved into this, that all the rays, proceeding from one point of the object, are again collected in a ſingle point by refraction; and it ſeems of little importance whether this refraction is performed by a ſingle lens, or by the ſeveral tranſparent ſubſtances of which the eye is compoſed. It might even be inferred from thence, that a ſtructure more ſimple than that of the eye, by employing one ſingle tranſparent ſubſtance, would have been productive of the ſame advantages; which would amount to a very powerful objection againſt the wiſdom of the Creator, who has aſſuredly purſued the ſimpleſt road in the formation of all his works.

Perſons have not been wanting who, from not having attentively examined the advantages reſulting from the apparent complication, preſumed to cenſure this beautiful production of the Supreme Being with a levity worthy of cenſure. They have pretended it was in their power to produce a plan more ſimple for the ſtructure of the eye, becauſe they were ignorant of all the functions which that organ had to diſcharge. I ſhall examine this plan of theirs; and I hope to convince you, that it would be highly defective, and altogether unworthy of being put in competition with that which actually exiſts.

Such an eye, therefore, would be reduced to a ſimple convex lens, A B C D, (*plate* II. *fig.* 10.) which collects, in a point, all the rays coming from one and the ſame correſponding point in the object. But this is only near to the truth. The ſpherical form, given to the ſurfaces of a lens, is liable to this inconvenience,

inconvenience, that it does not completely collect in one and the fame point the rays which pafs through it's centre, and thofe which pafs through the extremities. There is always a fmall difference, though almoft imperceptible, in the experiments, by means of which we receive the image on a piece of white paper; but if this happened in the eye itfelf, it would render vifion very confufed.

The perfons to whom I have been alluding, allege, that it may be poffible to find another figure for the furfaces of the lens, which fhall have the property of collecting anew all the rays iffuing from the point O, in a point R, whether they pafs through the centre, or through the extremities. I admit that this may be poffible; but fuppofing the lens to poffefs this property, with refpect to the point O, at the fixed diftance C O, it would not poffefs it at points at a greater or lefs diftance from the lens; or, even admitting this to be poffible, which it is not, the lens would moft certainly lofe that property with regard to objects placed on one fide, at T, for inftance. Accordingly we fee that when objects are reprefented on white paper, though fuch as are directly before the lens, fay at O, may be fufficiently well expreffed, thofe which are obliquely fituated, as at T, are always much disfigured, and very confufedly expreffed: and this is a defect which the moft ingenious artift is incapable of rectifying.

But there is another and one not lefs confiderable. In fpeaking of rays of different colours, I remarked, that in paffing from one tranfparent medium to another,



ther, they undergo a different refraction; that rays of a red colour undergo the leaft refraction, and violet-coloured rays the greateft. Hence, if the point O were red, and if it's rays, in paffing through the lens A B, were collected at the point R, this would be the place of the red image. But if the point O were violet, the rays would be collected nearer to the lens, at V. Again, as white is an affemblage of all the fimple colours, a white object, placed at O, would form feveral images at once, fituated at different diftances from the point O; the refult of which would be, on the retina, a coloured fpot that would greatly difturb the reprefentation.

It is accordingly obfervable, that when in a dark room the external objects are reprefented on white paper, they appear bordered with the colours of the rainbow, and it is impoffible to remedy this defect by employing only one tranfparent body. But it has been remarked, that this may be done by means of different tranfparent fubftances; but neither theory nor practice have hitherto been carried to the degree of perfection neceffary to the execution of a ftructure which fhould remedy all thefe defects.* The human eye,

* A fimilar defect has been remarked in the common telefcope. Objects do not appear in it very clearly. You fee, befides, at the circumference of the field which it encompaffes, a mixture of colours, which is called *iris*. To remedy this inconveniency, achromatic telefcopes have been conftructed, whofe object-glafs, being compofed of more than one lens of different denfities, and which of confequence refract the rays differently, produce an effect analogous to that of the tranfparent fubftances of the eye, of which our Author has been treating.—*F. E.*

eye, however, labours under none of the imperfections which I have mentioned, nor many others to which the hypothetical eye we have been analyzing would be liable. What a ſublime idea muſt we form of Him who has furniſhed not only the whole human ſpecies, but every animal, nay even the vileſt inſects, with an organ of ſuch curious conſtruction!*

* The object of the Tranſlator being not only to diſplay *Euler's* philoſophy, but likewiſe to exhibit the man as deſigned by his own pencil, he takes the liberty of preſenting the Engliſh Reader with the concluſion of this letter, in the Author's own manner and words, tranſcribed from the original edition of this work. Though a French philoſopher and ſtateſman may feel aſhamed of the alliance of ſcience to religion, and endeavour to keep it out of ſight, it would ſurely ill become us to follow the example. Let the Author expreſs his own ſentiments in his own way.

"But the eye which the Creator has formed is ſubject to no one of all the imperfections under which the imaginary conſtruction of the freethinker labours. In this we diſcover the true reaſon why infinite wiſdom has employed ſeveral tranſparent ſubſtances in the formation of the eye: it is thereby ſecured againſt all the defects which characteriſe every work of man. What a noble ſubject of contemplation! How pertinent that queſtion of the Pſalmiſt! *He who formed the eye, ſhall he not ſee? and He who planted the ear, ſhall He not hear?* The eye alone being a maſter-piece that far tranſcends the human underſtanding, what an exalted idea muſt we form of Him, who has beſtowed this wonderful gift, and that in the higheſt perfection, not on man only, but on the brute creation, nay, on the vileſt of inſects!"—*E. E.*

*19th Auguſt*, 1760.

LETTER



## LETTER XLIV.

*Perfections diſcoverable in the Structure of the Eye.*

THE eye, then, infinitely ſurpaſſes every piece of mechaniſm which human ſkill is capable of producing. The different tranſparent ſubſtances of which it is compoſed, have not only a degree of denſity capable of cauſing different refractions, but their figure is likewiſe determined in ſuch a manner that all the rays proceeding from one point of the object are exactly collected in one and the ſame point, whether that object be more or leſs diſtant, whether it be ſituated directly or obliquely with reſpect to the eye, and though it's rays undergo different refractions.

Were the leaſt change to be made in the nature and figure of theſe ſubſtances, the eye would loſe all the advantages which we have been admiring. The ſtrength of our ſight is exactly proportioned to the extent of our neceſſities; and far from complaining that objects too remote eſcape this organ, we ought, on the contrary, to conſider it as one of the moſt precious gifts of the Supreme Being.*

It

* Mr. *Euler's* idea is ingenious, that the three pellucid ſubſtances of which the eye is compoſed ſerve to correct the unequal refrangibility of the rays of light, and produce a perfect picture on the retina. Unfortunately this perfection is merely ideal, nor is the eye an achromatic inſtrument. A very ſimple experiment will evince the truth of this remark. Make two parallel black ſtrokes adjacent to each other, on a bit of paper; ſhut the one eye, and

hold

It muſt be farther remarked, that in order to ſee objects diſtinctly, it is not ſufficient that the rays which come from one point ſhould be collected in another. It is likewiſe neceſſary, that the point of re-union ſhould fall preciſely on the retina; if it fell either ſhort of, or beyond it, viſion would become confuſed. Now, if for a certain diſtance of objects, this point of union fall upon the retina, thoſe of more diſtant objects would fall in the eye ſhort of the retina; and thoſe of nearer objects would fall beyond the eye. In either caſe there would be a confuſion in the image painted on the retina.

The eyes of every man, therefore, are conſtructed for a certain diſtance. Some perſons ſee diſtinctly only ſuch objects as are very near to their eyes; we call them *Myops*, that is, ſhort-ſighted. Others, on the contrary, named *Preſbytes*, ſee diſtinctly objects only which are very diſtant. And thoſe who ſee diſtinctly objects at a moderate diſtance, are ſaid to have good eyes. Both the other two, however, have the power of contracting or dilating the globe of the eye to a certain degree, and thereby of bringing

hold the paper about half a foot from the other, in a ſtrong light, and bring it gradually nearer; at a certain diſtance the ſtrokes will appear fringed with rainbow-colours. The Roman characters III or IIII, on the dial-plate of a watch, will anſwer ſtill better. But though the eye is not conſtructed with mathematical accuracy, that organ is adapted, with ſufficient nicety, for all the ordinary purpoſes of life. They miſtake extremely the views of nature, who look for perfection in her works: ſhe is, in general, ſparing in her favours, and reſerves exquiſite ſkill for extraordinary occaſions.—*E. E.*

nearer



nearer, or of removing, the retina, which enables them, likewiſe, to ſee clearly, objects a little more or leſs diſtant; this, undoubtedly, greatly contributes to render the eye more perfect, and it cannot ſurely be aſcribed to chance merely.

Thoſe who have good eyes, derive moſt advantage from their ſtructure, as they are thus in a condition to ſee diſtinctly, objects very diſtant, and very near; but this never exceeds a certain bound. There is, perhaps, no one who can ſee at the diſtance of an inch, and, conſequently, ſtill leſs at a ſmaller diſtance. If you hold a writing cloſe to your eyes, you will ſee the characters but very confuſedly. This is all I preſume to offer, on a ſubject of ſuch high importance.

*21ſt Aug.* 1760.

## LETTER XLV.

*Of Gravity, conſidered as a general Property of Body.*

HAVING now treated of light, I proceed to the conſideration of a property common to all bodies, that of gravity. We find that all bodies, ſolid and fluid, fall downward, when they are not ſupported. I hold a ſtone in my hand; if I let it go, it falls to the ground, and would fall ſtill farther, were there an aperture in the earth. While I write, my paper would fall to the ground, were it not ſupported by the table. The ſame law applies to every

 body

body with which we are acquainted. There is not one that would not fall to the ground, if it were not ſupported, or ſtopped by the way.

The cauſe of this phenomenon, or of this propenſity of all bodies, is denominated gravity. When it is ſaid, that bodies are heavy, or poſſeſs gravity, we mean, that they have a propenſity to fall downward, and actually would fall, if we remove what before ſupported them.

The ancients were little acquainted with this property. They believed that there were bodies which had, naturally, a tendency to riſe, ſuch as ſmoke and vapours; and ſuch bodies they termed light, to diſtinguiſh them from thoſe which have a tendency to fall. But it has been diſcovered, by experiment, that it is the air which raiſes theſe ſubſtances aloft; for in a ſpace void of air, it is well known, by means of the air-pump, that ſmoke and vapours deſcend as well as ſtone, and that theſe ſubſtances are, of their own nature, heavy, like others. When, therefore, they riſe into the air, the ſame law acts upon them which acts upon a log of wood plunged into the water. Notwithſtanding it's gravity, it ſprings up, as ſoon as you leave it to itſelf, and ſwims, becauſe it is not ſo heavy as water; and, in virtue of a general rule, all bodies riſe in a fluid of more gravity than themſelves.

If you throw a piece of iron, of copper, of ſilver, and even of lead, into a veſſel full of quickſilver, they ſwim on the ſurface, and if you force them down, they re-aſcend when left to themſelves. Gold alone



alone ſinks, becauſe it is heavier than quickſilver. And, ſince there are bodies which riſe in water, and in other fluids, notwithſtanding their gravity, for this reaſon merely, that they are not ſo heavy as water, or thoſe other fluids; it is not at all ſurprizing, that certain bodies, leſs weighty than air, ſuch as ſmoke and vapours, ſhould riſe in it.

I have already remarked, that air itſelf poſſeſſes gravity, and that by means of this gravity, it ſupports the mercury in the barometer. When, therefore, it is affirmed, that all bodies are heavy, it is to be underſtood, that all bodies, without a ſingle exception, would fall downward in a vacuum. I might venture to add, that they would fall with an equal degree of rapidity; for a feather and a piece of gold deſcend with equal velocity in an exhauſted receiver.

It might be objected to this general property of body, that a ſhell, diſcharged from a mortar, does not at once fall to the ground, like a ſtone, which I let drop from my hand, but mounts into the air. It cannot, however, be inferred, that the ſhell has no gravity; for it is evident, that the ſtrength of the powder hurls the bomb aloft, and but for this, it would, without doubt, immediately fall to the ground. And we ſee, in fact, that it does not continue always to aſcend, but as ſoon as the force, which carries it upward, is exhauſted, down it comes with a rapidity, that cruſhes every thing it meets, a ſufficient proof of it's gravity.

When, therefore, it is affirmed, that all bodies are heavy, no one means to deny that they may be ſtopped,

ſtopped, or that they may be thrown aloft; but this is effected by an external power, and it remains indubitably certain, that all bodies whatever, as ſoon as left to themſelves, at reſt, or without motion, will aſſuredly fall when no longer ſupported. There is a cellar under my apartment, but the floor ſupports me, and preſerves me from falling into it. Were the floor ſuddenly to crumble away, and the arch of the cellar to tumble in at the ſame time, I muſt infallibly be precipitated into it, becauſe my body is heavy, like all other bodies with which we are acquainted. I ſay, *with which we are acquainted*, for there may, perhaps, be bodies deſtitute of weight; ſuch as, poſſibly, light itſelf, the elementary fire, the electric fluid, or that of the magnet.*

Except theſe bodies, the gravity of which is not

* I muſt once more take the pious *Euler* out of the hands of the *quondam* Marquis, and let him ſpeak for himſelf. The inſtance which the Author adduces, of bodies that, poſſibly, are deſtitute of gravity, is one taken from divine Revelation, that of the angels. "Such," ſays he, "as the bodies of angels, which have "formerly appeared to men. A body, like this, would not fall "downward, though the floor were ſuddenly to be removed from "under it, but would move as firmly through the air, as on the "earth." It is amuſing to obſerve, with what ſolicitude the Pariſian Annotator keeps clear of every thing that favours of religion. He ſeems apprehenſive, that a ſingle drop of water from Scripture, would contaminate the whole maſs of philoſophy. His terror is, with a little variation, that of Macbeth.

Will all great Neptune's ocean waſh this blood
Clean from my hand? No; this my hand will rather
The multitudinous ſeas incarnadine,
Making the green one red. SHAKESPEAR.

yet



yet confirmed by experiment, gravity may be conſidered as a general property of all the bodies which we know, in virtue of which, they all have a tendency to fall downward, and actually do ſo, when nothing oppoſes their deſcent.

*23d Aug.* 1760.

## LETTER XLVI.

*Continuation. Of ſpecific Gravity.*

YOU have juſt ſeen, that gravity is a general property of all the bodies with which we are acquainted, and that it conſiſts in the effect of an invincible force, which preſſes them downward.

Philoſophers have warmly diſputed, whether there actually exiſts a power, which acts in an inviſible manner upon bodies; or whether it be an internal quality, inherent in the very nature of the bodies, and, like a natural inſtinct, conſtraining them to deſcend. The queſtion amounts to this: If the cauſe of gravity is to be found in the very nature of every body; or if it exiſts without it, ſo that were this extrinſic power to fail in it's operation, the body would ceaſe to be heavy? Before we attempt a ſolution of this, it will be neceſſary to examine, more carefully, all the circumſtances connected with gravity.

I remark, firſt, that when you ſupport a body to prevent it's falling, if it reſts on a table, it's preſſure



is

is equal to the force with which it would tend to fall; and if a thread is affixed to it, by which it may be ſuſpended, the thread is ſtretched by that force; in other words, by the gravity of that body; ſo that if the thread were not of a certain ſtrength, it would break. We ſee, then, that all bodies exerciſe a degree of force on the obſtacles which ſupport them, and prevent their falling, and that this action is preciſely the ſame as that which would make the body deſcend, if it were at liberty. When a ſtone is laid upon a table, the table is preſſed by it. You have but to put your hand between the ſtone and the table, to be ſenſible of this force, which may be increaſed to ſuch a degree as even to cruſh the hand. This force is called the gravity of the body; and it is clear, that the weight, or the gravity, of every body, ſignifies the ſame thing, both denoting the force with which that body is preſſed downward, whether this force exiſts in the body itſelf, or out of it.

We have an idea too clear of the weight of bodies, to make it neceſſary to dwell longer on the ſubject. I only remark, that when two bodies are joined together, their weight too is added, ſo that the weight of the compound is equal to the ſum of the weight of the parts. From this we ſee, that the weight of bodies may be very different. We have alſo the certain means of exactly meaſuring and comparing them, by the help of a balance, which has the property of reſting in equilibrium, when the bodies, put in it's two ſcales, are of equal gravity. In order to



to make this compariſon, we agree on ſome fixed meaſurement, of a certain determinate weight, ſuch as a pound, and, by means of a good balance, all bodies may be weighed, and their gravity aſcertained, according to the number of pounds which they contain. A body too great to be put into the ſcale of a balance may be divided, and the parts being weighed ſeparately, you have only to add the particulars. The weight of a whole houſe, however large, may be thus aſcertained.

You muſt, no doubt, have frequently remarked, that a ſmall piece of gold weighs as much as a piece of wood greatly ſuperior in ſize; a proof that the gravity of bodies is not always regulated by their magnitude; a very ſmall body may be of great weight, while a very large one may be light. Every body, then, is ſuſceptible of two meaſurements, entirely different from each other. The one determines it's magnitude or extent, called likewiſe it's ſize; this meaſurement belongs to the province of geometry, which teaches the method of meaſuring the magnitude or extent of bodies. The other mode of meaſurement, by which their weight is determined, is totally different, and ſerves to diſtinguiſh the nature of the different ſubſtances of which bodies are formed.

You can eaſily conceive ſeveral maſſes of different ſubſtances, all of the ſame magnitude, or extent; each, for example, of a cubic figure, whoſe length, breadth, and height, ſhall be a foot. Such a maſs, if it be of gold, would weigh 1330 pounds; if of



ſilver,

ſilver, 770 pounds; if of iron, 500 pounds; and if of water, only 70 pounds; were it of air, it would weigh no more than the twelfth part of a pound. From this you ſee, that the different ſubſtances of which bodies are compoſed, vary conſiderably in reſpect of gravity.

To expreſs this difference, we employ certain terms, which might appear equivocal, if they were not perfectly underſtood. Thus, when it is ſaid, that gold is heavier than ſilver, it is not to be underſtood, that a pound of gold is heavier than a pound of ſilver; for a pound, of whatever ſubſtance, is always a pound, and has always preciſely the ſame weight; but the meaning is, that having two maſſes of the ſame ſize, the one gold and the other ſilver, the weight of the maſs of gold will exceed that of the ſilver. And when it is ſaid, that gold is 19 times heavier than water, we mean, that having two equal maſſes, the one of gold, the other of water, that which is of gold will have 19 times the weight of that which is of water. When we thus expreſs ourſelves, we ſay nothing of the abſolute weight of bodies, we only ſpeak by way of compariſon, and with a reference always to maſſes of an equal ſize. Neither is it of importance, whether the ſize be great or ſmall, provided they be equal.

*25th Aug.* 1760.

LETTER



## LETTER XLVII.

*Terms relative to Gravity, and their true Import.*

GRAVITY, or weight, ſeems ſo eſſential to the nature of bodies, that it is almoſt impoſſible to form the idea of a body diveſted of this quality. And it's influence is ſo univerſal, in all our operations upon body, that we muſt, in every inſtance, pay attention to it's gravity, or weight. As to our own perſons, whether we ſtand, ſit, or lie, we continually feel the effect of the gravity of our own body: we could never fall, if the body were not, as well as all it's parts, endowed with this force. Language itſelf is regulated according to this property of bodies. The place toward which a body tends in it's deſcent, we term *low*; and the oppoſite direction from the body, we term *high*.

It muſt be remarked, that when a body, in falling, is at perfect liberty, it always deſcends in a ſtraight line, purſuing which, it's direction is ſaid to be downward. This line is likewiſe called *vertical*, by which term we always mean a ſtraight line, drawn from high to low; and if we conceive this line produced upward, till it reaches heaven, we call that point in the heavens our *zenith*, an Arabian word, denoting that point in the heavens which is directly over our head. You comprehend, then, that a vertical line, is that ſtraight line in which a body falls, when no longer ſupported. When you affix a thread

to

to any body, holding it faſt at the other end, that thread will be ſtretched out into a ſtraight line, and that line will be vertical. Maſons employ a ſmall cord, with a leaden ball at one end, which they call a *plummet*, to direct the perpendicularity of the walls which they raiſe; for theſe, to be ſolid, muſt be vertical.

All the floors of a houſe ought to be ſo level, that the vertical line ſhall be perpendicular to them; the floor, in that caſe, is ſaid to be horizontal; and you will pleaſe to remember, that a horizontal plane is always that to which the vertical line is perpendicular. When you are in a perfect plane, bounded by no mountain, it's extremities are termed the *horizon*, a Greek word, which ſignifies the boundary of ſight; and this plane then repreſents a horizontal plane, juſt as the ſurface of a lake.

We make uſe of ſtill another term to expreſs what is horizontal. We ſay that ſuch a ſurface or line is *level*. We likewiſe ſay, that two points are on the level, when a ſtraight line, paſſing through theſe two points, is horizontal, ſo that the vertical, or plumb line, ſhall be perpendicular to it. But two points are not on the level, when the ſtraight line, drawn through theſe points, is not horizontal; for then one of them is more elevated than the other.

This is the caſe with rivers; their ſurface has a declivity; for were it horizontal, the river would be ſtagnant, and run down no longer, whereas all rivers are continually flowing toward places leſs elevated. There are inſtruments, by means of which we can aſcertain,



aſcertain, whether two points are on the ſame level, or which is the higher, and by how much. This inſtrument is called a *level*, and the application of it is called the art of levelling.

Were you to draw a ſtraight line from any point, in your apartment at Berlin, to a given point in your apartment at Magdeburg, you might, by means of ſuch an inſtrument, aſcertain, whether this line were horizontal, or whether one of theſe points were more or leſs elevated than the other. I believe the point at Berlin would be more elevated than that at Magdeburg: and I found this opinion on the courſe of the rivers Sprée, Havel, and Elbe. As the Sprée runs into the Havel, it muſt, of courſe, be higher; and, for the ſame reaſon, the Elbe muſt be lower than the Havel: Berlin, therefore, ſtands higher than Magdeburg, provided you compare two points at an equal degree of elevation from the ground; for were a ſtraight line to be drawn from the ſtreet pavement at Berlin to the pinnacle over the dome at Magdeburg, that line would perhaps be horizontal.

Hence you ſee how uſeful the art of taking levels is, when the conducting of water is concerned. For as water can run only from a more to a leſs elevated ſituation, before digging a canal, you muſt be well aſſured, that one of the extremities is more elevated than the other, and this is diſcovered by taking the level.

In building a city, the ſtreets ſhould be ſo diſpoſed, as that, by means of a declivity on one ſide, the water may run off. It is otherwiſe in the conſtruction

tion of houfes, the floors of which fhould be perfectly horizontal, and without the fmalleft declivity, becaufe there is no water to be difcharged, except in the floors of ftables, which are conftructed with a gentle declivity. Aftronomers take great pains to have the floors of their obfervatories perfectly level, to correfpond with the real horizon in the heavens. The vertical line, produced upward, marks the zenith.

*27th Auguft*, 1760.

## LETTER XLVIII.

*Reply to certain Objections to the Earth's fpherical Figure, derived from Gravity.*

YOU know well that the figure of the earth is nearly that of a globe. It has, indeed, been demonftrated, that it's form is not perfectly fpherical, but fomewhat flattened toward the poles. The difference, however, is fo trifling, that it does not at all affect the object I have in view. Neither does the difference of mountain and valley excite any folid objection to it's globular figure; for it's diameter being 1720 German miles,* whereas the higheft mountains being fcarcely half a mile† in height, fink into nothing, compared to this prodigious mafs.

The ancients had a very imperfect notion of the

* 7900 miles Englifh.

† About 12,000 feet, or 2 $^{3}$ miles Englifh.

real



real figure of the earth. It was in general confidered as a huge maffy fubftance A B C D (*plate* II. *fig.* 11.) flattened above as A B, and covered partly with earth, partly with water. According to their idea, the furface A B alone was habitable; and it was impoffible to go beyond the points A and B, which they confidered as the extremities of the world. When, in the progrefs of difcovery, it was found that the earth was nearly fpherical, and univerfally habitable, fo that there were upon the globe fpots diametrically oppofite to us, the inhabitants of which are therefore called our *antipodes*, becaufe their feet are turned directly toward ours; this opinion met with fuch violent contradiction, that certain fathers of the church reprefented it as a dreadful herefy, and thundered out anathemas againft all who believed in the exiftence of the antipodes. A man, however, would now pafs for an idiot, who would call it in queftion; efpecially fince the opinion has been confirmed by the experience of navigators, who have actually more than once failed round the globe. But another difficulty here prefents itfelf, the folution of which muft affift us in difcovering the real direction of gravity.

If the circle A B (*plate* II. *fig.* 12.) fay they, reprefents the earth, and we are at A, our antipodes will be diametrically oppofite, at B. As we, then, have the head upward, and the feet downward, our antipodes muft have the feet upward and the head downward, fuppofing thefe words to indicate the fame direction as when we pronounce the fame

words

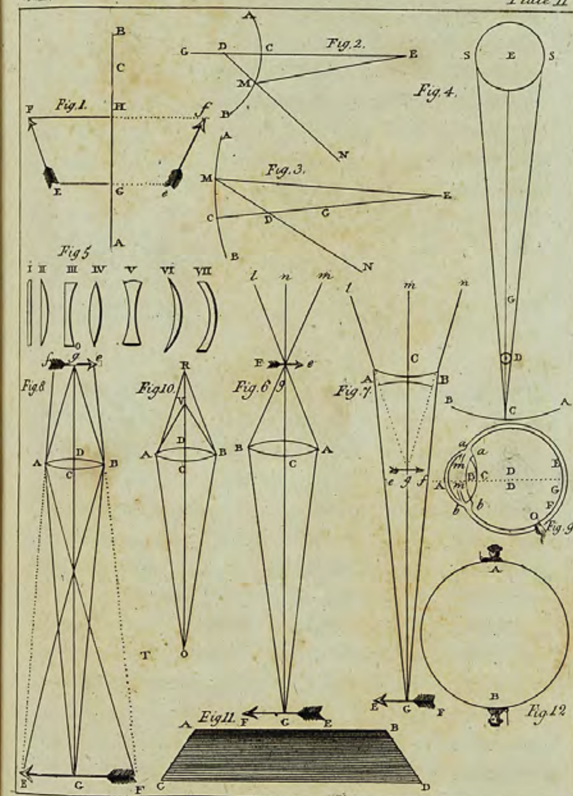
words at the place where we are. For navigators who have made the circuit of the globe, observe, that their head and feet had throughout maintained the same position relatively to the surface of the terrestrial globe.

Some persons whom this phenomenon embarrassed, formerly thought of explaining it, by the comparison of a globe, over the surface of which you see flies and other insects crawl on the under as well as the upper part. But they did not consider that the insects on the dependent surface adhere to it by their claws, and, without this assistance, would presently fall off. The antipode, then, must have his shoes furnished with hooks to hold him fast to the surface of the earth: but though he has none, he falls not any more than we do. Besides, as we imagine ourselves to be on the uppermost surface of the earth, the antipode has the same idea of his situation, and considers us as undermost.

But the whole phenomena are easily accounted for, on the hypothesis which experience has demonstrated, that the direction of gravity is sensibly perpendicular to the surface of the earth, at every point of that surface; that it varies at these different points; and that at those which are antipodes to each other, it must be exactly opposite. The terms *upward* and *downward*, therefore, do not express an invariable direction, but the direction of gravity, wherever it is. Our antipodes have their heads *downward* only with relation to us, but not with relation to themselves; they, as well as we, are in the position which

the

Vol. I. Plate II



the power of gravity conftrains them to preferve; and that pofition is fimilar relatively to the furface of the earth. You had, undoubtedly, no need of this explanation; but there was a time, and it is not long elapfed, when it would have been neceffary even to perfons who were then honoured with the appellation of the learned.

*28th Auguft*, 1760.

## LETTER XLIX.

*True Direction and Action of Gravity relatively to the Earth.*

THOUGH the furface of the earth is unequal, becaufe of the mountains and valleys which overfpread it, it is, however, perfectly level wherever there is fea; the furface of water being always horizontal, and the vertical line, in the direction of which bodies fall, being perpendicular to it. If, then, the whole globe were covered with water, at whatever fpot of the furface a perfon was, the vertical line would be perpendicular to the furface of the water.

Thus, the figure A B C D E F G H I (*plate* III. *fig.* 1.) reprefenting the earth, it's furface being every where horizontal; at A the line *a* A will be vertical; at B the line *b* B; at C the line *c* C; at D the line *d* D; at F the line *f* F; and fo of the reft. Now, at every place the vertical line determines what is to be denominated *upward* or *downward*; to perfons at A, then,

then, the point A is downward, and the point *a* upward: and to persons at F, the point F will be downward, and the point *f* upward, and so for every other spot on the surface of the earth. All these vertical lines *a* A, *b* B, *c* C, *d* D, &c. are likewise named the directions of gravity, or weight, because bodies universally descend in the direction of these lines; thus a body left to itself at *g*, would fall in the direction of the line *g* G. Hence it is evident, that bodies, universally, must fall toward the earth, and that perpendicularly to the surface of the earth, or rather of the water, if it were water.

At whatever place of the earth, therefore, you may happen to be, as bodies fall there toward it's surface, we call *downward* that which is directed toward the earth, or is nearest to it; and *upward* what is placed in the opposite direction, or is farthest from the earth: and, universally, men having their feet pressed to the earth, their feet will be downward, and their heads upward. If the earth were a perfect globe, all the vertical lines *a* A, *b* B, *c* C, being produced inwardly, would meet at the centre of the globe, which is likewise that of the earth; and for this reason we say that bodies universally tend toward the centre of the earth. Thus, wherever you are placed, when asked, what is downward? the answer must be, what approaches nearest to the centre of the earth. In fact, were you to dig a hole in the earth at whatever place, and to continue your labour incessantly, digging always downward and downward perpendicularly, you would at length





reach the centre of the earth. You will remember how *Voltaire* used to laugh at the idea of a hole reaching to the centre of the earth, mentioned by *Maupertuis*. It is true such a project could never be executed, as it would be necessary to dig to the depth of 860 German miles;* but there is no harm in supposing it, in order to discover what would be the result.

Let us suppose, then, such a hole (*plate* III. *fig.* 2.) to be dug at A, and continued beyond the centre of the earth O, the whole length of the diameter, as far as to our antipodes B, and that we were to descend along this aperture. Before arriving at the centre O, and having reached, for example, to point E, the centre of the earth O will there appear downward, and the point A upward; and, unless something supported us, we should fall toward O. But having passed beyond the centre to F, for example, our gravity would then have a tendency toward O; this point, and much more the point A, would appear downward, and the point B upward. Thus the terms upward and downward would suddenly change their signification, though we should have passed from A to B, in the direction of a straight line.

As long as we are on the passage from A to O, we are descending; but in going from O to B, we are actually rising, for we are removing from the centre of the earth; our own gravity being always directed toward that point; so that, if we were to fall, whether from E or from F, we should always fall toward

* 3950 miles English.

the centre of the earth. Our antipode at B, if he wanted to paſs from B to A, would be in preciſely the ſame ſituation. From B to the centre O he would have to deſcend; but from O to A it would be all an aſcent. Theſe conſiderations lead us thus to define gravity or weight. It is a power by which all bodies are forced toward the centre of the earth. The ſame body which, being at A, is forced in the direction A O, if tranſported to B, will be forced, by the power of gravity, in the direction B O, which is directly oppoſite to the other. By the direction of gravity, then, we every where regulate the ſignification of the terms *upward* and *downward*, *riſe* and *deſcend*, as gravity or weight has a very eſſential influence on all our operations and enterpriſes, and as even our own bodies are animated by it to ſuch a degree, as univerſally to feel it's effects.

*29th Auguſt*, 1760.

## LETTER L.

*Different Action of Gravity with reſpect to certain Countries and Diſtances from the Centre of the Earth.*

YOU are now ſenſible that all bodies are forced directly towards the centre of the earth, and perpendicularly to it's ſurface by their gravity: the perpendicular lines at the ſurface of our globe are accordingly conſidered as the directions of the power of gravity.

With



With ſtrict propriety is the term *power* applied to gravity, as every thing capable of putting a body in motion is expreſſed by that name. Thus we aſcribe power to horſes, becauſe they are able to draw along a chariot; or to the current of a river, or to the wind, becauſe by their means mills may be put in motion. There can be no doubt, therefore, that gravity is a power, as it forces bodies downward: and we are abundantly ſenſible of the effect of this power, by the preſſure which we feel when we carry a load.

Now, in every power two things are to be conſidered: firſt, the direction in which it acts, or forces along bodies; and, ſecondly, it's quantity, which is eſtimated by the effect it produces. As to the direction of gravity, it is ſufficiently known, for we are ſure that it forces all bodies toward the centre of the earth, or, which amounts to the ſame thing, that it acts perpendicularly to the ſurface of our globe.

It remains, therefore, that we examine it's quantity. This power is always determined by the weight of every body,* and as bodies differ greatly with reſpect

* In order to form an exact idea of the weight of a body, it muſt be recollected, that gravity impreſſes, or has a tendency to impreſs, on every particle of bodies, in an inſtant, a certain velocity, with which they would fall, if they were not ſupported; and that, abſtracting the influence of the air, this velocity would be the ſame for each of the particles of bodies, whatever be their ſubſtance. This being laid down, we muſt underſtand by the weight of a body the effort neceſſary to prevent it from falling; and it is evident that, in order to this, it is neceſſary to deſtroy the velocity which

fpect to weight, thofe which are heavieft are likewife forced downward with the greateft violence. It has been afked, Whether the fame body, tranfported to a different place of the globe, preferves always the fame weight? I fpeak of bodies which lofe nothing by evaporation. It has been demonftrated, by undoubted experiments, that the fame body weighs fomewhat lefs toward the equator, than toward the poles of the earth.

It will readily occur to you, that it is impoffible to afcertain this difference by the exacteft balance; becaufe the ftandard weights employed for determining the weight of matter in bodies, undergo the

which gravity has impreffed on every particle. This effort muft, therefore, be equal to the fum of the velocities of all thefe particles. Hence it may be eafily concluded, that bodies the moft compact, that is, thofe whofe particles are the clofeft, and which, confequently, contain a greater number of them in the fame bulk, will weigh more than others, becaufe the weight being the fum of the velocities impreffed on each particle, that fum muft be fo much greater, as there are more material particles contained in the mafs of the body.

From what I have juft faid, "we fee the neceffity of carefully "diftinguifhing between the effect of gravity and that of weight: "the former is the power of tranfmitting, or a tendency to tranf- "mit into every particle of matter a certain velocity, which is ab- "folutely independent on the number of material particles; and "the fecond is the effort which muft be exercifed to prevent a "given mafs from obeying the law of gravity. *Weight*, accord- "ingly, *depends on the mafs, but gravity has no dependance at all upon* "*it.*"

I thought myfelf obliged to enter thus minutely into the fubject, as the notions commonly entertained of it are not very exact. —*F. E.*

fame



fame variation. Thus a mafs, which with us might weigh 100 pounds, being tranfported to the equator, would ftill nominally be 100 pounds weight, but the effort will be fomewhat lefs than here. This variation has been difcovered by the effect itfelf of the power of gravity, which is the velocity of the defcent, for it is found that the fame body, under the equator, does not defcend with fo great velocity as in high latitudes. It is certain, therefore, that the fame body, being tranfported to different places of the earth, undergoes a little change as to weight.

Let us now return to the aperture made in the earth through it's centre; it is clear, that a body at the very centre muft entirely lofe it's gravity, as it could no longer move in any direction whatever, all thofe of gravity tending continually toward the centre of the earth. Since, then, a body has no longer gravity at the centre of the earth, it will follow that, in defcending to this centre, it's gravity will be gradually diminifhed; and we accordingly conclude, that a body, penetrating into the bowels of the earth, lofes it's gravity, in proportion as it approaches the centre. You muft be fenfible, then, that neither the intenfity nor the direction of gravity is a confequence from the nature of every body, as not only it's intenfity is variable, but likewife it's direction, which, on paffing to the antipodes, becomes quite contrary.

Having travelled, in idea, to the centre of the earth, let us return to it's furface, and afcend to the fummit of the loftieft mountains. We fhall obferve

 there

there no ſenſible change in the gravity of bodies, though there is very good reaſon to believe that the weight of a body diminiſhes in proportion as it removes from the earth. You have but to imagine a body gradually removing from our globe, till it reached the ſun, or one of the fixed ſtars, it would be ridiculous to think that ſuch a body muſt fall back to the earth, as it is almoſt a nothing compared to theſe ſtars. Hence, then, it may be concluded, that a body in removing from the earth muſt undergo a diminution of gravity, which will become ſmaller and ſmaller, till at laſt it wholly diſappear.

There are reaſons, however, which demonſtrate, that a body removed to the diſtance of the moon, will ſtill have ſome weight, though 3600 times leſs than it had on the earth. Let us conceive ſuch a body to weigh 3600 pounds on the earth, no one, ſurely, is capable of ſupporting it here; but convey it to the diſtance of the moon, and I ſhall engage to ſupport it with one of my fingers, for then it will weigh only one pound; and farther removéd, would weigh ſtill leſs. We are certain, therefore, that gravity is a power which forces all bodies toward the centre of the earth, that this power acts with the greateſt force at the ſurface of the earth, and is diminiſhed in proportion as it removes from thence, whether by penetrating toward the centre, or riſing above the ſurface of the globe. I have ſtill much to ſay on this ſubject.

*30th Auguſt*, 1760.

LETTER



## LETTER LI.

### *Gravity of the Moon.*

I HAVE ſaid that a terreſtrial body, placed at the diſtance of the moon, would be reduced to the 3600th part of it's weight, or, in other words, would be forced toward the centre of the earth with a power 3600 times leſs than it has at the ſurface of the globe. This power, however, would be ſufficient to make it deſcend to the earth, if it were no longer ſupported. It is true we are incapable of proving this by any experiment, as no means exiſt of raiſing ourſelves to ſuch a height. There is, however, a body at that height, the moon: ſhe muſt, therefore, be ſubject to this effect of gravity, and yet we ſee ſhe does not fall to the earth.

To this I anſwer, that if the moon were at reſt, ſhe would certainly fall, but the rapid motion which carries her along prevents her falling. There are experiments which prove the ſolidity of this anſwer. A ſtone dropped from the hand, without having any motion impreſſed upon it, falls immediately, in the direction of a ſtraight vertical line; but if you throw this ſtone, impreſſing on it a motion which forces it out of that direction, it does not fall immediately downward, but moves in a curve line before it reaches the earth, and this will appear more ſenſibly in proportion to the velocity impreſſed upon it.

A cannon ball, diſcharged in a horizontal direc-



tion,

tion, does not come to the earth till it has got to a confiderable diftance; and were it fired from the top of a high mountain, it might, perhaps, fly feveral miles before it reached the ground. If the direction of the cannon is farther elevated, and the quantity and ftrength of the powder increafed, the ball will be carried much farther. This might be carried fo far, that the ball fhould not light till it had reached the antipodes: nay, farther ftill, till it fhould not fall at all, but return to the place where it was fhot off, and thus perform a new tour round the globe. It would thus be a little moon, making it's revolutions round the earth like the real moon.

You will now pleafe to reflect on the height of the moon, and the prodigious velocity with which fhe moves, and you will no longer be furprifed that fhe fhould not fall to the earth, though forced by gravity toward it's centre. There is another reflection which will place this in a clearer light. We have only to confider the path defcribed by a ftone thrown, or a cannon ball fhot off, in an oblique direction. It is always a curve, fuch as reprefented in the annexed figure (*plate* III. *fig.* 3).

Let A be the fummit of a mountain from which the cannon ball is fired off, which, after having moved in the direction A E F B, falls to the ground at B; and the path which it defcribes is a curve line. I remark, then, that if the ball were not heavy, that is, if it were not forced toward the earth by the power of gravity, it would not fall, though left to itfelf, as gravity is the only caufe of it's defcent; much



much lefs, being fired off at A, as reprefented in the figure, would it ever fall to the ground. Hence we fee, it is gravity that brings it down to the ground, after having defcribed the curve A E F B; gravity, therefore, directs it's path in the curve A E F B; and if it were deftitute of gravity, the ball would not defcribe a curve, but proceed forward in the direction of the ftraight line A C, the direction in which it was fired off.

This being laid down, let us attend to the moon, which affuredly does not move in a ftraight line; her path muft of neceffity be a curve, as fhe always preferves nearly the fame diftance from us, and that curve almoft a circle, fuch as you would defcribe round the earth, with a radius equal to the moon's diftance.

It is very reafonable to demand, Why the moon does not move in a ftraight line? But the anfwer is obvious; for as gravity occafions the curve direction of the path purfued by a ftone thrown, or a cannon ball fired off, there is good ground for maintaining, that gravity acts likewife upon the moon, forcing her toward the earth; and that this gravity occafions alfo the curve direction of her orbit. The moon, then, has a certain weight, fhe is, of confequence, forced toward the earth; but this weight is 3600 times lefs than it would be at the furface of the earth. This is not merely a probable conjecture, but a truth demonftrated. For this gravity being fuppofed, we are enable to determine, on the moft eftablifhed mathematical

thematical principles, the path which the moon muſt purſue; and this is found perfectly to agree with that in which ſhe actually does move; and this is a complete demonſtration of the truth of the aſſertion.

*1ſt September*, 1760.

## LETTER LII.

### *Diſcovery of univerſal Gravitation by* Newton.

GRAVITY, then, or weight, is a property of all terreſtrial bodies, and it extends, likewiſe, to the moon. It is in virtue of gravity that the moon preſſes toward the earth; and gravity regulates her motion juſt as it directs that of a ſtone thrown, or of a cannon ball fired off.

To *Newton* we are indebted for this important diſcovery. This great Engliſh philoſopher and geometrician, happening one day to be lying under an apple-tree, an apple fell upon his head, and ſuggeſted to him a multitude of reflections. He readily conceived that gravity was the cauſe of the apple's falling, by overcoming the force which attached it to the branch. Any perſon whatever might have made the ſame reflection; but the Engliſh philoſopher purſued it much farther. Would this force have always acted upon the apple, had the tree been a great deal higher? He could entertain no doubt of it.

But had the height been equal to that of the moon? Here



Here he found himſelf at a loſs to determine whether the apple would fall or not. In caſe it ſhould fall, which appeared to him, however, highly probable, ſince it is impoſſible to conceive a bound to the height of the tree, at which it would ceaſe to fall, it muſt ſtill have a certain degree of gravity forcing it toward the earth; therefore, if the moon were at the ſame place, ſhe muſt be preſſed toward the earth by a power ſimilar to that which would act upon the apple. Nevertheleſs as the moon did not fall on his head, he conjectured that motion might be the cauſe of this, juſt as a bomb frequently flies over us, without falling vertically.

This compariſon of the motion of the moon to that of a bomb, determined him attentively to examine this queſtion; and, aided by the moſt ſublime geometry, he diſcovered, that the moon in her motion was ſubject to the ſame laws which regulate that of a bomb, and that if it were poſſible to hurl a bomb to the height of the moon, and with the ſame velocity, the bomb would have the ſame motion as the moon, with this difference only, that the gravity of the bomb at ſuch a diſtance from the earth, would be much leſs than at it's ſurface.

You will ſee, from this detail, that the firſt reaſonings of the philoſopher on this ſubject were very ſimple, and ſcarcely differed from thoſe of the clown; but he ſoon puſhed them far beyond the level of the clown. It is, then, a very remarkable property of the earth, that not only all bodies near it, but thoſe alſo which are remote, even as far as to the diſtance of of the moon, have a tendency toward the centre of the earth, in virtue of a power which is called gravity, and which diminiſhes in proportion as bodies remove from the earth.

The Engliſh philoſopher did not ſtop here. As he knew that the other planets are perfectly ſimilar to the earth, he concluded, that bodies adjacent to each planet poſſeſs gravity, and that the direction of this gravity is toward the centre of ſuch planet. This gravity might be greater or leſs there than on the earth; in other words, that a body of a certain weight with us, tranſported to the ſurface of any planet, might there weigh more or leſs.

Finally, this power of gravity of each planet extends, likewiſe, to great diſtances around them; and as we ſee that Jupiter has four ſatellites, and Saturn five, which move round them juſt as the moon does round the earth, it could not be doubted, that the motion of the ſatellites of Jupiter was regulated by their gravity toward the centre of that planet; and that of the ſatellites of Saturn by their gravitation toward the centre of Saturn. Thus, in the ſame manner as the moon moves round the earth, and their reſpective ſatellites move round Jupiter and Saturn, all the planets themſelves move round the ſun. Hence *Newton* drew this illuſtrious and important concluſion: That the ſun is endowed with a ſimilar property of attracting all bodies toward it's centre, by a power which may be called *ſolar gravity*.

This power extends to a prodigious diſtance around him, and far beyond all the planets, for it is this





power which modifies all their motions. The ſame great philoſopher diſcovered the means of determining the motion of bodies from the knowledge of the power by which they are attracted to a centre; and as he had diſcovered the powers which act upon the planets, he was enabled to give an accurate deſcription of their motion. In truth, before he aroſe, the world was in a ſtate of profound ignorance reſpecting the motion of the heavenly bodies; and to him alone we are indebted for all the light which we now enjoy in the ſcience of aſtronomy.

It is aſtoniſhing to think how much of their progreſs all the ſciences owe to an original idea ſo very ſimple. Had not *Newton* accidentally been lying in an orchard, and had not that apple by chance fallen on his head, we might, perhaps, ſtill have been in the ſame ſtate of ignorance reſpecting the motions of the heavenly bodies, and a multitude of other phenomena depending upon them.* This ſubject, undoubtedly, is altogether worthy of your attention, and ſhall therefore be reſumed in a future letter.

*3d September*, 1760.

* *Newton* was aſked one day, How he had diſcovered the ſyſtem of the univerſe? *By continually thinking upon it*, replied he. This anecdote has a greater air of probability than the ſtory of the apple.—*F. E.*

## LETTER LIII.

*Continuation. Of the mutual Attraction of the heavenly Bodies.*

THE Newtonian ſyſtem, you will eaſily believe, made at firſt a great noiſe, and with good reaſon, as no one had hitherto hit upon a diſcovery ſo very fortunate, and which diffuſed, at once, ſuch clear light over every branch of ſcience. It has been expreſſed by ſeveral names, of which it is proper you ſhould be informed, becauſe it is frequently the ſubject of converſation.

It has been denominated, the ſyſtem of univerſal gravitation; for *Newton* maintained, that not only the earth, but all the heavenly bodies, in general, are endowed with this property, of attracting thoſe which ſurround them, with a power ſimilar to that of weight, or gravity: hence is derived the term *Gravitation*. This power is, however, totally inviſible; for we ſee nothing acting upon bodies, and preſſing them toward the earth, and ſtill leſs toward the heavenly bodies.

The loadſtone, by which iron and ſteel are attracted, without our being able to diſcern the cauſe, preſents a phenomenon ſomewhat ſimilar. Though it be now certain, that this is produced by a ſubſtance extremely ſubtile, which penetrates through the pores of the loadſtone and of the iron, it may, however, be affirmed, that the loadſtone attracts iron, and that iron



iron is attracted by it, provided this manner of ſpeaking does not exclude the true cauſe. It may likewiſe be affirmed, then, that the earth attracts all bodies that are near it, nay thoſe which are at very great diſtances; and we may conſider the weight, or gravity, of bodies, as the effect of the attraction of the earth, which acts even upon the moon.*

Again, the ſun, and all the planets, are endowed with a ſimilar power of attraction, which extends to all bodies. In conformity to this manner of ſpeaking, we ſay, that the ſun attracts the planets, and that Jupiter and Saturn attract their reſpective ſatellites; hence *Newton*'s ſyſtem has likewiſe been denominated, the ſyſtem of *Attraction*. As there can be no doubt that bodies very near the moon muſt likewiſe be preſſed to it by a power ſimilar to gravity, it may likewiſe be affirmed, that the moon, too, attracts adjoining bodies.

It was natural to ſuppoſe, that this attraction of the moon ſhould extend as far as the earth, though it muſt be, undoubtedly, very feeble, as we have ſeen that

* So far is the exiſtence of a magnetic fluid from being undeniable, that it is highly improbable, if not abſurd. The various phenomena of magnetiſm may clearly be derived from two laws, or general facts; than which a greater ſimplicity can hardly be expected. If we recur to the agency of a fluid, we muſt gratuitouſly beſtow on it a number of properties; and, after all, we ſhall find it extremely difficult, I might ſay, impoſſible, to preſerve conſiſtency in our complicated hypotheſis; nor ſhall we ever be able, from our aſſumptive principles, to account for the facts obſerved. Such, at leaſt, has been the fate of the ſpeculations hitherto offered on the ſubject of magnetiſm.—*E. E.*

that of the earth upon the moon to be; now, the fame philofopher has placed this, alfo, beyond the reach of doubt, by demonftrating that the flux and reflux of the waters of the fea, of which I fhall take occafion to fpeak afterwards, are caufed by the attraction of the moon. It can no longer be doubted, therefore, that Jupiter and Saturn are reciprocally attracted by their refpective fatellites; and that the fun itfelf is fubject to the attraction of the planets, though this attractive power be exceedingly fmall.

This is the origin of the fyftem of univerfal attraction, in which it is maintained, and with good reafon, that not only does the fun attract the planets, but is reciprocally attracted by each of them; nay, that all the planets exert their attractive power upon each other. The earth, then, is attracted, not only by the fun, but alfo by all the other planets, though their power be almoft imperceptible, compared to that of the fun.

You will eafily comprehend, that the motion of a planet, which is attracted not only by the fun, but by the other planets, in however fmall a degree, muft be fomewhat different from what it would have been, were it attracted by the fun only; and that, confequently, the attractions of the other planets muft caufe fome fmall derangement of that motion. Now thefe derangements are, likewife, confirmed by experience; and this has carried the fyftem of univerfal attraction to the higheft poffible degree of certainty, fo that no one now prefumes to difpute it's truth.

I muft,



I muft likewife remark, that comets, too, are fubject to this law; that they are principally attracted by the fun, whofe action regulates their motion; but that they, likewife, feel the attractive power of all the planets, efpecially when they are not very diftant from them. It is a general rule, as we fhall fee afterwards, that the attraction of all the heavenly bodies diminifhes in proportion to the diftance, and increafes in proportion to the nearnefs. Now, comets, likewife, are endowed with a power, by which other bodies are attracted toward them, and fo much the more fenfibly, as they approach nearer. When, therefore, a comet paffes fomewhat more clofely to a planet, it may derange the motion of that planet by it's attractive power; and it's own will likewife be difturbed by that of the planet. Thefe confequences are verified by real obfervation.

Examples might be adduced to prove, that the motion of a comet has been deranged by the attraction of the planets, near which it happened to pafs,*

* The comet of 1682, which fhould have re-appeared in 1757, underwent, from the attractive powers of Jupiter and Saturn, near which it paffed, a confiderable derangement, which retarded it's appearance nearly two years. Mr. *Clairaut* calculated, theoretically, the perturbations which it's motion muft have fuffered, and predicted the return of that comet, with a degree of exactnefs, which conftitutes a convincing proof in favour of the fyftem of gravitation. There was, however, an error of two months. But Mr. *de la Place* has fince demonftrated, that it would have been much lefs, had we then been able to calculate the perturbations of Jupiter and Saturn, with as much exactnefs as it now can be done.—*F. E.*



and

and that the motion of the earth, and of the other planets, has already undergone ſome derangement, from the attraction of comets.

The fixed ſtars being bodies ſimilar to the ſun, are likewiſe endowed, no doubt, with an attractive power, but their enormous diſtance prevents our feeling any ſenſible effect from it.

*5th Sept.* 1760.

## LETTER LIV.

*Different Sentiments of Philoſophers, reſpecting univerſal Gravitation. The Attractioniſts.*

IT is eſtabliſhed, then, by reaſons which cannot be controverted, that an univerſal gravitation pervades all the heavenly bodies, by which they are attracted toward each other; and that this power is greater in proportion to their proximity.

This fact is inconteſtable, but it has been made a queſtion, Whether we ought to give it the name of *impulſion*, or *attraction?* The name, undoubtedly, is a matter of indifference, as the effect is the ſame. The aſtronomer, accordingly, attentive only to the effect of this power, gives himſelf little trouble to determine, whether the heavenly bodies are impelled toward each other, or whether they mutually attract one another: and the perſon, who examines the phenomena only, is unconcerned, whether the earth attracts



tracts bodies, or whether they are impelled toward it, by ſome inviſible cauſe.

But, in attempting to dive into the myſteries of nature, it is of importance to know, if the heavenly bodies act upon each other by impulſion, or by attraction; if a certain ſubtile inviſible matter impels them toward each other, or if they are endowed with a ſecret, or occult, quality, by which they are mutually attracted? On this queſtion philoſophers are divided. Some are of opinion, that this phenomenon is analogous to an impulſion; others maintain, with *Newton*, and the Engliſh in general, that it conſiſts in attraction.

It muſt be obſerved, that the terms *attract*, and *draw*, are not perfectly ſynonymous; that, accordingly, it is not to be ſuppoſed, there is an intermediate body between the ſun and the earth.

The Engliſh, and thoſe who have adopted the ſame opinion, explain it in this manner. They maintain, that the quality of mutual attraction is proper to all bodies; that it is as natural to them as magnitude, and that it is a ſatisfying ſolution of the queſtion, That the Creator willed this mutual attraction of bodies. Had there been but two bodies in the univerſe, however remote from each other, they would have had, from the firſt, a tendency toward each other, by means of which they would have, in time, approached and united. Hence it follows, that the greater a body is, the more conſiderable is the attraction which it exerts upon others; for, as this quality

quality is essential to matter, the more of it any body contains, the greater is it's attractive force.

As the sun, therefore, considerably surpasses all the planets in magnitude, it's attractive force must be much greater than theirs. They likewise remark, that the mass of Jupiter, being much greater than that of the earth, the attractive force which he exercises over his satellites, is much more powerful than that with which the earth acts upon the moon.

According to this system, the gravity of bodies on the earth, is the result of all the attractions exercised upon them by the particles of our globe; and if it contained more matter than it actually does, it's attraction would become more powerful, and the gravity of bodies would be increased. But if, on the contrary, the mass of the earth should happen, by some accident, to be diminished, it's attractive force, too, would be diminished, as well as the gravity of bodies, at it's surface.

It has been objected to these philosophers, that, on their hypothesis, any two bodies, whatever, at rest, for instance, on a table, must attract each other, and, consequently, approach. They admit the consequence, but they insist, that, in this case, the attraction would be too small to produce any sensible effect; for, if the whole mass of the earth, by it's attractive force, produces in every body, only that effect which we perceive in the weight of a body, a mass many millions of times smaller than the earth, will produce an effect as many times smaller.





It must readily be admitted, that if the weight of a body became many millions of times less, the effect of gravity upon it must be reduced to almost nothing: attraction, therefore, cannot be perceptible, except in bodies of very great magnitude. The partizans of the system of gravitation, therefore, are not vulnerable on this side, and they produce, in support of their opinion, an experiment made in Peru, by the French academicians,* in which they perceived the effect of a slight attraction of a prodigious mountain on adjacent bodies. In adopting, therefore, the system of attraction, we need to be under no apprehension of it's leading us to false consequences; and it has hitherto been always confirmed by the new facts which have been discovered.

*7th September*, 1760.

## LETTER LV.

*Power by which the Heavenly Bodies are mutually attracted.*

YOU are well acquainted with the property of the loadstone, that of attracting iron. You have seen small bits of iron and steel, such as needles, when

* The academicians sent to Peru, in 1735, to measure a degree of the meridian, observed a deviation of 8" in the plumb-line of their quadrant, occasioned by the attraction of *Pichencha*, a mountain near the place where they were making their observations. Dr. *Maskelyne* has more recently made observations for ascertaining the effect of the attraction of the mountains of Scotland.—*F. E.*

placed near the loadſtone, move to it with a force proportioned to their proximity. As you ſee nothing that impels them toward the loadſtone, we ſay that the loadſtone attracts them, and this phenomenon we call *attraction*. It cannot be doubted, however, that there is a very ſubtile, though inviſible, matter, which produces this effect, by actually impelling the iron toward the loadſtone; but as modes of expreſſion are regulated by appearances, it has become cuſtomary to ſay, that the loadſtone attracts iron.

Though this phenomenon be peculiar to the loadſtone and iron, it is perfectly adapted to convey an idea of the ſignification of the word attraction, which philoſophers ſo frequently employ. They allege, then, that all bodies, in general, are endowed with a property ſimilar to that of the loadſtone, and that they all mutually attract; but that this effect becomes not perceptible, unleſs they are very great, and cannot be perceived when they are ſmall.

However great, for example, a ſtone may be, it exerciſes no ſenſible attraction on other bodies adjacent to it, becauſe it's power is too ſmall. But if it's maſs were to increaſe, and to become many thouſands of times greater, it's effect would, at length, become perceptible. It has already been remarked, that, from actual obſervation, it was found, that a lofty mountain in Peru had produced attraction, though, indeed, in a very ſmall degree. A mountain ſtill greater, would produce, therefore, a more ſenſible attraction; and a body much greater, ſuch





as the whole globe, would attract others with a force proportionably greater; and this force would be, preciſely, the gravity with which we ſee that they are actually impelled toward the earth.

According to this ſyſtem, then, the gravity which obliges all bodies to deſcend, is nothing elſe but the reſult of the attraction of the whole maſs of the earth. If this maſs were greater, or leſs, the gravity, or weight, of bodies would be proportionably greater or leſs. Hence it follows, that all the other great bodies in the univerſe, as the ſun, the planets, and the moon, are endowed with a ſimilar attractive power, but greater or leſs, in proportion as they themſelves are ſo.

As the ſun is many thouſands of times greater than the earth, his attractive power exceeds that of the earth, ſo many thouſand times. The maſs of the moon is calculated to be forty times leſs than that of the earth: it will follow, that her attractive force is ſo many times leſs; and the ſame rule applies to all the heavenly bodies.

*9th September*, 1760.

## LETTER LVI.

*The ſame Subject continued.*

IN virtue of the ſyſtem of attraction, or univerſal gravitation, each of the heavenly bodies attracts all the reſt, and is reciprocally attracted by them.

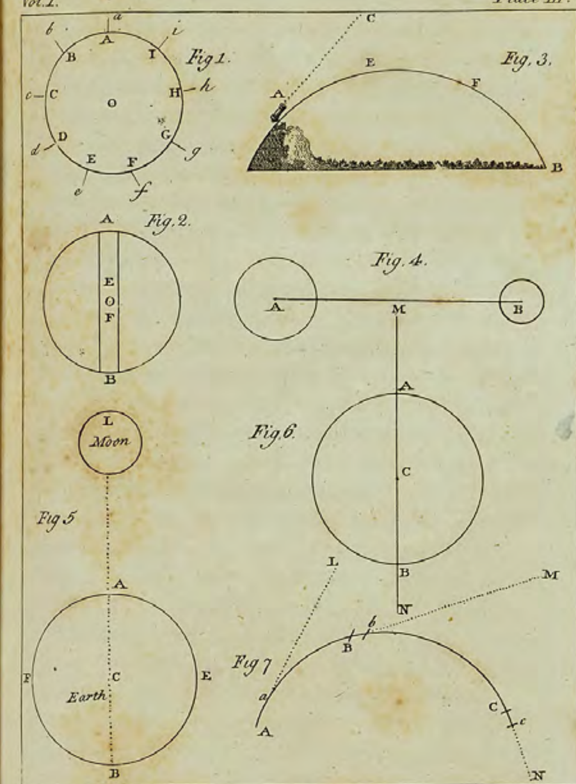
In order to form a judgment of the force with which theſe bodies attract the others, we have only to conſider two bodies, whoſe attraction is mutual. And here we muſt attend to three things; firſt, to the body attracting; ſecondly, to the body attracted; and, finally, to their diſtance; for on theſe three circumſtances the attractive power depends.

Let A (*plate* III. *fig.* 4,) be the attracting body, and B the body attracted; both of them ſpherical, the heavenly bodies being nearly of this figure. Take for their diſtance that of their centres A and B, that is, the ſtraight line A B. Now, with reſpect to the maſs of the attracting body A, it muſt be remarked, that the greater it is, the greater alſo will be it's power to attract the body B. Conſequently, if A were twice as great as B, this laſt would feel an attraction, twice as powerful, exerciſed over it, by the other; if it were three times as great, the effect would be triple, and ſo on, always ſuppoſing the diſtance of their centres to be the ſame.

If, then, the earth contained more or leſs matter than it actually does, it would attract all adjacent bodies, with greater or leſs force, or their weight would be increaſed or diminiſhed. And, as the earth itſelf is attracted by the ſun, the ſame thing might be affirmed as to it, ſhould the maſs of that luminary happen to change. As to the attracted body B, ſuppoſing the attracting body A, and the diſtance A B, to continue the ſame, it is to be remarked, that the greater or ſmaller it's maſs is, the greater or leſs, alſo, is the power with which it is attracted to-

ward

*Vol. I.* *Plate III.*



ward A. Thus, if the body B were twice as great, it would be attracted toward A, with double the force; if three times greater, with triple the force, and fo on.

In order more clearly to elucidate this remark, we have only to fubftitute the earth in the place of the attracting body A; then the force with which the body B is attracted, is nothing elfe but the weight of that body. Now, it is demonftrated, that the greater or fmaller the body B is, the greater or lefs, alfo, is it's gravity; hence it follows, that while the attracting body A, and the diftance, A B continue the fame, the attraction which B feels, precifely follows the magnitude of that body. To exprefs this circumftance, mathematicians employ the term *proportional*; thus they fay, The body B is attracted by the body A, with a force proportional to it's mafs; the meaning of which is, that if the mafs of body B were twice, thrice, or four times greater, the attractive power would be precifely fo many times increafed. Thus, with refpect to the attracting body A, they fay, that the power which it exercifes over the body B, is proportional to it's mafs, fo long as that of B, and the diftance A B continue the fame.

I muft farther obferve, that when we fpeak of the quantity of the attracting body A, or of the attracted body B, we mean the quantity of matter which each contains, and not their magnitude merely. You will recollect, that bodies differ confiderably, in this refpect, and that there are fome, which, in a very fmall compafs, contain a great deal of matter, gold, for example,

example, while others, ſuch as air, contain very little in a great ſpace. When, therefore, we here ſpeak of bodies, we are always to be underſtood as referring to the quantity of matter which they contain: this is what we mean by their maſs.

All that now remains is, to examine the third circumſtance, namely, the diſtance A B of the two bodies, ſuppoſing them to continue always the ſame. It muſt be obſerved, that as the diſtance A B increaſes, the attraction diminiſhes: and that as they approach nearer, it increaſes: but in conformity to a law, which it is not ſo eaſy to expreſs. When the diſtance becomes twice as great, the force with which the body B is attracted toward the body A, will be twice two, or four times leſs; and for triple the diſtance, the attraction becomes three times three, that is nine times leſs. If the diſtance becomes four times greater, the power of attraction becomes four times four, that is ſixteen times leſs, and ſo on. Finally, for a diſtance a hundred times greater, the power of attraction will be a hundred times a hundred, or ten thouſand times leſs. From this it follows, that at very great diſtances, it muſt become altogether imperceptible. And reciprocally, when the diſtance A B is very ſmall, the attraction may be very conſiderable, though the bodies may be of no great magnitude.

*11th September*, 1760.

LETTER



## LETTER LVII.

*The ſame Subject continued.*

I HAVE now demonſtrated, that when a body B is attracted by a body A, the power of attraction is proportional to the maſs of the attracting body A, and to that of the attracted body B; but it depends, to ſuch a degree, on the diſtance of theſe bodies, that if it ſhould become twice, thrice, four or five times greater, the power of attraction would become four, nine, ſixteen, or twenty-five times leſs.

In order to aſcertain the rule of theſe quantities, we muſt multiply, into itſelf, the number which marks how many times the diſtance is increaſed, and the product will ſhew how many times leſs the power of attraction has become. To put this rule in it's cleareſt light, it muſt be obſerved, that when we multiply a number into itſelf, the product, reſulting from it, is called it's *ſquare*. Thus, to find theſe ſquares, we muſt multiply the numbers by themſelves, as below.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Multiplied by | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Square | 1 | 4 | 9 | 16 | 25 | 36 | 49 | 64 | 81 | 100 |

| | | | |
|---|---|---|---|
| | 11 | | 12 |
| Multiplied by | 11 | Multiplied by | 12 |
| | 11 | | 24 |
| | 11 | | 12 |
| Square | 121 | Square | 144 |

It

It is clear, from this laſt example, that the ſquare of number 12 is 144; and if you wiſh to know the ſquare of any number whatever, ſay 258, you muſt multiply that number by itſelf, as in the following ſeparation:

$$\begin{array}{r} 258 \\ 258 \\ \hline 2064 \\ 1290\phantom{0} \\ 516\phantom{00} \\ \hline 66564 \end{array}$$

From which we ſee, that the ſquare of 258 is 66564; and the ſquares, of all numbers whatever, may be calculated in like manner.

As the diſtance of bodies, then, muſt be multiplied by itſelf, it is evident, that the power of attraction diminiſhes, as much as the ſquare of the diſtance increaſes: or, that the ſquare of the diſtance becomes as many times greater, as the power of attraction is diminiſhed.

In treating ſubjects of this nature, mathematicians employ expreſſions, whoſe ſignification it is proper you ſhould know, becauſe they ſometimes occur in the courſe of converſation. If the attractive power increaſed in proportion to the ſquare of the diſtance, we would call it *proportionally* to the ſquare of the diſtance; but as the direct contrary takes place, and as the attractive power diminiſhes as the ſquare of the diſtance increaſes, we employ the term *recipro-*

*cally*,



*cally*, to expreſs this contrariety, ſaying, that the power is reciprocally proportional to the ſquare of the diſtance.* It is a geometrical mode of expreſſion, the meaning of which you perfectly comprehend, and it refers to what I have juſt been attempting to explain.

In order to judge aright of the power which one body exerciſes over another, you have only to remark, that this power is, firſt of all, proportional to the maſs of the attracting body: then, to that of the body attracted; and finally, reciprocally to the ſquare of their diſtance. Hence, it is evident, that though the earth, and the other planets, are likewiſe attracted toward the fixed ſtars, this power muſt be imperceptible, on account of their prodigious diſtance.

Suppoſing, therefore, the maſs of a fixed ſtar to be equal to that of the ſun, at equal diſtances, the earth would be attracted toward it, with a force as great as toward the ſun; but as the diſtance of the fixed ſtar is 400,000 times greater than that of the ſun, the ſquare of this number being 160,000,000,000, that is, a hundred and ſixty thouſand millions, the power with which it acts upon our globe, is a hundred and ſixty thouſand millions of times leſs than that of the ſun; and, conſequently, too feeble to produce any perceptible effect. For this reaſon, the attractive power of the fixed ſtars does not at all affect the earth's motion, nor that of the planets and the

* It is more cuſtomary to ſay, that attraction is in the direct ratio of the maſſes of the attracting and attracted bodies; and in the inverſe ratio of the ſquare of their diſtance.—*F. E.*

moon;

moon; but it is that of the ſun which chiefly regulates their motions, becauſe his maſs exceeds many thouſands of times the maſs of each planet.

When, however, two planets approach, ſo that their diſtance becomes leſs than that of the ſun, their attractive power increaſes, and may become ſufficiently perceptible to derange their motion. Such derangement has, in fact, been obſerved; and conſtitutes an irreſiſtible proof of the ſyſtem of univerſal gravitation. Accordingly, when a comet approaches very near to a planet, the motion of this laſt may be conſiderably affected by it.

*13th September*, 1760.

## LETTER LVIII.

*Motion of the heavenly Bodies. Method of determining it by the Laws of univerſal Gravitation.*

FROM what has been ſaid, reſpecting the power by which all the heavenly bodies mutually attract each other, proportionally to their maſs and diſtance, you are enabled to comprehend, how their motions may be determined, and the real place of each body, at any given time, accurately aſſigned.

In this aſtronomy conſiſts; the object of which is an exact knowledge of the motions of the heavenly bodies, in order to be able to determine, for every inſtant of time, whether paſt or to come, the place in which each of them muſt be, and in what place of the heavens it muſt appear, whether viewed from the earth, or any other point whatever of the univerſe.



The ſcience which treats of motion in general, is named *mechanics*, or *dynamics*. It's object is to determine the motion of all bodies whatever, animated by whatever power. This ſcience conſtitutes one of the principal branches of mathematics; and thoſe who apply to it, exert all their efforts to carry mechanics to the higheſt poſſible degree of perfection. The ſubjects about which this ſcience is converſant, are, however, ſo intricate, that there is hitherto no great ground of boaſting of our progreſs in the inveſtigation of them; and we muſt reſt ſatisfied with advancing ſtep by ſtep. Not many years are elapſed ſince we began to make any progreſs at all in this career, and what has been done is chiefly to be aſcribed to the academy of ſciences at Paris, which propoſes annual prizes to the beſt proficients in the proſecution of this ſcience.

The greateſt difficulty ariſes from the number of powers which act upon the heavenly bodies. If each of theſe were attracted toward only one ſingle point, there would be very little difficulty in the way; and the great *Newton*, who died in 1728, was the firſt who gave a complete demonſtration of the motion of two bodies which have a mutual attraction, in conformity to the law which I have laid down. In virtue of this law, were the earth attracted toward the ſun only, we ſhould be able perfectly, without reſearch, to determine it's motion. The ſame thing would apply to the other planets, Saturn, Jupiter, Mars,

Mars, Venus, and Mercury, if they were attracted only by the ſun. But the earth being attracted, not only by him, but by all the other heavenly bodies, the queſtion becomes infinitely more complex and difficult, from the great diverſity of powers to which we muſt pay attention.* You may neglect, however, the powers with which it is attracted toward the fixed ſtars, becauſe, however enormous their maſſes may be, they are ſo prodigiouſly diſtant, that the power which they exerciſe upon the earth, may be conſidered as juſt nothing.

The motion of the earth, therefore, and of the other planets, will always be as perfectly the ſame, as if the fixed ſtars did not exiſt. Excepting, then, the power of the ſun, we have only to conſider the power with which the planets mutually attract each other. Now, theſe powers are extremely ſmall, compared to thoſe by which each planet is attracted toward the ſun, becauſe the maſs of the ſun is much greater than that of each planet.

As, however, theſe powers increaſe according as the diſtances diminiſh, ſo that a power four times greater correſponds to a diſtance twice leſs; and a

* They are uſually combined by three and three; that is, the effect reſulting from the attraction of two bodies upon a third is ſought. This celebrated problem, known by the name of the problem of three bodies, has been an object of the reſearches of all the great geometricians of our age; and though it has hitherto been reſolved only by an approximation to the truth, the moſt fortunate applications have, however, been made, ſuch as the theory of the moon, that of Jupiter, of Saturn, &c.—*F. E.*





power nine times leſs correſponds to a diſtance three times greater, and ſo on, according to the ſquares of the numbers, as I explained the ſubject in the preceding letter, it might be poſſible for two planets to approach ſo near, that their attractive power ſhould become equal to that of the ſun, nay, greatly exceed it.

Fortunately, this never takes place in our ſyſtem, and the planets always remain at ſuch a diſtance from each other, that their attractive power is ever incomparably ſmaller than that of the ſun. For this reaſon, without extending our views beyond what is thus certainly known, we may conſider every planet as attracted only by the power of the ſun, and by that it is eaſy to determine it's motion. This, however, can take place, only when we are diſpoſed to reſt ſatisfied with a reſult near the truth; for if we wiſh to have more exact information, we muſt attend to thoſe feebler powers with which the planets act upon each other; powers which really produce the little irregularities clearly obſerved by aſtronomers; and to the attainment of the perfect knowledge of theſe, is directed all the ſagacity of both aſtronomers and geometricians.

*15th September*, 1760.

## LETTER LIX.

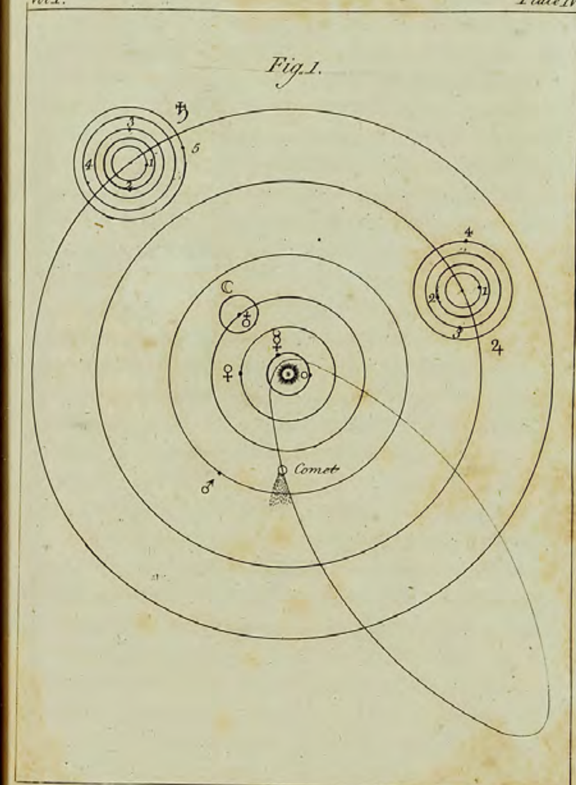
*Syſtem of the Univerſe.*

IN order the more clearly to elucidate what I have been advancing, reſpecting the motion of the heavenly bodies, and the powers which produce it, permit me to preſent to you, (*plate* IV. *fig.* 1.) the ſyſtem of the univerſe, or a deſcription of the heavenly bodies which compoſe it.

We muſt, firſt of all, obſerve, that the fixed ſtars are bodies entirely ſimilar to the ſun, and luminous of themſelves; that they are at a very great diſtance from that luminary; and alſo very diſtant from each other, and that every one of them is, perhaps, of equal magnitude with the ſun. You are already informed, that the fixed ſtar neareſt to us, is at leaſt 400,000 times more diſtant than the ſun. Each of the fixed ſtars ſeems deſigned to communicate light and heat, to a certain number of opaque bodies, ſimilar to our earth, and, undoubtedly, inhabited likewiſe, placed near them, but which we cannot ſee, on account of their prodigious diſtance.

Though it is impoſſible to aſcertain this by actual obſervations, we muſt conclude it, from their analogy to the ſun, who ſerves to warm and to illuminate the earth and the other planets. We know, particularly, ſix of theſe bodies; they are not in a ſtate of reſt, but each of them moves round the ſun, in the direction of a curve line, ſomewhat different from

Vol. I. Plate IV



from a circle, and which is called the planet's orbit. The ſun himſelf is, nearly, in a ſtate of reſt, as well as all the fixed ſtars; the motion which they appear to have, being entirely owing to that of the earth.

I have, accordingly, repreſented on the annexed ſheet, what is called the ſolar ſyſtem, which contains all the opaque bodies that move round the ſun, and derive from him all the benefits which he imparts to us. This ſign ☉ (*plate* IV. *fig.* 1.) repreſents the ſun at reſt. You ſee, beſides, ſix concentric circles, repreſenting the orbits deſcribed by the planets in their motion round him.

That neareſt to the ſun is Mercury, marked by the ſign ☿, and the black dot you ſee in the orbit repreſents the body of Mercury, who performs his revolution round the ſun in about 88 days.

Next comes Venus, marked by ♀, who completes a revolution round the ſun in ſeven months nearly.

The third circle is the orbit of the earth, marked by the ſign ♁, and which completes a revolution round the ſun in a year. We have no other meaning, in truth, to the word year, but the time employed by the earth in performing a revolution round the ſun; and the duration of the common year nearly approaches to this ſolar year.

But while the earth is moving round the ſun, there is another body moving round the earth, and keeping the direction of it's orbit; this is the moon, whoſe own circle, or orbit, is marked by ☽.

The two firſt planets, Mercury and Venus, have no viſible bodies which attend them; neither has Mars ♂, which is the fourth, and performs his revolution in about two years.

The fifth circle is the orbit of Jupiter, marked by ♃, who performs his revolution in twelve years nearly. Round him move four ſatellites, repreſented in the plate, with their orbits, and marked by the figures 1, 2, 3, 4.

Finally, the ſixth and laſt circle is the orbit of Saturn, marked thus, ♄, who employs almoſt thirty years in performing one revolution round the ſun. This planet is attended, in his courſe, by five ſatellites, marked by the figures 1, 2, 3, 4, 5. Thus, then, the ſolar ſyſtem conſiſts of ſix primary planets, Mercury ☿, Venus ♀, the Earth ♁, Mars ♂, Jupiter ♃, Saturn ♄, and ten ſecondary planets or ſatellites, namely, the moon, the four attendants of Jupiter, and the five of Saturn.*

* To this enumeration muſt now be added, the planet diſcovered at Bath the 17th of March, 1781, by Mr. *Herſchel*, and taken at firſt for a comet. It is more diſtant from the ſun than Saturn, and it's orbit muſt be repreſented by a ſeventh circle, circumſcribing all the others. The period of it's revolution is about 83 years. Tables of it's motion have been conſtructed, which repreſent already the obſervations with an exactneſs, that announces the perfection both of the inſtruments, and of the method of calculation.

It is admitted, that this ſtar was ſeen in 1756, in the month of September, by Mr. *Mayer*, of Gottingen; but that aſtronomer took it for a fixed ſtar, and having obſerved it only once, he could not aſcertain it's motion: his determination agrees in other reſpects with the place which the tables aſſign to the planet of Mr. *Herſchel*, for that epoch. It bears the name of the perſon who diſcovered it.

The mean diſtances of the planets from the ſun, may be thus reſpectively expreſſed: that of Mercury by 4, that of Venus by 7, that of the earth by 10, that of Mars by 15, that of Jupiter by 52, that of Saturn by 95, and, finally, that of the planet *Herſchel* *(a)* by 191—*F. E.*



This ſyſtem contains, beſides, ſeveral comets, the number of which is unknown. The figure on the plate repreſents one of them, whoſe orbit differs from that of the planets, becauſe it is drawn out into extreme length, ſo that a comet ſometimes approaches very near to the ſun, and ſometimes removes to ſuch an immenſe diſtance, as entirely to diſappear. Of comets it has been remarked, that one finiſhes his revolutions in his orbit, in about ſixty years; this is the one that was viſible laſt year. As to the other comets, it is certain, that they employ ſeveral centuries in performing one revolution in their orbits; and as, in paſt ages, no exact obſervations were made of them, we are totally in the dark with reſpect to their return. Of theſe, then, conſiſts the ſolar ſyſtem; and, moſt probably, every fixed ſtar has one ſimilar to it.*

*17th September*, 1760.

* Aſtronomers expect about 1790 the comet obſerved in 1531, and in 1661, which they believe to be the ſame ſtar, and the period of which appears to be about 130 years.—*F. E.*

*(a)* In compliment to his patron, King George III. Mr. *Herſchel* named his recently diſcovered planet *Georgium Sidus*. The republican *Condorcet*, in contempt of Kings, gives it the name of the Diſcoverer.—E. E.

## LETTER LX.

*The fame Subject continued.*

IN addition to what I have faid refpecting the folar fyftem, I muft communicate fome obfervations for the explanation of the figures. And, firft, it muft be remarked, that the lines which mark the paths in which the planets move, have no real exiftence in the heavens, as the whole immenfity of fpace in which they move is a vacuum, or rather filled with that fubtile matter which we call the *ether*, and which I have already fo often mentioned.

Again, the orbits of the planets are not all in the fame plane, as the figure prefents them: but if the orbit which the earth defcribes round the fun, is properly reprefented on the paper, we muft imagine the orbits of the five other planets to be partly elevated, and partly depreffed, with reference to it; or, that the orbit of each planet bears upon it an oblique direction, making an interfection with the paper, under a certain angle, which it is impoffible to reprefent in a figure drawn upon a plane.

Farther, the orbits of the planets are not circles, as the figure appears to indicate, but rather fomewhat oval, one more, another lefs fo; no one, however, recedes very confiderably from the circular form. The orbit of Venus is almoft a perfect circle; but thofe of the other planets are more or lefs extended





tended lengthwife, fo that thefe planets are fometimes nearer to the fun, fometimes farther off.

The orbits of comets are particularly diftinguifhable, being greatly extended in length, as I have reprefented it in the figure. As to the moon, and the fatellites of Jupiter and Saturn, their orbits, too, are nearly circular.

Neither muft we conceive them as moving in one and the fame direction, as they appear on the plane of the paper; for they do not remain in the fame place, but are themfelves carried round the fun along with the primary planet to which they belong. It is thus we muft underftand the lines reprefented in the figure. Imagination muft fupply what it is impoffible, on a plane furface, accurately to exhibit.

You are now enabled to comprehend, with eafe, what the late Mr. *de Fontenelle* meant to difplay, in his book on the plurality of worlds. The earth, with it's inhabitants, is fometimes denominated a world; and every planet, nay, every one of the fatellites, has an equal right to the fame appellation, it being highly probable, that each of thefe bodies is inhabited as well as the earth.

There are fixteen worlds, then, in the folar fyftem alone. And every fixed ftar being a fun, round which a certain number of planets perform their revolutions, and of which fome have, undoubtedly, their fatellites, we have an almoft infinite number of worlds, fimilar to our earth, confidering, that the number of ftars, perceptible to the unaffifted eye, exceeds fome thoufands, and that the telefcope difcovers to us an incomparably greater number.

If it is meant to comprehend under the name of *world* the fun, with the planets and their fatellites, and which derive heat and light from him, we fhall have as many worlds as there are fixed ftars. But if by the term *world*, we underftand the earth, with all the heavenly bodies, or all the beings which were created at once, it is clear that there can be but one world, to which we refer every thing that exifts. It is in this fenfe the term *world* is employed in philofophy, particularly in metaphyfics; it is in this fenfe we fay, that there is but one world, the affemblage of all created beings, paft, as well as prefent, and future, whofe exiftence is fubject to general laws.

When, therefore, philofophers difpute, whether our world is the beft or not, they proceed on the fuppofition of a plurality of worlds; and fome maintain, that the one which exifts, is the beft of all thofe which could have exifted. They confider the Deity as an architect, who, intending to create this world, traced feveral different plans, of which he felected the beft, or that in which the greateft perfections were all combined, in the higheft degree, and executed it in preference to all the others.

But the great quantity of evil that prevails, and is diffufed over the furface of our globe, and which flows from the wickednefs of man, fuggefts an important enquiry, namely, Whether it would have been poffible to create a world, wholly exempted from thefe evils?





In my opinion, a diftinction muft be carefully made, between the plans of a world, which fhould contain corporeal fubftances only, and thofe of another world, which fhould contain beings intelligent and free. In the former cafe, the choice of the beft, would be involved in very little difficulty; but in the other, where beings intelligent and free conftitute the principal part of the world, the determination of what is beft is infinitely beyond our capacity; and even the wickednefs of free agents may contribute to the perfection of the world in a manner which we are unable to comprehend.

It would appear, that philofophers have not been fufficiently attentive to this diftinction, however effential it may be. But I am too fenfible of my own incapacity, to enter any deeper into this difficult queftion.

*19th September, 1760.*

## LETTER LXI.

*Small Irregularities in the Motions of the Planets, caufed by their mutual Attraction.*

IN order to determine the motion of the bodies which compofe the folar fyftem, it is neceffary to diftinguifh the primary planets, which are Mercury, Venus, the Earth, Mars, Jupiter, and Saturn, from their fatellites, namely, the moon, the four fatellites of Jupiter, and the five of Saturn.

It has been explained to you, that thefe fix planets are principally attracted toward the fun, or, that the force with which they are impelled toward him, is incomparably greater, than the powers which they exert one upon another, becaufe his mafs is incomparably greater than that of the planets, and becaufe they never fufficiently approach to each other to render their reciprocal attraction very confiderable. Were they attracted only toward the fun, their motion would be fufficiently regular, and eafily determined. But the feebler powers of which I have been fpeaking, occafion fome flight irregularities in their motion, which aftronomers are eager to difcover, and which geometricians endeavour to determine, on the principles of motion.

An important queftion is here agitated, namely, *The powers which act upon a body being known, how to find the motion of that body?* Now, upon the principles above laid down, we are acquainted with the powers, to the influence of which every planet is fubjected. Thus the motion of the earth is fomewhat affected; firft, by the attraction of Venus, which fometimes paffes very near it; and, fecondly, by that of Jupiter, which, on account of the prodigious mafs of this planet, becomes confiderable, though he be always at a great diftance. The mafs of Mars is too fmall to produce any perceptible effect, though he is fometimes very near us; and Saturn, though his mafs be the greateft, next to that of Jupiter, is too diftant.

The moon, though her mafs be very fmall, produces,



duces, however, fome derangement, from her being very near the earth. The comet, which appeared laft year, was feven times nearer to us than the fun, when his diftance was fmalleft; there is a great degree of probability, therefore, that it may have deranged the earth's motion, efpecially if his mafs was confiderable, a circumftance with which we are not acquainted. If this comet were as great as the earth, the effect muft have been very confiderable; but it's apparent fmallnefs induces me to believe, that it's mafs is much lefs than that of the earth, and, confequently, it's effect muft have been proportionally lefs. When we faw this comet, however, it had got to a great diftance; at the time when it was neareft, it was invifible to us, but it muft have appeared very brilliant to our antipodes.

What has been faid, refpecting the derangements occafioned in the earth's motion, takes place likewife in the other planets, regard being had to their mafs, and to their proximity. As to the moon, and the other fecondary planets, the principle of their motion is fomewhat different. The moon is fo near the earth, that the attraction fhe feels from hence greatly exceeds that of the fun, though the mafs of this luminary be many thoufands of times greater than that of the earth. Hence it is, that the motion of the moon follows that of the earth, and that fhe remains, as it were, attached to it, which makes the moon to be confidered as a fatellite to our planet.

Had the moon been placed much farther from us, and had fhe been attracted lefs toward the earth than toward

toward the ſun, ſhe would have become a primary planet, and performed her own revolutions round the ſun; but ſhe is 300 times nearer to us than ſhe is to the ſun; hence it is evident, that he muſt exercíſe a much feebler influence upon her than the earth does. The moon being principally attracted by two bodies, the ſun and the earth, it is evident that the determination of her motion, muſt be much more difficult than that of the primary planets, which are ſubject to the attraction of the ſun only, excepting the ſlight derangements which have been mentioned. The motion of the moon has, accordingly, in all ages, greatly embarraſſed philoſophers; and never have they been able to aſcertain, for any future given time, the exact place of the moon in the heavens.

You perfectly comprehend, that in order to predict an eclipſe, whether of the moon or of the ſun, we muſt be able accurately to aſcertain the moon's place. Now, in calculating eclipſes, formerly, there was frequently a miſtake of an hour or more: the eclipſe actually taking place an hour earlier or later than the calculation. Whatever pains the ancient aſtronomers took to determine the moon's motion, they were always very wide of the truth. It was not till the great *Newton* diſcovered the real powers which act upon the moon, that we began to approach nearer and nearer to truth, after having ſurmounted many obſtacles which retarded our progreſs.

I too have employed much time and attention on the ſubject; and Mr. *Meyer*, of Gottingen, purſuing the



the track which I had opened, has arrived at a degree of preciſion, beyond which it is perhaps impoſſible to go. Not much more, then, than ten years have elapſed ſince we could boaſt of any thing like accurate knowledge of the moon's motion. Since that time we are able to calculate eclipſes ſo exactly, as not to make the miſtake of a ſingle minute, whereas, before, there was frequently the difference of eight minutes, and more. To analyſis, then, we are indebted for this important diſcovery, the ſource of unſpeakable advantages, not to the aſtronomer only, but likewiſe to the geographer, and the navigator.

*23d September, 1760.*

## LETTER LXII.

*Deſcription of the Flux and Reflux of the Sea.*

THE attractive power of the heavenly bodies extends, not only to the maſs of the earth, but to all the parts of which it is compoſed. Thus all the bodies, which we ſee on the ſurface of the earth, are attracted, not only toward the earth itſelf, from which reſults their gravity, and the weight of every one in particular, but, likewiſe, toward the ſun, and toward all the other heavenly bodies, and that more or leſs, according to the maſs of theſe bodies and their diſtance.

Now, it is evident, that the force with which a body,

body, say a stone, is attracted toward the earth, must be incomparably greater than that with which the same body is attracted toward the sun, the other planets, and the moon, because of their great distance. Such a body, being at a distance from the centre of the earth, equal to a radius of this globe, is 60 times farther from the moon. Though, then, the mass of the moon were equal to that of the earth, the attraction toward the moon would be 60 times 60, that is 3600 times less than the attraction toward the earth, or, the gravity of the body. But, the mass of the moon is about 70 times less than that of the earth; hence the attractive power of the moon becomes still 70 times 3600, that is, 252,000 times less than the gravity of the body.

Again, though the sun be many thousands of times greater than the earth, he is about 24,000 times more distant from us, than the centre of the earth; and for this reason, the attraction of the sun upon a stone is extremely small, compared to it's gravity. Hence you see, that the gravity of terrestrial bodies, which is nothing else but the force with which they are attracted toward the earth, cannot be perceptibly affected by the attraction of the heavenly bodies.

Though this attraction, however, be very inconsiderable, there results from it a remarkable phenomenon, which long puzzled philosophers; I mean the flux and the reflux of the sea. It occurs so frequently, even in common conversation, that it is almost a matter of necessity to understand it. For this reason, I propose to explain more minutely, this singular



gular phenomenon, and to unfold the causes which produce it.

I begin, then, with the description of the well-known phenomenon, of the *flux* and *reflux* of the sea. Hardly any one is ignorant, that by far the greatest part of the surface of our globle is covered with a mass of water, called the *Sea*, or the *Ocean*. This immense fluid mass is very different from rivers and lakes, which, according to the different seasons of the year, contain sometimes less water, sometimes more, whereas, in the sea, the quantity of water, at all times, continues nearly the same. It is, however, observed, that the water of the sea rises and falls alternately, with wonderful regularity, twice every twenty-four hours.

If, for instance, in a harbour, the water is now at it's greatest height, it will presently begin to subside, and this decrease continues for six hours, at the end of which, it's depth will be at the lowest. It then begins again to rise, and the increase, likewise, lasts six hours, when it is again at it's greatest depth. It immediately begins again to fall for six hours, and then rises as many, so that in the space of about 24 hours, the water rises and falls twice; and arrives, alternately, at it's greatest and least depth.

It is this alternate increase, and diminution of the water of the sea, which we call it's *flux* and *reflux*, or it's flowing and ebbing: and more particularly, the flux denotes the time, during which it encreases or rises, and the reflux, the time of it's decrease or falling. The flux and reflux together, likewise, go by the

the name of *tide*. This alternation, then, is to be the ſubject of our preſent diſquiſition.

It is, firſt of all, to be remarked, that the difference between riſing and falling, keeps pace with the variations of the moon. At full, and new moon, the water riſes higher than at the quarters: and about the time of the vernal, and autumnal equinoxes, in the months of March and September, this alternate motion of the ſea is moſt conſiderable. A great difference is, likewiſe, obſerved, according to the ſituation of the coaſts. The flux, in ſome places, is never more than a few feet, while, in others, the riſe is 40 feet and upwards. Such are the tides in the ports of St. *Malo*, in France, and of *Briſtol*, in England.

It is farther to be remarked, that this phenomenon is perceptible, chiefly, in the ocean, where there is a vaſt extent of water, and that in ſeas bounded and confined, ſuch as the Baltic, and the Mediterranean, it is much leſs conſiderable. The interval, from the flux to the ſucceeding reflux, is not exactly ſix hours, but about 11 minutes more; ſo that the ſame changes do not take place, the day after, at the ſame hour, but fall out about three quarters of an hour later: ſo that a revolution of 30 days is requiſite, to bring them round to the ſame hour; now, this is preciſely the period of one revolution of the moon, or the interval, between one new moon, and that which immediately follows.

*26th September, 1760.*

LETTER



## LETTER LXIII.

### *Different Opinions of Philoſophers reſpecting the Flux and Reflux of the Sea.*

WHEN the water of the ſea riſes at any place, we are not to imagine that it ſwells from any internal cauſe, as milk does when put in a veſſel upon the fire. The elevation of the ſea is produced by a real increaſe of water flowing hither from ſome other place. It is a real current which is very perceptible at ſea, conveying the waters toward the place where the flux is.

In order to have a clearer comprehenſion of this, you muſt conſider that in the vaſt extent of the ocean there are always places where the water is low, while it is high at others; and that it is conveyed from the former to the latter. When the water riſes at any place, there is always a current, conveying it from other places, where it is of courſe at that time low. It is an error, therefore, to imagine, with ſome authors, that during the flux of the ſea the total maſs of water becomes greater, and that it diminiſhes during the reflux. The entire maſs or bulk of water remains ever the ſame; but it is ſubject to a perpetual oſcillation, by which the water is alternately tranſported from certain regions to others; and when the water is high at any place, it is of courſe low ſomewhere elſe, ſo that the increaſe at places where it is

 high

high is preciſely equal to the decreaſe at thoſe where it is low.

Such are the phenomena of the flux and reflux of the ſea, the cauſe of which ancient philoſophers endeavoured to diſcover, but in vain. *Kepler*, in other reſpects a great aſtronomer, and the ornament of Germany, believed that the earth, as well as all the heavenly bodies, was a real living animal, and conſidered the flux and reflux of the ſea as the effect of it's reſpiration. According to this philoſopher, men and beaſts were juſt like inſects feeding on the back of the huge animal. You will hardly expect I ſhould go into the refutation of an opinion ſo ridiculous.

*Deſcartes*, that great French philoſopher, endeavoured to introduce a more rational philoſophy; and remarked, that the flux and reflux of the ſea was principally regulated by the moon's motion; which was indeed a very important diſcovery, though the ancients had already ſuſpected a connection between theſe two phenomena. For if high water or the top of the flux happen to-day at noon, it will be low water at 11 minutes after ſix in the evening: it will riſe till 22 minutes after midnight; and the next low water will be 33 minutes after ſix in the morning of the day after; and the enſuing high water, or flux, will be three quarters of an hour after noon: ſo that from one day to another the ſame tides are later by three quarters of an hour.

And as the ſame thing preciſely takes place in the moon's motion, which riſes always three quarters of an



an hour later than the preceding day, it was preſumable that the tides followed the courſe of the moon. If at any given place, for example, on the day of new moon, high water happen to be at three of the clock, afternoon, you could reſt aſſured, that ever after, on the firſt day of the moon, the flux would invariably be at the height at three o'clock afternoon, and that every following day it would fall later by three quarters of an hour.

Again, not only the time when every flux and reflux happen exactly follows the moon, but the ſtrength of the tides, which is variable, appears ſtill to depend on the poſition of the moon. They are every where ſtronger after the new and full moon, that is, at theſe periods the elevation of the water is greater than at other times; and after the firſt and laſt quarters, the elevation of the water, during the flux, is ſmaller. This wonderful harmony between the tides, and the motion of the moon, was, undoubtedly, ſufficient ground to conclude, that the chief cauſe of the flux and reflux of the ſea was to be ſought for in the action of the moon.

*Deſcartes* accordingly believed, that the moon, in paſſing over us, preſſed the atmoſphere, or the air which ſurrounds the earth, and that the air preſſing on the water, in it's turn, forced it to ſubſide. Had this been the caſe, the water muſt have been depreſſed at the places over which the moon was, and that the ſame effect ſhould be produced 12 hours after, in the enſuing tide; which, however, does not happen. Beſides the moon is too diſtant from the earth,



and

and the atmoſphere too low to be impreſſed by the moon; and admitting that the moon, or any other great body, were to paſs along the atmoſphere, it would be very far from undergoing any preſſure from it, and ſtill leſs would the ſea feel this pretended preſſure.

This attempt of *Deſcartes* to explain the flux and reflux of the ſea, has therefore failed; but the connection of this phenomenon with the moon's motion, which this philoſopher has ſo clearly unfolded, enabled his ſucceſſors to employ the application of their reſearches with more ſucceſs. This ſhall be the ſubject of ſome following letters.

*30th September*, 1760.

## LETTER LXIV.

*Explanation of the Flux and Reflux, from the attractive Power of the Moon.*

DESCARTES's method of explaining the flux and reflux of the ſea, by the preſſure of the moon upon our atmoſphere, not having ſucceeded, it was reaſonable to look for the cauſe of it in the attraction which the moon exerciſes upon the earth, and conſequently alſo upon the ſea.

The attractive power of the heavenly bodies having been already ſufficiently eſtabliſhed, by ſo many other phenomena, as I have ſhewn, it could not be doubted that the flux and reflux of the ſea muſt be an



an effect of it. As ſoon as it is demonſtrated that the moon, as well as the other heavenly bodies, is endowed with the property of attracting all bodies, in the direct ratio of their maſs, and in the inverſe ratio of the ſquare of their diſtance, it is eaſily comprehended that it's action muſt extend to the ſea; and the more ſo, as you muſt frequently have obſerved, that the ſmalleſt force is capable of agitating a fluid. All that remains, therefore, is to enquire, whether the attractive power of the moon, ſuch as we ſuppoſe it, is capable of producing in the ſea the agitation known to us by the name of flux and reflux.

Let the annexed figure (*plate* III. *fig.* 5.) repreſent the earth and the moon. A is the place where we ſee the moon over the earth; B that which is directly oppoſite, or the antipodes of A; and C is the centre of the earth. As the point A is nearer the moon than the point B, a body at A is more powerfully attracted toward the moon than a ſimilar body at B. And if we ſuppoſe a third ſimilar body to be placed at the centre of the earth C, it is evident that the body A will be more powerfully attracted toward the moon than the body C, and this laſt than the body B, becauſe the body A is nearer to the moon, and the body B more remote than the body C. But ſimilar bodies placed at E and F, are almoſt as much attracted by the moon as that which is at the centre of the earth C, as they are all three nearly equi-diſtant from the moon.

Hence we ſee that bodies placed on the ſurface of the

the earth are not all equally attracted toward the moon. This inequality of attraction depends on the inequality of their diſtance from the centre of the moon L, ſo that a body is ſo much the more powerfully attracted by the moon, as it's diſtance is leſs; and the contrary takes place according as the diſtance is greater.

To theſe differences in the action of the moon on bodies differently ſituated, we muſt here chiefly pay attention; for if all bodies were equally attracted toward the moon, they would equally obey this power, and no derangement could take place in their mutual ſituation.

You can eaſily form the idea of ſeveral carriages drawn along by powers perfectly equal; they will proceed on the road, always preſerving the ſame order, and the ſame diſtances; but as ſoon as ſome of them advance more briſkly, and others more ſlowly, the order will be deranged. The ſame thing takes place in the caſe of the different bodies which are attracted by the moon; if they all felt, in the ſame degree, the action of that luminary, they would preſerve the ſame relative ſituation, and we ſhould perceive no change in them: but as ſoon as the force with which they are attracted toward the moon varies as to each of them, their order and their relative ſituation neceſſarily change, unleſs they are attached to each other by bands which that power is unable to burſt aſunder.

But this is not the caſe with the ſea, as all the particles of a fluid are eaſily ſeparated from each other, and



and every one may obey the impreſſions which it receives. It is evident, then, that when the powers which act on the different parts of the ſea are not equal to one another, an agitation, or derangement, muſt be the conſequence.

We have juſt ſeen that the different parts of the ſea are attracted unequally by the moon, according as they are unequally diſtant from her centre; the ſea muſt, therefore, be agitated by the force of the moon, which, continually changing her ſituation, with reſpect to the earth, and performing a revolution round it in about twenty-four hours and three quarters, makes the ſea undergo the ſame changes, and preſents the ſame phenomena in the ſame period of twenty-four hours and three quarters; the flux and reflux muſt, therefore, be retarded from one day to another three quarters of an hour, which is confirmed by conſtant experience.

It now remains that we ſhew, How the alternate elevation and depreſſion of the ſea, which ſucceed each other after an interval of ſix hours and eleven minutes, reſult from the inequality of the powers of the moon. This I propoſe to examine in my next letter.

*4th October, 1760.*

## LETTER LXV.

*The ſame Subject continued.*

YOU have ſeen that the moon cauſes no alteration in the ſtate of the earth, but in ſo far as ſhe acts unequally on it's different parts. The reaſon of it is, that if all it's parts equally felt the ſame action, they would be equally attracted, and no change in their relative ſituation would reſult from it.

But a body being at A (*plate* III. *fig.* 5.) nearer the moon than the centre of the earth C, is more powerfully attracted to it than a body at C would be: it will approach it, then, with greater velocity than this laſt: from hence it neceſſarily follows, that the body A retires from the centre C, and approaches the moon: as if there were two chariots, the one at A, the other at C, and if the chariot A were drawn toward L with greater force than the chariot C, it would remove from C. It is thus that the power of the moon has a tendency to withdraw the point A from the centre C.

Now to remove a body from the centre of the earth is to raiſe it: and the water at A being now the thing in queſtion, it is certain that the force of the moon tends to raiſe the water which is at A, by a power equal to the exceſs of the attraction toward the moon felt at A, above that felt at C. By this power, then, the moon raiſes the waters of the earth which are immediately under her.

Let



Let us now, likewiſe, attend to a body at B, directly oppoſite to the point A; the centre of the earth C, more powerfully attracted by the moon than the point B, will approach nearer to it, and this laſt, ſo to ſpeak, will remain behind, juſt as a chariot, which was drawn more ſlowly than that which precedes it. The point B will conſequently remove from the centre C, and riſe; for to remove from the centre of the earth, and to riſe, is one and the ſame thing.

It is evident, therefore, that the power of the moon tends to raiſe the waters, not only at A, but likewiſe at B, the point diametrically oppoſite, and that by a force equal to the difference of the attraction of the moon at B and at C, which is leſs at B than at C. Now, thoſe who are at A, have the moon directly above them, or in their zenith; and thoſe who are at B ſee nothing of the moon, becauſe ſhe is then in a point of the heavens diametrically oppoſite to their zenith, called *Nadir*.

Hence it appears, that at whatever part of the ſea it may be, the water muſt riſe equally when the moon is in the zenith of that place, and in it's nadir, or, when the moon is at it's greateſt elevation above the horizon, or at it's greateſt depreſſion under it. At the intermediate periods, when the moon is in the horizon, either riſing or ſetting, ſhe exerciſes no power capable of raiſing the ſea; a ſmall contrary power tends even to make it fall.

According to this ſyſtem, at the place of the ſea, where the moon is in the zenith, it's power has a

tendency

tendency to raiſe the waters; about ſix hours after, when ſhe has reached the horizon, her power has a tendency to make them fall. Twelve hours and twenty-two minutes after, the moon being then at the point moſt diſtant, under the horizon, ſhe exerciſes the ſame power to raiſe the water; and at the end of eighteen hours, thirty-three minutes, when ſhe has got to the oppoſite horizon, the waters are fallen: till at length, twenty-four hours and forty-five minutes from the firſt period, ſhe returns to the zenith, raiſing the water as on the preceding day: and this is confirmed by uniform experience.

This alternate elevation and depreſſion of the ſea, at intervals of ſix hours and eleven minutes, having ſuch a perfect conformity with the moon, leaves us no room to doubt that the flux and reflux of the ſea are cauſed by the attractive power of the moon.

It is a remarkable circumſtance that ſhe acts equally on the ſea, in raiſing it, whether ſhe is at her greateſt height above the horizon, or at the moſt diſtant point under it. This appeared at firſt very ſtrange to philoſophers, who imagined that the moon muſt produce, under the horizon, an effect contrary to that which ſhe produces when in the zenith. But you ſee clearly that the moon produces the ſame effect in theſe two diametrically oppoſite poſitions, as I have demonſtrated in the figure above referred to, that the effect of the moon is the ſame at A and at B.

*7th October*, 1760.





## LETTER LXVI.

*The ſame Subject continued.*

FROM what has been ſaid reſpecting the flux and reflux of the ſea, you muſt be ſenſible that the ſyſtem of *Newton*, which I have adopted, is directly contrary to that of *Deſcartes*. According to this laſt, the moon exerciſes a preſſure, and the ſea muſt ſubſide at places ſituated directly under her; but, according to *Newton*, ſhe acts by attraction, and forces the water to riſe at theſe very places.

Experience, then, muſt determine which of theſe two ſyſtems is to be received. No more is neceſſary than to conſult the obſervations made with reſpect to the ocean, in order to ſee whether the water riſes or falls when the moon is in the zenith. Recourſe has actually been had to this; but it is found that when the moon is at either the zenith, or nadir, of a given place, the water there is neither high nor low; and that high water does not take place till ſome hours after the moon has paſſed the zenith.

From this circumſtance, perſons who examine things ſuperficially, concluded at once, that neither of the ſyſtems was admiſſible; and the Carteſians have taken advantage from it, preſuming, that if *Newton's* was rejected, that of *Deſcartes* muſt neceſſarily be adopted, though the obſervations referred to are as contrary to the ſyſtem of *Deſcartes* as they appear to be to that of *Newton*.

But the ſyſtem of *Deſcartes* is overturned by this ſingle phenomenon, that the ſea is always in the ſame ſtate after a period of twelve hours and twenty-two minutes, or that it's ſtate is always the ſame, whether the moon be above or below the horizon; and it is impoſſible for it's ſupporters to ſhew how the moon, being over the heads of our antipodes, can produce the ſame effect as when ſhe is over ours. To this purpoſe, ſee *plate* III. *fig.* 6.

Experience proves that the ſtate of the water at A is the ſame, whether the moon be at M, the zenith of the point A, or at N, it's nadir, which is conſequently the zenith of the antipodes at B. The effect, of the moon, then, on the water at A, is the ſame in both caſes. But if the moon acted by preſſure, according to *Deſcartes*, it would follow, that when the moon is at M, the water at A muſt fall; and if ſhe were at N, it is impoſſible that the water at A ſhould undergo the ſame preſſure.

In the ſyſtem of attraction, on the contrary, it is inconteſtably certain, that the action of the moon muſt be nearly the ſame, whether that luminary be at M or at N; and this is demonſtrated by actual obſervation.

I muſt here repeat a preceding explanation, becauſe it is a matter of the utmoſt importance. When the moon is at M, the point A is nearer it than the centre C; it is, therefore, more powerfully attracted than the centre; the point A will remove from the centre, conſequently it will then riſe: the moon being at M, has a tendency to raiſe the water at A. Let



Let us now ſee what effect the moon, being at N, will produce, where ſhe arrives in twelve hours and twenty-two minutes after ſhe was at M. As the point A is more diſtant from the moon at N than the centre C, it will be more feebly attracted; the centre C will advance with greater velocity toward N, than the point A; the diſtance A C will accordingly become greater; the point A will, therefore, be more diſtant from the centre C. But to be more diſtant from the centre of the earth is to riſe, conſequently the moon being at N, makes the point A to aſcend, that is, ſhe has a tendency to raiſe the water at A, as if the moon were at M.

But here experience preſents a very formidable objection; for it is obſerved, that the moon being at M, or at N, the water is not then at it's greateſt elevation at A. This does not take place till a conſiderable time after, and thence ſome have been induced to reject this explanation altogether. But you will eaſily ſee that their deciſion is extremely precipitate.

I have not ſaid, that when the moon is at M or N, the water at A is at it's greateſt height; I have only ſaid, that the power of the moon has then a tendency to make the water riſe. But the water at A could not riſe, unleſs it's quantity were increaſed; and that increaſe can be produced only by the flowing of the water from other parts, ſome of them very diſtant. A conſiderable time, therefore, is requiſite to the accumulation of a ſufficient quantity of water; it is, then, very natural to ſuppoſe, that high water at A ſhould not take place for ſome time after the moon has

has paſſed M or N. This obſervation, therefore, is ſo far from overturning our ſyſtem, that it tends ſtrongly to confirm it.

There is no room to doubt that the power which has a tendency to raiſe the ſea, muſt precede it's greateſt elevation, nay, that a conſiderable time muſt intervene, as the water muſt flow thither from places very remote, that is, from places where the water muſt be low, while it is high at A. If the water has to paſs through ſtraights, or has it's current otherwiſe obſtructed, high water will be ſtill more retarded;* and if, in the ocean, it is high water at A, two hours after the moon has paſſed M or N, it will not be at the height, in narrow and bounded ſeas, for three hours or more: and this perfectly agrees with daily obſervation.

*11th October*, 1760.

* It may be proper, in this place, to give a popular view of ſo intereſting a ſubject as that of tides. Suppoſe, therefore a ciſtern of water communicates with another, alſo of water, and in the ſame ſtate; the ſurface of both will conſtantly preſerve, or endeavour to preſerve, the ſame level. But if one of the ciſterns were filled with oil, or any ſuch light fluid, the ſurface would evidently riſe above the level of the other; and the more ſo, the greater was the depth of the oil. The ſame conſequence would follow, if, by any cauſe, the ſpecific gravity of the water in one of the ciſterns was diminiſhed. And this is actually the effect which the moon and ſun produce on the waters of the ocean; thoſe particles neareſt theſe luminaries are more attracted by them than the particles at the centre, or at the extremities of the tranſverſe diameter, which are more attracted than the particles on the fartheſt ſide; and therefore, in both caſes, the tendency to the centre is diminiſhed. Hence a protuberance will be formed on the nearer and farther ſides of the globe, proportional to the depth of the ocean. But this general ſwell is never ſuffered to attain it's juſt elevation; for the neceſſary motions are not ſupported a ſufficient length of time, and the impreſſions ſoon give a contrary tendency. The flow of the waters is moſt obſtructed in narrow ſeas, which are remote from the great ocean. Hence the lateneſs and irregularity of the tides in ſuch ſeas. When a large river, or an arm of a ſea, frequently contracts and widens, it often happens that the tide, in puſhing up, occaſions a great ſwell in the narrows, which produces a ſtrong current, that continuing, after it's cauſe has ceaſed to operate, reduces the water below it's proper level, till a quantity is again accumulated, and repeats the ſame effects; and thus an ebb and flow may happen ſeveral times in the courſe of a day. This is particularly remarked in the river St. Lawrence, in North America.

A large lake cannot have any ſenſible tides, for every portion of it's waters is almoſt equally attracted by the ſun or moon.



## LETTER LXVII.

*The ſame Subject continued.*

IT is no longer, then, a matter of doubt, that the flux and reflux of the ſea is cauſed by the attractive power of the moon. But there remains one difficulty more to be removed: Why is the motion of the ſea much more conſiderable at the time of new and full moon than at the other quarters? If the moon were nearer the earth when ſhe is new, or full, than when ſhe is in her quarters, there would be no difficulty in the queſtion, as her proximity would increaſe her power. But though the moon approaches the earth ſometimes more, ſometimes leſs, the

the difference is always too fmall to occafion a change fo confiderable in the flux and reflux of the fea.

Befides, this difference is not regulated by the new and full moon; and it may happen, that the moon, in the intermediate quarters, fhould be nearer to us than when fhe is new or full. We muft have recourfe, therefore, to another caufe capable of increafing the flux and reflux of the fea at the new and full moon, and of diminifhing it at the intermediate quarters.

The fyftem of attraction fhews us, at firft, that it is the action of the fun which, joined to that of the moon, furnifhes a complete folution of all the phenomena prefented to us by the flux and reflux of the fea. Indeed, all that I have faid refpecting the power which the moon exercifes on the fea, is equally applicable to the fun, whofe attractive power acts likewife unequally on all the parts of the earth, according as they are more or lefs remote from him. The attraction of the fun is even much more intenfe than that of the moon, as it chiefly regulates the motion of the earth, and carries it round it's orbit.

As to the motion which he communicates to the fea, it depends on the inequality of that action, with relation to the different points of the furface of the earth, which are more or lefs attracted toward the fun than it's centre, as I have already fhewed you, in explaining the effect of the moon. If all the parts of the earth were attracted equally, no change in their mutual fituation would take place. But though the power of the fun be much greater than that of the



the moon, the inequality, with relation to different parts of the earth is, neverthelefs, fmaller, on account of the great diftance of the fun, which is 300 times farther from us than the moon. The difference of the power with which the centre of the earth, and the points of it's furface, are attracted toward the fun, is, therefore, very fmall; and from calculations actually made, it is found to be three times lefs, nearly, than that of the moon upon thefe points. The attractive power of the fun alone, then, would likewife be capable of caufing the flux and reflux of the fea; but it would be about three times lefs than that which is the effect of the combined influence of thefe two luminaries.

It is evident, then, that the flux and reflux of the fea are produced by the power of both the fun and the moon, or that there are really two tides, occafioned, the one by the moon, the other by the fun, and called the *lunar tide* and the *folar tide*. That of the moon, nearly three times greater, follows it's motion, and from one day to another is retarded three quarters of an hour: that which follows the action of the fun, would conftantly correfpond to the fame hours of the day, if it exifted alone, or if there were no moon. Thefe two tides, the lunar and the folar together, produce the flux and reflux of the fea; but as the one and the other, feparately, make the waters of the fea alternately to rife and fall, when it happens that thefe two caufes, conjointly, make the fea rife and fall, it's flux and reflux become much more confiderable; but when the one tends to raife

 the

the ſea, and the other to lower it, at the ſame place, when they act in contrary directions, the one will then be diminiſhed by the other, and the lunar tide will be weakened by the ſolar. According as theſe two tides aſſiſt, or check, each other, the flux and reflux will, then, be more or leſs conſiderable.

Now, as at the time of new moon, the ſun and moon are in the ſame parts of the heavens, their effects being perfectly in uniſon, the flux and reflux muſt then be greateſt, being equal to the ſum of the two tides. This will equally take place at the time of full moon, when the moon is oppoſite to the ſun, as we know that ſhe produces the ſame effect, though ſhe be in a point of the heavens diametrically oppoſite to the firſt. The flux and reflux muſt, therefore, be greater at new and full moon, than at the firſt and laſt quarters. For then the power of the ſun is exerted to lower the waters, and that of the moon to raiſe them. It is evident, therefore, that, at theſe ſeaſons, the flux and reflux muſt be leſs conſiderable, and actual obſervation confirms it.

It might be ſtill farther demonſtrated, by calculation, that the effect of the moon, or of the ſun, is ſomewhat greater, when theſe bodies are at the equator, or equally diſtant from the two poles of the globe: which happens at the time of the equinoxes, toward the end of the months of March and September. It is found, too, that then the tides are ſtrongeſt. It follows beyond all doubt, then, that the tides, or the flux and reflux of the ſea, are cauſed by the attractive power of the moon and of the ſun, in



in as much as theſe powers act unequally on the different parts of the ſea. The happy explanation of this phenomenon, which had ſo dreadfully perplexed the ancients, is a complete confirmation of the ſyſtem of attraction, or of univerſal gravitation, on which is founded the motion of all the heavenly bodies.

*14th October, 1760.*

## LETTER LXVIII.

*More particular Account of the Diſpute reſpecting univerſal Gravitation.*

HAVING given you a general, but exact, idea of the powers which produce the principal phenomena of the univerſe, and on which are founded the motions of all the heavenly bodies, it is of importance to conſider, with more attention, thoſe powers which are the principal points of the ſyſtem of attraction.

It is ſuppoſed, in this ſyſtem, that all bodies mutually attract each other, in the ratio of their maſs, and relatively to their diſtance, in conformity to a law already explained. The ſatisfying manner in which moſt of the phenomena in nature are accounted for, proves that this ſuppoſition is founded in truth; and that the attraction which different bodies exerciſe upon each other, may be conſidered as a moſt undoubted fact. It now remains, that we enquire into the cauſe of theſe attractive powers; but this

 reſearch

refearch belongs rather to the province of metaphyfics than of mathematics. I dare not, therefore, flatter myfelf with the profpect of affured fuccefs in the profecution of it.

It being certain, that any two bodies whatever are attracted to each other, the queftion is, What is the caufe of this attraction? On this point philofophers are divided. The Englifh maintain, that attraction is a property effential to all the bodies in nature, and that thefe bodies, hurried along by an irrefiftible propenfity, tend mutually to approach, as if they were impelled by feeling.

Other philofophers confider this opinion as abfurd, and contrary to the principles of a rational philofophy. They do not deny the fact; they even admit, that powers exift, which are the caufes of the reciprocal tendency of bodies toward each other; but they maintain, that they are foreign to the bodies; that they belong to the ether, or the fubtile matter which furrounds them, and that bodies may be put in motion by the ether, juft as we fee that a body, plunged into a fluid, receives feveral impreffions from it. Thus, according to the firft, the caufe of the attraction refides in the bodies themfelves, and is effential to their nature; and, according to the laft, that it is out of the bodies, and in the fluid which furrounds them. In this cafe, the term attraction would be improper; and we muft rather fay, that bodies are impelled toward each other. But as the effect is the fame, whether two bodies are reciprocally impelled, or attracted, the word attraction



tion need not give offence, provided it is not pretended, by that term, to determine the nature itfelf of the caufe.

To avoid all confufion which might refult from this mode of expreffion, it ought rather to be faid, that bodies move, as if they mutually attracted each other. This would not decide, whether the powers which act on bodies refide in the bodies themfelves, or out of them; and this manner of fpeaking might thus fuit both parties. Let us confine ourfelves to the bodies which we meet with on the furface of the earth.

Every one readily admits, that all thefe would fall downward, unlefs they were fupported. Now, the queftion turns on the real caufe of this fall. Some fay, that it is the earth which attracts thefe bodies, by an inherent power natural to it; others, that it is the ether, or fome other fubtile or invifible matter, which impels the body downward: fo that the effect is, neverthelefs, the fame in both cafes. This laft opinion is moft fatisfactory to thofe who are fond of clear principles in philofophy, as they do not fee, how two bodies at a diftance can act upon each other, if there be nothing between them. The others have recourfe to the divine Omnipotence, and maintain, that God has endowed all bodies with a power of mutual attraction.

Though it be dangerous to venture on difputing concerning the limits of divine power, it is, neverthelefs, certain, that if attraction were an immediate work of that power, without being founded in the nature

nature of bodies, this would be the ſame thing as ſaying, that God immediately impels bodies toward each other, and this would amount to a perpetual miracle.

Let us ſuppoſe, that before the creation of the world, God had created only two bodies, at a diſtance from each other; that nothing abſolutely exiſted out of them, and that they were in a ſtate of reſt; would it be poſſible for the one to approach the other, or that they ſhould have a propenſity to approach? How could the one feel the other at a diſtance? Whence could ariſe the deſire of approaching? Theſe are perplexing queſtions. But if you ſuppoſe that the intermediate ſpace is filled with a ſubtile matter, we can comprehend, at once, that this matter may act upon the bodies, by impelling them; the effect would be the ſame as if they poſſeſſed a power of mutual attraction.

Now, as we know, that the whole ſpace which ſeparates the heavenly bodies, is filled with a ſubtile matter, called *ether*, it ſeems more reaſonable to aſcribe the mutual attraction of bodies to an action which the ether exerciſes upon them, though it's manner of acting may be unknown to us, rather than to have recourſe to an unintelligible property.

Ancient philoſophers ſatisfied themſelves with explaining the phenomena of nature, from qualities which they called *occult*, ſaying, for example, that opium cauſes ſleep, from an occult quality, which diſpoſes it to procure ſleep. This was ſaying juſt nothing, or rather was an attempt to conceal ignorance.





rance. We ought, therefore, likewiſe to conſider attraction as an occult quality, in as far as it is given for a property eſſential to bodies. But, as the idea of all occult qualities is now baniſhed from philoſophy, attraction ought not to be conſidered in this ſenſe.

*18th October*, 1760.

## LETTER LXIX.

*Nature and Eſſence of Bodies: or Extenſion, Mobility, and Impenetrability of Body.*

THE metaphyſical diſquiſition, Whether bodies may be endowed with an internal power of attracting each other, without being impelled by an external force, cannot be terminated, till we have examined more particularly the nature of body in general. As this ſubject is of the laſt importance, not only in mathematics and phyſics, but in every branch of philoſophy, you muſt permit me to go into a more particular detail of it.

Firſt, it is aſked, What is body? However abſurd this queſtion may appear, as no one is ignorant of the difference between what is body and what is not, it is, however, difficult to aſcertain the real characters which conſtitute the nature of bodies. The Carteſians ſay, it conſiſts in extenſion, and that whatever is extended is a body. They clearly underſtand, that extenſion has, in this caſe, three dimenfions; and that a fingle dimenfion, or extenfion in length only, gives only a line; and that two dimenfions, length and breadth, form only a furface, which ftill is not a body. To conftitute a body, therefore, we muft have three dimenfions, and every body muft have length, breadth, and depth, or thicknefs; in other words, an extenfion in three dimenfions.

But, it is afked, at the fame time, if every thing which has extenfion is a body? This muft be the cafe, if the definition of *Defcartes* be juft. The idea which the vulgar form of fpectres contains extenfion; it is, however, denied that they are bodies. Though this idea be purely imaginary, it ferves to prove, however, that fomething may have extenfion without being a body. Befides, the idea which we have of fpace, contains, undoubtedly, an extenfion with three dimenfions. It is admitted, neverthelefs, that fpace alone is not a body; it only furnifhes the place which bodies occupy and fill.

Let us fuppofe, that all thofe which are at prefent in my apartment, air and every thing, were annihilated by the divine Omnipotence, there would remain ftill in the apartment the fame length, breadth and height, but without a body in it. Here, then, is the poffibility of an extenfion that fhall not be a body. Such a fpace, without body in it, is called a vacuum; a vacuum then is extenfion without body.

It may likewife be faid, according to the vulgar fuperftition, that a fpectre has extenfion, but that body, or corporality, is wanting to it. It is clear, then, that extenfion is not fufficient to conftitute a body,



body, that fomething more is neceffary; hence it follows, that the definition of the Cartefians is not exact. But what more is neceffary, befide extenfion, to conftitute a body? The anfwer is, mobility, or the poffibility of being put in motion; for, though a body be at reft, whatever may be the caufes which preferve it in that ftate, it would, however, be poffible to move it, provided the powers applied to it were fufficient. By this, fpace is excluded from the clafs of bodies, as we fee that fpace, which only ferves to receive bodies, remains immoveable, whatever motion the bodies that it contains may have.

It is likewife faid, that, by the help of motion, bodies are tranfported from one place to another; by which we are given to underftand, that the places and fpace remain unchangeable. My apartment, however, with the vacuum which I have above fuppofed, might undoubtedly be moved, and actually is fo, as it follows the motion which carries round the earth itfelf; here, then, is a vacuum in motion, without being a body. The vulgar fuperftition, too, beftows motion on fpectres; and this is fufficient to prove, that the power of being moved, and extenfion, alone, do not conftitute the nature of bodies. Something more is wanting; there muft be matter to conftitute a body, or rather, it is this which diftinguifhes a real body from fimple extenfion, or from a fpectre.

Here, then, we are reduced to explain what is to be underftood by the term *matter*, without which extenfion cannot be body. Now, the fignification of of thefe two terms is fo much the fame, that all body is matter, and all matter is body; fo that even now we have made no great progrefs. We eafily difcover, however, a general character, infeparable from all matter, and, confequently, pertaining to all bodies; it is *impenetrability*, the impoffibility of being penetrated by other bodies, or the impoffibility that two bodies fhould occupy the fame place at once. In truth, impenetrability is what a vacuum wants in order to be a body.

It will, perhaps, be objected, that the hand may be eafily moved through air and through water, which are, neverthelefs, acknowledged bodies; thefe, then, muft be penetrable bodies, and, confequently, impenetrability is not an inherent character of all bodies. But it is worthy of remark, that when you plunge your hand into water, the particles of the water make way for your hand, and that there is no water in the fpace which your hand occupies. If the hand could move through the water, while that fluid did not make room for it, but remained in the place which the hand occupied, then it would be penetrable; but it is evident this is not the cafe. Bodies, then, are impenetrable: a body, therefore, always excludes, from the place which it occupies, every other body; and as foon as a body enters into any place, it is abfolutely neceffary that the body which occupied it before fhould leave it. This is the fenfe which we muft affix to the term impenetrability.

*21ft October*, 1760.

LETTER



## LETTER LXX.

### *Impenetrability of Bodies.*

THE inftance of a fpunge will, perhaps, be produced as an objection to the impenetrability of bodies; which, plunged into water, appears completely penetrated by it. But the particles of the fpunge are very far from being fo, in fuch manner as that one particle of the water fhould occupy the fame place with one particle of the fpunge. We know that fpunge is a very porous body; and that before it is put into the water, it's pores are filled with air; as foon as the water enters into the pores of the fpunge, the air is expelled, and difengages itfelf under the form of little bubbles; fo that, in this cafe, no penetration takes place, neither of the air by the water, nor of the water by the air, as this laft always makes it's efcape from the places into which the water enters.

It is, then, a general, and effential property of all bodies, to be impenetrable; and, confequently, the juftnefs of this definition muft be admitted: *that a body is an impenetrable extenfion*; as not only all bodies are extended and impenetrable, but likewife, reciprocally, as that which is, at the fame time, extended and impenetrable, is, beyond contradiction, a body. Vacuum is, accordingly, excluded from the clafs of bodies; for, though it has extenfion, it wants impenetrability; and wherever we meet with a vacuum, there

there bodies may be introduced, without thrufting any thing out of it's place.

We muft attempt to remove another difficulty, raifed againft the impenetrability of bodies. There are, fay the objectors, bodies, which admit of compreffion into a fmaller fpace, as, for example, wool, and efpecially air, which it is poffible to reduce into a fpace a thoufand times fmaller than what it occupies. It appears, then, that the different particles of air are reduced in the fame place, and that, confequently, they mutually penetrate.

There is, however, nothing in this; for the air, too, is a body, or a fubftance full of empty pores, or filled with that fluid, incomparably more fubtile, which we call *ether*. In the firft cafe, no penetration will enfue, as the particles of air only approach nearer to each other, according as the vacuum is diminifhed; and, in the other cafe, the ether finds a fufficiency of fmall paffages by which to efcape, as the particles of the air approach each other, but all the while without any mutual penetration. For this reafon, it is neceffary to employ a greater force, when we want to comprefs the air more: and if the air were compreffed to fuch a degree, that it's minute particles touched each other, we could not carry the compreffion farther, becaufe, were it poffible, the minute particles of the air muft mutually penetrate.

It is, then, a neceffary and fundamental law in nature, that no two bodies can penetrate each other, or occupy the fame place at once: and it is in a conformity to this principle, that we muft look for the real fource



fource of all the motions which we obferve in all bodies, and of the changes which befal them. As two bodies cannot continue their motion without penetrating each other, it is abfolutely neceffary that the one fhould give place to the other. If, then, two bodies are moving in the fame line, the one to the left, the other to the right, as it frequently happens at billiards, if each were to continue it's motion, they muft mutually penetrate, but this being impoffible, as foon as they come to touch, a fhock takes place, by which the motion of each body is almoft inftantly changed; and this fhock is produced, in nature, only to prevent penetration. The motion of each body is precifely changed no further than is neceffary to prevent all penetration; and in this confifts the real caufe of all the changes which happen in the world.

When all thefe changes are attentively confidered, they are found always to take place, in order to prevent fome penetration, which, without thefe changes, muft have enfued. At the moment I am writing, I obferve, that if the paper were penetrable, the pen would pafs freely into it, without writing: but as the paper fuftains the preffure of my pen, moiftened with ink, it receives from it fome particles which form thefe letters; which could not happen if bodies penetrated each other.

This property of all bodies, known by the term *impenetrability*, is, then, not only of the laft importance, relatively to every branch of human knowledge, but we may confider it as the mafter-fpring which

which nature ſets a-going, in order to produce all her wonders. It merits, then, an attentive examination, in order that we may be enabled to explain more clearly the nature of bodies, and the principles of every ſpecies of movement, commonly called *law of motion*.

*25th October*, 1760.

## LETTER LXXI.

*Of the Motion of the Bodies, real and apparent.*

ALL bodies are at reſt, or in motion. However evident this diſtinction may be, it is almoſt impoſſible to judge whether a body is in the one ſtate, or in the other. The paper which I ſee on my table ſeems to me really at reſt; but when I reflect that the whole earth is moving with that aſtoniſhing velocity which I explained in a former letter,* my houſe, my table, and the paper, muſt abſolutely be carried along with the ſame rapidity. Thus every thing that ſeems to be at reſt, has, in reality, the ſame motion as the earth.

We muſt therefore diſtinguiſh between two kinds of reſt, the one abſolute, the other apparent. Abſolute reſt takes place when a body remains conſtantly in the ſame place, not with relation to the earth, but with relation to the univerſe. If the fixed ſtars remained always in the ſame place of the univerſe,

* Letter II.

they



they would be at reſt, though they ſeem to move very rapidly; but as we are not certain of it, we muſt not pretend to affirm, that the fixed ſtars are in a ſtate of abſolute reſt.

A body is ſaid to be in a ſtate of apparent reſt, when it preſerves the ſame ſituation on the earth. It is likewiſe to be preſumed, that theſe terms, reſt and motion, have been introduced into language to mark rather appearances than truth; and in this ſenſe, I affirm, without heſitation, that my table is at reſt, as well as the whole earth; and that the ſun and the fixed ſtars are in motion, and that a very rapid motion, although they are really at reſt. We ſhould, therefore, be aſcribing ſtrange and purely metaphyſical ideas to theſe expreſſions, if we underſtood by them *abſolute reſt*, or *motion*; and it is abſurd to employ, as ſome perſons do, paſſages of the Holy Scriptures to prove that the earth is at reſt, and the ſun in motion.

Language is formed for general uſe; and philoſophers are under the neceſſity of forming a particular language for themſelves. As we are incapable to judge of abſolute reſt, it is very natural for us to conſider thoſe bodies as at reſt which preſerve the ſame ſituation relatively to the earth; as it is very probable the inhabitants of other planets, likewiſe, form their judgment of reſt from the ſame ſituation relatively to their reſpective planet.

We obſerve, that navigators conſider as at reſt the objects which preſerve the ſame ſituation relatively to their veſſel, and that the coaſts which they diſ-

7 cover

cover appear to them to be in motion; and no one thinks of finding fault with their uſing the common modes of expreſſion. There is, therefore, a great difference between reſt and motion, real or abſolute, and between reſt and motion apparent, or relative to a body, conſidered at the time as in a ſtate of reſt, though perhaps it may be in motion. The principles or laws of motion refer chiefly to the abſolute ſtate of bodies, that is, to their reſt or motion, real or abſolute. In order to diſcover theſe laws, we begin with conſidering a body ſingly and abſtractedly from all others.

This hypotheſis, though it never can take place, is, in reality, very proper to aſſiſt us in diſtinguiſhing what is operated by the nature of body itſelf, from that which other bodies are capable of operating upon it.

Let a body, then, be alone, and at reſt; it may be aſked, Will it continue at reſt, or will it begin to move? As there is no reaſon which ſhould incline it to move to one ſide rather than to another, it is concluded that it would remain always at reſt. The ſame thing muſt happen, on the ſuppoſition of the exiſtence of other bodies, provided they do not act on the body in queſtion; hence reſults this fundamental law: *When a body is once in a ſtate of reſt, and nothing external acts upon it, it will remain always in that ſtate: and if it begin to move, the cauſe of motion would be out of it, ſo that there is nothing in the body itſelf which is capable of putting it in motion.* When, therefore, we ſee a body which has been at reſt begin to move, we may reſt aſſured that this motion has been occaſioned by an exterior power, as there is nothing in the body itſelf capable of putting it in motion; and if it were alone, and cut off from all communication with other bodies, it would remain always at reſt.



However well founded this law may be, and however entitled to rank with geometrical truths, there are perſons little accuſtomed to profound inveſtigation, who pretend that it is contradicted by experience. They allege the example of a thread, to which a ſtone is appended; the ſtone is at reſt, but falls the moment that the thread is cut. It is certain, ſay they, that the action by which the thread is cut is not capable of making the ſtone move; the ſtone, therefore, muſt fall by a power which is proper to itſelf, and internal.

The fact is certain; but it is evident, at the ſame time, that gravity is the cauſe of the deſcent, and not an internal power in the ſtone.

They ſay farther, that gravity may be an intrinſic power, attached to the nature of the ſtone; on which it muſt be remarked, that gravity is produced either by a ſubtile matter, or by the attraction of the earth. In the firſt caſe it certainly is that ſubtile matter which cauſes the deſcent of the ſtone; in the ſecond, which appears favourable to our opponents, it can with no propriety be affirmed, that the ſtone deſcends by an intrinſic power; it is rather the earth which contains the cauſe of it, and which produces the deſcent of the ſtone, by it's attractive power: for

for if the earth did not exiſt, or were deprived of it's attractive power, they admit that the ſtone would not deſcend.

It is certain, therefore, that the cauſe of the deſcent does not reſide in the ſtone itſelf: the cauſe, then, is always extrinſic, whether it be in the ſubtile matter or in the earth, ſuppoſing it to be endowed with an attractive power, as the partiſans of attraction pretend. This difficulty being removed, the law, which I have laid down, ſubſiſts in full force; namely, That a body, once at reſt, will always remain ſo, unleſs it be put in motion by ſome foreign cauſe. This law muſt take place, provided the body has been at reſt but a ſingle inſtant, though it was in motion immediately before; and, when once reduced to a ſtate of reſt, it will always preſerve that ſtate, unleſs ſome foreign cauſe intervene to put it again in motion. This principle being the foundation of all mechanics, it was neceſſary for me to eſtabliſh it with all poſſible preciſion.

*28th October*, 1760.

## LETTER LXXII.

### *Of uniform, accelerated, and retarded Motion.*

I RETURN to the caſe of a body placed in ſuch a manner as to have no connection with any other. Let us ſuppoſe it to have received ſome motion from whatever cauſe; it remains that we enquire, What





will afterwards happen to it? Will it continue to move? Or will it ſuddenly return to a ſtate of reſt; or after ſome time? You muſt be ſenſible, that this is an enquiry of ſome importance, and that all our reſearches reſpecting the motion of bodies depend upon it. Let us examine if, by means of reaſoning, we are able to reſolve it.

A body is at reſt, as long as it, and all it's parts, remain in the ſame place; and it is in motion when that body, or ſome of it's parts only, paſs from one place to another. Now, there are two things to be conſidered in motion, the direction and the velocity. The direction is the place toward which the body is carried, and the velocity is the ſpace, greater or leſs, through which it moves in a certain time. I am perſuaded you have already juſter ideas of this than I could communicate by the moſt ample explanation. I remark only, that as long as a body preſerves the ſame direction, it moves in a ſtraight line; and reciprocally, as long as a body moves in a ſtraight line, it preſerves the ſame direction; but when it moves in a curve, it is continually changing it's poſition.

If a body, then, (*plate* III. *fig.* 7.) moves in the curve A B C; when it is at A, it's direction is the ſmall line A *a*; when it is at B, it's direction is the ſmall line B *b*; and at C, the ſmall line C *c*. Let theſe ſmall lines be produced; the continuations of which are marked by the ſtraight dotted lines A L, B M, C N; and it will be affirmed, that when the body paſſes through A, it's direction is the ſtraight line A L, becauſe, if the body preſerved the ſame direction which it had at A, it would move in the ſtraight line A L. It is evident, then, that it moves in the curve only in ſo far as it is continually changing it's direction. And when it arrives at B and at C, the direction from which it deviates is expreſſed by the ſtraight lines B M and C N.*

A body preſerves the ſame velocity in it's motion as long at it moves through equal ſpaces in equal times. This motion is called *uniform*. Thus, for example, if a body moves in ſuch a manner as always to proceed ten feet during every ſecond, we call this motion uniform. If another body proceeds twenty feet in a ſecond, it's motion too would be uniform, but it's velocity would be twice as great as that of the preceding.

* The argument, *cauſa ſufficiens*, or *ſufficient reaſon*, is a ſort of jargon introduced by ſome metaphyſicians in the beginning of the preſent century, which has ſtill it's advocates on the continent. To conclude that a thing is ſuch becauſe we ſee no ſufficient reaſon to the contrary, is, indeed, a ſtrange method of reaſoning. What can be more prepoſterous than to employ our ignorance as the inſtrument of diſcovering truth? And yet this is the plain ſtatement of the argument. The inſtance mentioned in the text, is a noted one, though the ingenious Father *Boſcovich* remarks, that any inference whatever may with equal juſtice be drawn from the ſame premiſes. Thus, we may ſay, that no ſufficient reaſon can be given that a moving body A ſhould approach a point B, rather than recede from it; it will, therefore, keep conſtantly at the ſame diſtance, and, conſequently, deſcribe a circle about that point. Hence bodies move not in ſtraight lines, but in circles. In the ſame manner we might ſay that motion is not uniform, and indeed prove any thing we pleaſe. The fact is, that we derive no part of our knowledge from any abſtract reaſoning on the nature of things.

From



From what I have juſt ſaid of the uniformity of motion, it is eaſy to comprehend what is not uniform motion; for when the velocity of a body is not equal, it's motion is not uniform. When the velocity of a body goes on increaſing, it's motion is ſaid to be *accelerated*, and when it is continually diminiſhing, we ſay it is *retarded*. In this laſt caſe, the velocity may come to be retarded to ſuch a degree, that the body ſhall at length come to a ſtate of reſt.

Having made theſe remarks on the velocity and direction of moving bodies, I return to the caſe of a ſolitary body, which I ſuppoſe to be put in motion by any cauſe whatever. As ſoon as it has begun to move, it muſt have acquired a certain direction, and a certain velocity: and the queſtion is, Will it afterwards preſerve the ſame direction and the ſame velocity; or, Will it undergo ſome alteration? We cannot affirm that it will be reduced to a ſtate of reſt in an inſtant, for, in this caſe, it could not have had any motion, all motion ſuppoſing duration, however ſhort. Now, as long as the motion laſts, it is certain that the direction will remain the ſame.

In truth, it is impoſſible to conceive why the body ſhould go out of it's road, to one ſide rather than to another; and, as nothing comes to paſs without reaſon, it follows, that the body in queſtion will always perſevere in the ſame direction, or, that it's motion will proceed in a ſtraight line, which is a great ſtep made toward the deciſion of the queſtion.

It is likewiſe maintained, that the velocity of the



body,

body, of which I ſpeak, cannot change: for in that caſe it muſt either increaſe or diminiſh, and no reaſon can be aſſigned capable of producing this change. Hence it is concluded, that this body will always continue to move with the ſame velocity, and in the ſame direction, or that it will proceed continually in the direction of a ſtraight line, without ever deviating from it, and always with equal ſpeed. This motion will be performed, then, always in a ſtraight line, and with an equal velocity, without ever being ſlackened or retarded; the body, therefore, will never be reduced to a ſtate of reſt.

What has been ſaid of a body, which I have ſuppoſed ſolitary, would happen in like manner to our globe, if no other bodies had any influence upon it, for then it would be the ſame thing as if they did not exiſt. The queſtion, then, is reſolved. A body in motion will always preſerve it in the ſame direction, and with the ſame velocity, unleſs ſome external cauſe interpoſe, capable of altering it's motion. So long, therefore, as a body is not ſubject to the action of ſome external cauſe, it will remain at reſt, if it has once been in a ſtate of reſt; or will be moved in the direction of a ſtraight line, and always with the ſame velocity, if it has once been put in motion; and this is the firſt and principal law of nature on which the whole ſcience of motion muſt be founded.

From it we deduce at once this concluſion, that as often as we ſee a body which was at reſt put in motion, or a body moving in a curve line, or whoſe velocity



locity changes, it is certain, that an external cauſe acts upon it. No change can poſſibly take place either as to direction or velocity, but what is the operation of a foreign cauſe.

*1ſt November, 1760.*

## LETTER LXXIII.

*Principal Law of Motion and Reſt. Diſputes of Philoſophers on the Subject.*

WITH whatever ſolidity this principle is eſtabliſhed, that every body put in motion continues to move in the ſame direction, and with the ſame velocity, unleſs ſome exterior cauſe interpoſe to derange this motion; it has, nevertheleſs, been combated by certain philoſophers, who have never made any great progreſs in the ſcience of motion; while thoſe to whom we are indebted for all the great diſcoveries which have been made in this ſcience, unanimouſly agree, that all their reſearches have proceeded entirely on this principle. It is attacked by two ſects of philoſophers, whoſe objections I proceed to propoſe, and ſhall endeavour to refute.

It is alleged by the one, That all bodies have a propenſity to reſt, which is their natural ſtate, and that motion is to them a ſtate of violence; ſo that when a body is put in motion, it has a tendency, from it's very nature, to return to the ſtate of reſt; and that it makes every effort to deſtroy it's motion,



indepen-

independently of every external or foreign cauſe. They allege, in proof, experience, ſo convincing, according to them, that we know of no motion in nature that does not very ſenſibly betray this reluctance. Do we not ſee, ſay they, on the billiard table, that with whatever force we ſtrike a ball, it's motion is quickly ſlackened, and it ſoon returns to a ſtate of reſt. As ſoon as the motion of a clock ceaſes to be kept up by the external force which ſet it a going, it ſtops. It is remarked of all machines in general, that their motion laſts no longer than the external powers by which they are agitated. Hence they conclude, that a body put in motion is ſo far from preſerving it from any thing in it's own nature, that, on the contrary, an external force muſt be employed to keep it up.

You muſt be ſenſible that, if this concluſion is juſt, our principle is completely ſubverted; as, in virtue of this principle, the ball and the machines in queſtion, once put in motion, muſt always preſerve the ſame, unleſs external cauſes have occaſioned ſome change in it. Thus, in the experiments referred to, had there been no external cauſe which tended to deſtroy the motion, we ſhould have been under the neceſſity of abandoning our principle.

But, if we attend to every thing, we ſhall find ſo many obſtacles oppoſed to the motion, that we need no longer wonder it ſhould be ſo ſpeedily extinguiſhed. In fact, it is firſt the friction on the billiard table which diminiſhes the motion of the ball, for it cannot advance without rubbing againſt the cloth.

Again,



Again, the air being a ſubſtance, cauſes likewiſe a reſiſtance capable of diminiſhing the motion of bodies. To be convinced of this, you have only to move your hand rapidly through the air. It is evident, then, that in the caſe of the billiard table, it is the friction and the reſiſtance of the air which counteract the motion of the ball, and ſoon reduce it to a ſtate of reſt.

Now, theſe cauſes are external, and it is eaſily comprehenſible that, but for theſe obſtacles, the motion of the ball muſt have always continued. The ſame reaſoning is applicable to machines of all kinds, in which the friction which acts on the different parts is ſo conſiderable, that it is viſibly a very ſufficient cauſe of ſoon reducing the machine to reſt.

Having, then, diſcovered the real cauſes which produce, in the caſes alleged, the extinction of motion, and that theſe cauſes are external, and not reſident in the moving body, it is evidently falſe, that bodies have in their nature a propenſity to reſt. Our principle, therefore, ſubſiſts in full force, and even acquires additional ſtrength from the preceding objections. Every body, then, always preſerves the motion which it has once received, unleſs foreign cauſes interpoſe to change the direction or the velocity, or both at once. And thus we have got rid of one phalanx of the adverſaries who combat our principle.

The other is more formidable, for they are no leſs than the celebrated Wolfian philoſophers. They do not, indeed, openly declare againſt our principle, nay

they

they even expreſs much reſpect for it; but they advance others which directly oppoſe it.

They maintain, That all bodies, in virtue of their nature, are making continual efforts to change their ſtate; that is, when they are at reſt, they make an effort to move; and, if they are in motion, make continual efforts to change their velocity and direction. They allege nothing in proof of this aſſertion, except certain crude reaſonings, drawn from their ſyſtem of metaphyſics, which I ſhall hereafter take occaſion to lay before you. I only remark, at preſent, that this opinion is contradicted by the principle which we have ſo firmly eſtabliſhed; and by experience, which is in perfect conformity with it.

In fact, if it be true that a body at reſt remains, in virtue of it's nature, in that ſtate, it muſt be undoubtedly falſe that it ſhould make, in virtue of it's nature, continual efforts to change it's ſtate. And if it be true that a body in motion preſerves, in virtue of it's nature, this motion, in the ſame direction, and with the ſame velocity, it is impoſſible that the ſame body ſhould, in virtue of it's nature, be making continual efforts to change it's motion.

Theſe philoſophers, in attempting to maintain, at the ſame time, the true principle of motion, and their own abſurd opinion, have fallen into ſelf-contradiction, and thereby ſubverted their own ſyſtem. It is, therefore, placed beyond the reach of diſpute, that our principle is founded in the very nature of body, and that whatever is contrary to it ought to be baniſhed from ſound philoſophy: and this ſame principle



ciple enables us to clear it of certain ſubtilties in which it has been involved.

This principle is commonly expreſſed in the two following propoſitions: Firſt; *A body once at reſt will remain eternally at reſt, unleſs it be put in motion by ſome external or foreign cauſe:* Secondly; *A body once in motion will preſerve it eternally, in the ſame direction, and with the ſame velocity; or will proceed with an uniform motion, in a ſtraight line, unleſs it is diſturbed by ſome external, or foreign cauſe.* In theſe two propoſitions conſiſts the foundation of the whole ſcience of motion, called *mechanics.*

*4th November,* 1760.

## LETTER LXXIV.

### *Of the* Inertia *of Bodies: Of Powers.*

AS we ſay, that a body, ſo long as it is at reſt, remains in the ſame ſtate, ſo we likewiſe ſay of a body in motion, that as long as it moves in the ſame direction, and with the ſame velocity, it remains in the ſame ſtate. To continue in the ſame ſtate, then, ſignifies nothing more than to remain at reſt, or to preſerve the ſame motion.

This manner of ſpeaking has been introduced for the purpoſe of expreſſing more ſuccinctly our grand principle, that every body, in virtue of it's nature, preſerves itſelf in the ſame ſtate, till an extraneous cauſe come to diſturb it, that is, to put the body in motion when at reſt, or to derange it's motion.

It

It muſt not be imagined that a body, in order to preſerve the ſame ſtate, muſt remain in the ſame place; this, indeed, is the caſe when the body is at reſt; but when it moves with the ſame velocity, and in the ſame direction, we ſay, equally, that it continues in the ſame ſtate, though it is every inſtant changing it's place. It was neceſſary to make this remark, to prevent the poſſibility of confounding change of place with that of ſtate. If it be now aſked, Why bodies continue in the ſame ſtate? The anſwer muſt be, that this is in virtue of their peculiar nature.

All bodies, in as far as they are compoſed of matter, have the property of remaining in the ſame ſtate, if they are not drawn out of it by ſome external cauſe. This, then, is a property founded on the nature of bodies, by which they endeavour to preſerve themſelves in *the ſame ſtate*, whether of reſt or motion. This quality with which all bodies are endowed, and which is eſſential to them, is called *inertia*,* and it enters as neceſſarily into their conſtitution as extenſion and impenetrability; to ſuch a de-

* We have already in common uſe, in our own language, the adjective *inert*, and the adverb *inertly*, and their meaning is generally underſtood. But hitherto no author of name, except in works of philoſophy, has ventured to introduce the correſpondent ſubſtantive noun into general compoſition, much leſs to clothe it with an Engliſh form. The Latin term *inertia* is, therefore, retained in this tranſlation. The linguiſt and the philoſopher need no interpretation. The unlearned reader is referred to what Mr. Euler ſays in the context, or to the explanation of foreign and ſcientific terms affixed to this work.—*E. E.*

gree,



gree, that it would be impoſſible for a body to exiſt, diveſted of this *inertia*.

This term was firſt introduced into philoſophy by thoſe who maintained that all bodies have a propenſity to reſt. They conſidered bodies as ſomewhat reſembling indolent perſons, who prefer reſt to exertion, and aſcribed to bodies an averſion to motion, ſimilar to that which ſluggards have for labour; the term *inertia* ſignifying nearly the ſame thing as ſluggiſhneſs. But though the falſeneſs of this opinion has been ſince detected, and though it is certain that bodies remain equally in their ſtate of motion, as in that of reſt, yet the term *inertia* has been ſtill retained to denote in general the property of all bodies to continue in the ſame ſtate, whether of reſt or of motion.*

The exact idea of *inertia*, therefore, is a repugnance to every thing that has a tendency to change the ſtate of bodies; for as a body, in virtue of it's nature, preſerves the ſame ſtate of motion, or of reſt, and cannot be drawn out of it but by external cauſes, it follows that, in order to a body's changing it's

* The diſtinguiſhing property of inanimate matter is it's abſolute paſſiveneſs or want of diſpoſition to change it's ſtate, whether that of reſt, or of motion. The term *inertia* is improper, ſince it conveys an idea of ſluggiſhneſs, or a reluctance to be put in motion; whereas bodies are obedient to the ſmalleſt impulſe, and the action generated is ever proportioned to the force. The expreſſion *vis inertiæ*, commonly uſed, is really a contradiction of terms. Indeed, it would be no diſſervice to natural philoſophy, if the law that "action and re-action are equal and oppoſite," were entirely omitted.—*E. E.*

ſtate,

ſtate, it muſt be forced out of it by ſome external cauſe: without which it would always continue in the ſame ſtate. Hence it is, that we give to this external cauſe the name of *power* or *force*. It is a term in common uſe, though many by whom it is employed have but a very imperfect idea of it.

From what I have juſt ſaid you will ſee that the word *force* ſignifies every thing that is capable of changing the ſtate of bodies. Thus, when a body which has been at reſt is put in motion, it is a force which produces this effect; and when a body in motion changes it's direction, or velocity, it is likewiſe a force which produces this change. Every change of direction, or of velocity, in the motion of a body, requires either an increaſe or a diminution of force. Such force, therefore, is always out of the body whoſe ſtate is changed; for we have ſeen that a body left to itſelf, preſerves always the ſame ſtate, unleſs a force from without acts upon it.

Now, the *inertia* by which a body tends to preſerve itſelf in the ſame ſtate, exiſts in the body itſelf, and is an eſſential property of it: when, therefore, an external force changes the ſtate of any body, the *inertia* which would maintain it in the ſame ſtate, oppoſes itſelf to the action of that force; and hence we comprehend, that the *inertia* is a quality ſuſceptible of meaſurement, or that the *inertia* of one body may be greater or leſs than that of another body.

But bodies are endowed with this *inertia* in as far as they contain matter. It is even by the *inertia*, or the reſiſtance which they oppoſe to every change of ſtate,



ſtate, that we judge of the quantity of a body; the *inertia* of a body, accordingly, is greater in proportion to the quantity of matter which it contains. Hence we conclude, that it requires a greater force to change the ſtate of a great body, than that of a ſmall one; and we go on to conclude, that the great body contains more matter than the ſmall one. It may even be affirmed that this ſingle circumſtance, the *inertia*, renders matter ſenſible to us.

It is evident, then, that the *inertia* is ſuſceptible of meaſurement, and that it is the ſame with the quantity of matter which a body contains: as we denominate, likewiſe, the quantity of matter in a body, it's maſs, the meaſure of the *inertia* is the ſame as that of the maſs.

To this, then, is reduced our knowledge of bodies in general. Firſt, we know, that all bodies have an extenſion of three dimenſions; ſecondly, that they are impenetrable; and hence reſults their general property, known by the name of *inertia*, by which they preſerve themſelves in their ſtate; that is, when a body is at reſt, by it's *inertia* it remains ſo; and when it is in motion, it is likewiſe by it's *inertia* that it continues to move with the ſame velocity, and in the ſame direction; and this preſervation of the ſame ſtate laſts till ſome external cauſe interpoſe to produce a change in it. As often as the ſtate of a body changes, we muſt never look for the cauſe of ſuch change in the body itſelf; it exiſts always out of the body, and this is the juſt idea which we muſt form of a power or force.

*8th November*, 1760.

## LETTER LXXV.

*Changes which may take place in the State of Bodies.*

THE fundamental principle of mechanics, with the idea of *inertia*, which I have endeavoured to explain, enables us to reaſon on ſolid ground reſpecting various phenomena preſented to us in nature. On ſeeing a body in motion, which ſhould proceed uniformly in a ſtraight line, that is, which ſhould preſerve the ſame direction, and the ſame velocity, we would ſay, that the cauſe of this continuation of motion is not to be found out of the body, but that it is founded in it's very nature, and that, in virtue of it's *inertia*, it remains always in the ſame ſtate; as we would ſay, were the body at reſt, that this took place in virtue of it's *inertia*.

We would likewiſe be right in ſaying that this body undergoes no action from any external cauſe; or, if any ſuch exiſted, that theſe powers reciprocally deſtroyed each other in ſuch a manner that the body is in the ſtate in which it would be if no force acted upon it.

If it is aſked, then, Why the body continues to move in this manner? The anſwer is obvious. But if it is aſked, Why this body has begun thus to move? The queſtion is totally different. It muſt be ſaid, that this motion has been impreſſed upon it by ſome external force, if it was before at reſt; but it would be impoſſible to affirm any thing with certainty



tainty reſpecting the quantity of that force, becauſe, perhaps, no traces of it remain. It is, therefore, abundantly ridiculous to aſk, Who impreſſed motion on every body at the beginning of the world? Or, Who was the prime mover? Thoſe who put the queſtion admit, then, a beginning, and, conſequently, a creation; but they imagine that God created all bodies at reſt. Now, it may be anſwered, That he who could create bodies could impreſs motion upon them. I aſk them, in my turn, If they believe it to be more eaſy to create a body at reſt than in motion? They both equally require the omnipotence of God, and this queſtion belongs not to the province of philoſophy.

But when a body has once received motion, it preſerves that motion by it's own nature, or by it's *inertia*, in the ſame ſtate in which it muſt conſtantly remain, until a force, or ſome foreign cauſe, oppoſe an obſtacle to it. As often, then, as we obſerve that a body does not remain in the ſame ſtate, that a body at reſt begins to move, or that a body in motion changes it's direction, or velocity, we muſt admit that this change has it's cauſe out of the body, and that it is occaſioned by a foreign force. Thus, as a ſtone, left to itſelf, deſcends, the cauſe of that deſcent is foreign to the body, and it is not from it's own nature that the body deſcends, but from the effect of a foreign cauſe, to which we give the name of *gravity*.

Gravity, then, is not an intrinſic property of body; it it is rather the effect of a foreign force, the ſource of which muſt be ſought for out of the body. This is geometrically true, though we know not the foreign forces which occaſion gravity. It is the ſame when we throw a ſtone. We ſee clearly, that it does not follow, in it's motion, the direction of a ſtraight line, and that it's velocity does not always continue the ſame. It is gravity, likewiſe, which changes the direction or the velocity of the body; but for it, the ſtone would deſcribe a ſtraight line in the air, and proceed forward with the ſame velocity; and were gravity to be ſuddenly annihilated, during the motion of the ſtone, it would continue to move in a ſtraight line, and would preſerve the ſame direction, and the ſame velocity, which it had at the inſtant when gravity ceaſed to act upon it.

But as gravity acts continually, and upon all bodies, we need not be ſurprized, that we meet with no motion in which the direction and the velocity continue the ſame. The caſe of reſt may very well take place; it is when ſomething invincibly oppoſes the fall of a body; thus the floor of my apartment prevents my falling into that below it. But the bodies which appear to us at reſt, are carried along by the motion of the earth, which is neither rectilinear nor uniform: it cannot be affirmed, therefore, that theſe bodies remain in the ſame ſtate. Neither is there one of the heavenly bodies which moves in a ſtraight line, and always with the ſame velocity: they are continually changing their ſtate; and even the forces which pro-





duce this continual change are not unknown to us; they are the attractive powers which the heavenly bodies exerciſe over one another.

I have already remarked, that theſe forces may, very probably, be cauſed by the ſubtile matter which ſurrounds all the heavenly bodies, and fills the whole ſpace of the heavens; but, according to the opinion of thoſe who conſider attraction as a power inherent in matter, this force is always foreign to the body on which it acts. Thus, when we ſay the earth is attracted toward the ſun, it is acknowledged, that the force which acts upon the earth is not reſident in the earth itſelf, but in the ſun; as in fact, if the ſun did not exiſt, there would be no ſuch force.

This opinion, however, that attraction is eſſential to all matter, is ſubject to ſo many other inconveniences, that it is hardly poſſible to allow it a place in a rational philoſophy. It is certainly much ſafer to proceed on the idea, that what is called attraction, is a power contained in the ſubtile matter which fills the whole ſpace of the heavens; though we cannot tell how. We muſt accuſtom ourſelves to acknowledge our ignorance on a variety of other important ſubjects.

*11th November, 1760.*