of the glass exceeds in magnitude the image of the sun, named its *focus*, from which, if the glass be very great, you may produce the greatest effects of heat. Combustible substances placed in the focus of such a glass, are instantly consumed. Metals are melted, and even vitrified by it; and other effects are produced far beyond the reach of the most active and intense fire.

The reason is the same as in the case of burning mirrors. In both, the rays of the sun, diffused over the whole surface of the mirror or glass, are collected in the small space of the sun's image. The only difference is, that in mirrors the rays are collected by reflection, and in glasses by refraction. Such is the effect of convex glasses, which are thicker in the middle than at the extremities, and which I have represented in Nos. II. IV. and VI. Those represented 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 I. *Fig.* 24.) be a glass of this form. If you expose to it, at a great distance, 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 glass in the direction of A *l*, C *m*, and B *n*, as if they had issued from the point *g*; and an eye placed behind the glass, at *m*, for example, will see the object just as if it were placed at *e g f*, and in a situation similar to that in which it is at the point G, but as many times smaller as the distance C G exceeds the distance G *g*. Convex glasses, then, represent the image of a very distant object behind them, concave glasses represent it before them; the former represent it inverted, and the latter in its real situation. In both the image is as many times smaller as the distance of the object from the glass exceeds that of the glass from the image. On this property of glasses is founded the construction of telescopes, spectacles, and microscopes.

11*th August* 1760.

Letter XL.—Continuation. Of Burning Glasses, and their Focus.

Convex glasses furnish some farther remarks, which I beg leave to lay before you. I speak here of those glasses in general which are thicker in the middle than at the extremities; whether both surfaces be convex, or one plain and the other convex; or, finally, one concave and the other convex; provided, however, that the convexity exceed the concavity, or that the thickness be greater at the middle than at the extremities. It is farther supposed, that the glasses have a spherical figure.

They have first this property, that being exposed to the sun, they present 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 reason is, that all the rays issuing from 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 I. *Fig.* 25.) 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 will be to its surface. With regard to the distance, if you bring the object E F nearer to the glass, its 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 its 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 its focus at the distance of 600 feet.* I am convinced it was of no great value; but they wished to have it on account of its rarity.

To be satisfied that the representation of the image *e g f*, in Figure 25, 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

* The largest lenses ground by Campani of Bologna, had a focal length of 100 and 136 feet. Huygens presented to the Royal Society two lenses, one of which was 120, and the other 123 feet in focal length.—Ed.

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.*

13*th August* 1760.

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 per-

* The theory of light adopted and illustrated by Euler in the preceding letters, was originally proposed by Huygens, in his *Traité de la Lumiere*, published in 1690. In this ingenious work he has shown how all the phenomena of refraction and reflection may be explained and calculated, by the hypothesis, that light consists of undulations of an ethereal medium; and he considers it as supported by the phenomena of double refraction. Notwithstanding the attempts of Euler to revive this theory, it fell into total neglect, and was received in no part of Europe as a branch of sound physics.

About the year 1800, Dr. Thomas Young ventured to maintain it, almost single-handed, against the rest of the philosphical world. He pointed out its applicability to explain a great variety of natural phenomena, that could not be referred to any general principle; and by his discovery of the law of interference, he may be said to have established the theory of undulations. The singular phenomena of the polarization, and the double refraction of light, which were afterwards discovered, have successively found an explanation in the theory of undulations; and some of the recent discoveries in that branch of optics may be considered as placing it upon the firmest basis.

The Newtonian doctrine, of the emanation of luminous particles, we have always regarded as the true one. A partiality for the name of its great founder,—the simplicity with which it explains the general phenomena, and perhaps a portion of national feeling, have conspired to give it permanency in this country. The force of truth, however, compels us to acknowledge, that the theory of undulations is likely to be soon adopted by every philosopher who has studied the vast variety of phenomena which it embraces and explains. An account of the Huygenian theory of light will be found in the *Edinburgh Encyclopædia*, Art. Optics, vol. xv. p. 524.—ED.

fect 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 I. *Fig.* 26.) 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 resembling in form a small burning glass; it is perfectly transparent, and is covered with a thin membrane, called its *Capsule*. Behind the crystalline humour the cavity of the eye is filled with a transparent jelly, called the *vitreous humour*. The anterior space between the thick coat *a* A *b*, and the crystalline *a b*, contains a fluid like 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 anterior coat, 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 surpass 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 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 dexterous anatomist is unable to pursue these nerves to their source—the union of the soul with the body must for ever remain a mystery.

15*th 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 *m m*, 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 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 when 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 experiencing a 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 it is so enlarged, as almost to occupy the 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 vision; 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.

* Although we cannot do this by muscular exertion, yet by putting a drop of the juice of the Belladonna, or of the Hyoscyamus, upon the eye, the pupil will dilate itself in an extraordinary degree, and retain itself in that state for *one* or *two* hours.—Ed.

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, 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 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 satisfactory 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.

17*th August* 1760.

Letter XLIII.—Farther Continuation.—Astonishing difference between the Eye of an Animal, and the Artificial 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 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 this 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 I. *Fig.* 27.) 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, that it does not completely collect in one and the same point the rays which pass through its centre, and those which pass through its extremities. There is always a small difference, though almost

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 itself, it would render vision very confused.

The persons to whom I have been alluding, allege, that it may be possible to find another figure for the surfaces of the lens, which shall have the property of collecting anew all the rays issuing from the point O, in a point R, whether they pass through the centre or through the extremities. I admit that this may be possible; but supposing the lens to possess this property with respect to the point O, at the fixed distance C O, it would not possess it at points at a greater or less distance from the lens; or even admitting this to be possible, which it is not, the lens would most certainly lose that property with regard to objects placed on one side, at T, for instance. Accordingly we see, when objects are represented on white paper, that though such as are directly before the lens, as at O, may be sufficiently well expressed, yet those which are obliquely situated, as at T, are always much disfigured, and very confusedly represented: and this is a defect which the most ingenious artist is incapable of rectifying.

But there is another, and one not less considerable. In speaking of rays of different colours, I remarked, that in passing from one transparent medium to another, they undergo a different refraction; that rays of a red colour undergo the least refraction, and violet-coloured rays the greatest. Hence, if the point O were red, and if its rays, in passing 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 assemblage of all the simple colours, a white object, placed at O, would form several images at once, situated at different distances from the point O; the result of which would be, on the retina, a coloured spot that would greatly disturb the representation.

It is accordingly observable, that when in a dark room the external objects are represented on white paper, they appear bordered with the colours of the rainbow; and it is impossible to remedy this defect by employing only one transparent body. But it has been remarked, that this may be done by means of different transparent substances; but neither theory nor practice have hitherto been carried to the degree of perfection necessary to the execution of a structure which should remedy all these defects.

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 characterize 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 masterpiece 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!

19*th August* 1760.

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 really 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 its 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 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 on a part within 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 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 limit. 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 piecee of 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. *

21*st 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.

* The wonders of the human eye, so well pointed out by Euler, are still greater than he conceived. He was not acquainted with the fact, that the *crystalline lens* diminishes in density from the centre to the circumference, that it is composed of successive concentric laminæ, and that each of these laminæ consists of minute transparent fibres, varying in thickness, and arranged with the most beautiful symmetry in relation to the axis of vision. In some of the lower animals the structure of the crystalline lens is more perfectly displayed than in man, and exhibits most striking phenomena, both in reference to the variations in its density, and the distribution of its fibres. The complication of its parts, in some animals, and the admirable skill with which they are suited to the various purposes of their existence, exceed all description, and confound all human intelligence.—Ed.

† The subject of optics is resumed by our Author in the 2d. volume.—Ed.

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 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 its 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 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 surprising, 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 its gravity.

When, therefore, it is affirmed, that all bodies are heavy, no one means to deny that they may be 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; or such 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.

Except these bodies, the gravity of which is not 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.

23*d August* 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 its 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 its falling, if it rests on a table, its pressure 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 its two scales, are of equal gravity. In order 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 bodiea 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 its magnitude or extent, called likewise its 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, 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.

25*th August* 1760.

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 its influence is so universal in all our operations upon body, that we must in every instance pay attention to its 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 its parts, endowed with this force. Language itself is

regulated according to this property of bodies. The place toward which a body tends in its 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, its 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 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, its 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 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 of houses, the floors of which should be perfectly horizontal, and without the smallest declivity, because there is no water to be discharged, except in the floors of stables, which are constructed with a gentle declivity. Astronomers take great pains to have the floors of their observatories perfectly level, to correspond with the real horizon in the heavens. The vertical line, produced upward, marks the zenith.

27th August 1760.

Letter XLVIII.—Reply to certain Objections to the Earth's Spherical Figure, derived from Gravity.

You know well, that the figure of the earth is nearly that of a globe. It has, indeed, been demonstrated, that its form is not perfectly spherical, but somewhat flattened toward the poles. The difference, however, is so trifling, that it does not at all affect the object I have in view. Neither does the difference of mountain and valley excite any solid objection to its globular figure; for its diameter being 7912 English miles, whereas the highest mountains being about five English miles in height, sink into nothing, compared to this prodigious mass.

The ancients had a very imperfect notion of the real figure of the earth. It was in general considered as a huge massy substance, A B C D (Plate I, *Fig.* 28.) flattened above as A B, and covered partly with earth, partly with water. According to their idea, the surface A B alone was habitable; and it was impossible to go beyond the points A and B, which they considered as the extremities of the world. When, in the progress of discovery, it was found that the earth was nearly spherical, and universally habitable, so that there were upon the globe spots diametrically opposite to us, the inhabitants of which are therefore called our *Antipodes*, because their feet are turned directly toward ours—this opinion met with such violent contradiction, that certain fathers of the church represented it as a dreadful heresy, and thundered out anathemas against all who believed in the existence of the antipodes. A man, however, would now pass for an idiot, who would call it in question; especially since the opinion has been confirmed by the experience of navigators, who have frequently sailed round the globe. But another difficulty here presents itself, the solution of which must assist us in discovering the real direction of gravity.

If the circle A B (Plate I. *Fig.* 29.) say they, represents the earth, and we are at A, our antipodes will be diametrically opposite at B. As we, then, have the head upward, and the feet downward, our antipodes must have the feet upward and the head downward, supposing these words to indicate the same direction as when we pronounce the same 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 does not fall 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 power of gravity constrains them to preserve; and that position is similar relatively to the surface of the earth. You had, undoubtedly, no need of this explanation; but there was a time, and it is not long elapsed, when it would have been necessary even to persons who were then honoured with the appellation of the learned.

28*th August* 1760.

Letter XLIX.—True Direction and Action of Gravity relatively to the Earth.

Though the surface of the earth is unequal, because of the mountains and valleys which overspread it, it is, however, perfectly level wherever there is sea; the surface 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 spot of the surface a person was, the vertical line would be perpendicular to the surface of the water.

Thus, the figure A B C D E F G H I (PLATE I. *Fig.* 30.), representing the earth, its surface 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 so of the rest. Now, at every place the vertical line determines what is to be denominated *upward* or *downward*; to persons at A, 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 its 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 3956 English 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 I. *Fig.* 31.) 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, the 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 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 its 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 its 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 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, its 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 its quantity. This power is always determined by the weight of every body; and as bodies differ greatly with respect to weight, those which are heaviest are likewise forced downward with the greatest violence. It has been asked, Whether the same body, transported to a different place of the globe, preserves always the same weight? I speak of bodies which lose nothing by evaporation. It has been demonstrated, by undoubted experiments, that the same body weighs somewhat less toward the equator, than toward the poles of the earth.

It will readily occur to you, that it is impossible to ascertain this difference by the exactest balance, because the standard weights employed for determining the weight of matter in bodies, undergo the same variation. Thus a mass, which with us might weigh 100 pounds, being transported to the equator, would still nominally be 100 pounds weight, but the effort will be somewhat less than here. This variation has been discovered by the effect itself of the power of gravity, which is the velocity of the descent; for it is found that the same body, under the equator, does not descend with so great velocity as in high latitudes. It is certain, therefore, that the same