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.

29*th 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

body, being transported 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 its centre; it is clear, that a body at the very centre must entirely lose its gravity, as it could no longer move in any direction whatever, all those 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 descending to this centre, its gravity will be gradually diminished; and we accordingly conclude, that a body, penetrating into the bowels of the earth, loses its gravity, in proportion as it approaches the centre. You must be sensible, then, that neither the intensity nor the direction of gravity is a consequence from the nature of every body, as not only its intensity is variable, but likewise its direction, which, on passing to the antipodes, becomes quite contrary.

Having travelled, in idea, to the centre of the earth, let us return to its surface, and ascend to the summit of the loftiest mountains. We shall observe 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 if farther removed, it 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.

30*th August* 1760.

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 its 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 from 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 direction, does not come to the earth till it has got to a considerable distance; and were it fired from the top of a high mountain, it might, perhaps, fly several miles before it reached the ground. If the direction of the cannon is farther elevated, and the quantity and strength of the powder increased, the ball will be carried much farther. This might be carried so far, that the ball should not light till it had reached the antipodes: nay, farther still, till it should not fall at all, but return to the place where it was shot off; and thus perform a new tour round the globe. It would thus be a little moon, making its revolutions round the earth, like the real moon.

You will now please to reflect on the height of the moon, and the prodigious velocity with which she moves, and you will no longer be surprised that she should not fall to the earth, though forced by gravity toward its centre. There is another reflection which will place this in a clearer light. We have only to consider the path described by a stone thrown, or a cannon ball shot off, in an oblique direction. It is always a curve, such as represented in the annexed figure (PLATE I. *Fig.* 32).

Let A be the summit 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 describes 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

itself, as gravity is the only cause of its descent; much less, being fired off at A, as represented in the figure, would it ever fall to the ground. Hence we see, it is gravity that brings it down to the ground, after having described the curve A E F B; gravity, therefore, directs its path in the curve A E F B; and if it were destitute of gravity, the ball would not describe a curve, but proceed forward in the direction of the straight line A C, the direction in which it was fired off.

This being laid down, let us attend to the moon, which assuredly does not move in a straight line; her path must of necessity be a curve, as she always preserves nearly the same distance from us, and that curve almost a circle, such as you would describe round the earth, with a radius equal to the moon's distance.

It is very reasonable to demand, Why the moon does not move in a straight line? But the answer is obvious; for as gravity occasions the curved direction of the path pursued by a stone thrown, or a cannon ball fired off, there is good ground for maintaining, that gravity acts likewise upon the moon, forcing her toward the earth; and that this gravity occasions also the curved direction of her orbit. The moon, then, has a certain weight—she is, of consequence, forced toward the earth; but this weight, is 3600 times less than it would be at the surface of the earth. This is not merely a probable conjecture, but a truth demonstrated. For this gravity being supposed, we are enabled to determine, on the most established mathematical 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 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 its 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 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 the 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 its 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.

3*d September* 1760.

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 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 of the earth upon the moon to be; now the same philosopher has placed this also beyond the reach of doubt, by demonstrating, that the flux and reflux of the waters of the sea, of which I shall take occasion to speak afterwards, are caused by the attraction of the moon. It can no longer be doubted, therefore, that Jupiter and Saturn are reciprocally attracted by their respective satellites; and that the sun itself is subject to the attraction of the planets, though this attractive power be exceedingly small.

This is the origin of the system of universal attraction, in which it is maintained, and with good reason, that not only does the sun 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 sun, but also by all the other planets, though their power be almost imperceptible compared to that of the sun.

You will easily comprehend, that the motion of a planet, which is attracted not only by the sun, but by the other planets, in however small a degree,

must be somewhat different from what it would have been were it attracted by the sun only; and that consequently the attractions of the other planets must cause some small derangement of that motion. Now these derangements are likewise confirmed by experience; and this has carried the system of universal attraction to the highest possible degree of certainty, so that no one now presumes to dispute its truth.

I must likewise remark, that comets too are subject to this law; that they are principally attracted by the sun, whose action regulates their motion; but that they likewise feel the attractive power of all the planets, especially when they are not very distant from them. It is a general rule, as we shall see afterwards, that the attraction of all the heavenly bodies diminishes in proportion to the distance, and increases in proportion to the nearness. Now comets likewise are endowed with a power by which other bodies are attracted toward them, and so much the more sensibly as they approach nearer. When, therefore, a comet passes somewhat more closely to a planet, it may derange the motion of that planet by its attractive power; and its own will likewise be disturbed by that of the planet. These consequences are verified by real observation.

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 pass; 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 September 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 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 is essential to matter, the more of it any body contains, the greater is its attractive force.

As the sun, therefore, considerably surpasses all the planets in magnitude, its 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, its 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, its attractive force too would be diminished, as well as the gravity of bodies at its 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 attrac-

tion would be too small to produce any sensible effect; for if the whole mass of the earth, by its 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 be under no apprehension of its 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 placed near the loadstone, move to it with a force

* Dr. Maskelyne has more recently found, that a deviation of 5″ 8 was produced by the attraction of the mountain called *Schehallien* in Scotland, the double effect being about 11″ 6. Mr. Cavendish also succeeded in measuring the mutual attraction of balls of lead, by means of an apparatus for that purpose. Hence it was found, that the mean density of the earth was about *five* times that of *water*.—Ed.

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 does not become 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 its power is too small. But if its mass were to increase, and to become many thousands of times greater, its 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, 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 I. *Fig.* 33.) 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 its 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 its mass is, the greater or less, also, is the power with which it is attracted toward 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 so on.

In order more clearly to elucidate this remark, we have only to substitute the earth in the place of the attracting body A; then the force with which the body B is attracted, is nothing else but the weight of that body. Now, it is demonstrated, that the greater or smaller the body B is, the greater or less also is its gravity; hence it follows, that while the attracting body A, and the distance A B, continue the same, the attraction which B feels precisely follows the magnitude of that body. To express this circumstance, mathematicians employ the term *proportional*; thus they say, The body B is attracted by the body A, with a force proportional to its mass; the meaning of which is, that if the mass of body B were twice, thrice, or four times greater, the attractive power would be precisely so many times increased. Thus, with respect to the attracting body A, they say, that the power which it exercises over the body

B, is proportional to its mass, so long as that of B, and the distance A B, continue the same.

I must farther observe, that when we speak 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 considerably in this respect, and that there are some, which, in a very small compass, contain a great deal of matter, gold, for 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.

11*th September* 1760.

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 show how many times less the power of attraction has become. To put this rule in its clearest light, it must be observed, that when we multiply a number into itself, the product resulting from it is called its *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
Multiply 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 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 scheme:—

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  258
  258
 ----
 2064
1290
516
 ----
66564
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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 *reciprocally* 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 towards the fixed stars, the 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 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.

13*th 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*. Its 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 its motion. The same thing would apply to the other planets, Saturn, Jupiter, Mars, Venus, and Mercury, if they were attracted only by the sun. But the earth being attracted, not only by 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 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 its 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.

15*th 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 II. *Fig.* 4.) 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 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 II. *Fig.* 4.) represents the *Sun* at rest. You see, besides, the *Eleven* 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 little circle 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 its 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 next 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.

The next 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 seven satellites, marked by the figures 1, 2, 3, 4, 5, 6, 7. Thus, then, the solar system consists of six (now *Eleven*) primary planets, Mercury ☿, Venus ♀, the Earth ♁, Mars ♂, Jupiter ♃, Saturn ♄, and eighteen secondary planets or satellites, namely the Moon, the four attendants of Jupiter, the seven of Saturn,* and the six of the Georgium Sidus.

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

* We have added in the figure the orbits of the new Planets, discovered since the time of Euler, viz. *Ceres, Pallas, Juno,* and *Vesta,* whose orbits are situated between those of Mars and Jupiter; and the *Georgium Sidus,* which is situated beyond the orbit of Saturn. The last of these planets is attended with *Six* Satellites.—Ed.

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.

Letter LX.—The same Subject continued.

In addition to what I have said respecting the solar system, I must communicate some observations for the explanation of the figures. And, first, it must be remarked, that the lines which mark the paths in which the planets move, have no real existence in the heavens, as the whole immensity of space in which they move is a vacuum, or rather filled with that subtile matter which we call the *Ether*, and which I have already so often mentioned.

Again, the orbits of the planets are not all in the same plane, as the figure presents them: but if the orbit which the earth describes round the sun is properly represented on the paper, we must imagine the orbits of the five other planets to be partly elevated, and partly depressed, with reference to it; or that the orbit of each planet bears upon it an oblique direction, making an intersection with the paper, under a certain angle, which it is impossible to represent in a figure drawn upon a plane.

* A comet has lately been discovered, which performs its revolution within the Planetary System in 1204 days.—Ed.