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.

Farther, the orbits of the planets are not circles, as the figure appears to indicate, but rather somewhat oval, one more, another less so; no one, however, recedes very considerably from the circular form. The orbit of Venus is almost a perfect circle; but those of the other planets are more or less extended lengthwise, so that these planets are sometimes nearer to the sun, sometimes farther off.

The orbits of *Comets* are particularly distinguishable, being greatly extended in length, as I have represented it in the figure. As to the moon, and the satellites of Jupiter and Saturn, their orbits, too, are nearly circular.

Neither must we conceive them as moving in one and the same direction, as they appear on the plane of the paper; for they do not remain in the same place, but are themselves carried round the sun along with the primary planet to which they belong. It is thus we must understand the lines represented in the figure. Imagination must supply what it is impossible, on a plane surface, accurately to exhibit.

You are now enabled to comprehend with ease what the late *Mr. de Fontenelle* meant to display, in his book on the plurality of worlds. The earth, with its inhabitants, is sometimes denominated a world; and every planet, nay, every one of the satellites, has an equal right to the same appellation—it being highly probable, that each of these bodies is inhabited as well as the earth.

There are twenty-nine worlds, then, in the solar system alone. And every fixed star being a sun, round which a certain number of planets perform their revolutions, and of which some have, undoubtedly, their satellites, we have an almost infinite number of worlds, similar to our earth, considering that the number of stars, perceptible to the unassisted eye, exceeds some thousands, and that the telescope discovers to us an incomparably greater number.

If it is meant to comprehend under the name of *world* the sun, with the planets and their satellites, and which derive heat and light from him, we shall have as many worlds as there are fixed stars. But if by the term *world*, we understand the earth, with all the heavenly bodies, or all the beings which were created at once, it is clear that there can be but one world, to which we refer every thing that exists. It is in this sense the term *world* is employed in philosophy, particularly in metaphysics; it is in this sense we say, that there is but one world, the assemblage of all greated beings, past, as well as present, and future, whose existence is subject to general laws.

When, therefore, philosophers dispute, whether our world is the best or not, they proceed on the supposition of a plurality of worlds; and some maintain, that the one which exists, is the best of all those which could have existed. They consider the Deity as an architect, who, intending to create this world, traced several different plans, of which he selected the best, or that in which the greatest perfections were all combined, in the highest degree, and executed it in preference to all the others.

But the great quantity of evil that prevails, and is diffused over the surface of our globe, and which flows from the wickedness of man, suggests an important inquiry, namely, Whether it would have been possible to create a world wholly exempted from these evils?

In my opinion, a distinction must be carefully made between the plans of a world which should contain corporeal substances only, and those of another world, which should contain beings intelligent and free. In the former case, the choice of the best would be involved in very little difficulty; but in

the other, where beings intelligent and free constitute the principal part of the world, the determination of what is best is infinitely beyond our capacity; and even the wickedness of free agents may contribute to the perfection of the world in a manner which we are unable to comprehend.

It would appear that philosophers have not been sufficiently attentive to this distinction, however essential it may be. But I am too sensible of my own incapacity to enter any deeper into this difficult question.

19*th September* 1760.

Letter LXI.—Small Irregularities in the Motions of the Planets, caused by their Mutual Attraction.

In order to determine the motion of the bodies which compose the solar system, it is necessary to distinguish the primary planets, which are *Mercury*, *Venus*, the *Earth*, *Mars*, *Ceres*, *Pallas*, *Juno*, *Vesta*, *Jupiter*, *Saturn*, and the *Georgium Sidus*, from their satellites, namely, the moon, the *four* satellites of Jupiter, the *seven* of Saturn, and the *six* of the Georgium Sidus.

It has been explained to you, that these eleven planets are principally attracted toward the sun, on that the force with which they are impelled toward him is incomparably greater than the powers which they exert one upon another, because his mass is incomparably greater than that of the planets, and because they never sufficiently approach to each other to render their reciprocal attraction very considerable. Were they attracted only toward the sun, their motion would be sufficiently regular, and easily determined. But the feebler powers of which I have

been speaking, occasion some slight irregularities in their motion, which astronomers are eager to discover, and which geometricians endeavour to determine on the principles of motion.

An important question is here agitated—namely, *The powers which act upon a body being known, how to find the motion of that body?* Now, upon the principles above laid down, we are acquainted with the powers, to the influence of which every planet is subjected. Thus the motion of the earth is somewhat affected, first, by the attraction of Venus, which sometimes passes very near it; and, secondly, by that of Jupiter, which, on account of the prodigious mass of this planet, becomes considerable, though he be always at a great distance. The mass of Mars is too small to produce any perceptible effect, though he is sometimes very near us; and Saturn, though his mass be the greatest next to that of Jupiter, is too distant.

The moon, though her mass be very small, produces, however, some derangement, from her being very near the earth. The comet which appeared last year was seven times nearer to us than the sun when his distance was smallest; there is a great degree of probability, therefore, that it may have deranged the earth's motion, especially if his mass was considerable—a circumstance with which we are not acquainted. If this comet were as great as the earth, the effect must have been very considerable; but its apparent smallness induces me to believe, that its mass is much less than that of the earth, and consequently its effect must have been proportionally less. When we saw this comet, however, it had got to a great distance; at the time when it was nearest it was invisible to us, but it must have appeared very brilliant to our antipodes.

What has been said respecting the derangements occasioned in the earth's motion, takes place likewise in the other planets, regard being had to their mass, and to their proximity. As to the moon, and the other secondary planets, the principle of their motion is somewhat different. The moon is so near the earth, that the attraction she feels from hence greatly exceeds that of the sun, though the mass of this luminary be many thousands of times greater than that of the earth. Hence it is that the motion of the moon follows that of the earth, and that she remains, as it were, attached to it, which makes the moon to be considered as a satellite to our planet.

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

You perfectly comprehend, that in order to predict an eclipse, whether of the moon or of the sun, we must be able accurately to ascertain the moon's place. Now in calculating eclipses formerly, there was frequently a mistake of an hour or more, the

eclipse actually taking place an hour earlier or later than the calculation. Whatever pains the ancient astronomers took to determine the moon's motion, they were always very wide of the truth. It was not till the great *Newton* discovered the real powers which act upon the moon, that we began to approach nearer and nearer to truth, after having surmounted many obstacles which retarded our progress.

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

23*d September* 1760.

LETTER LXII.—DESCRIPTION OF THE FLUX AND REFLUX OF THE SEA.

THE attractive power of the heavenly bodies extends not only to the mass of the earth, but to all the parts of which it is composed. Thus, all the bodies which we see on the surface of the earth are attracted, not only toward the earth itself, from which

* The average error of Mayer's best tables, with the improvements of Mason, was from 1783 to 1788, 30″ in Longitude and 14″ in Latitude; whereas the average error of our present tables in 1821, is only 4″ in Longitude and 4″ in Latitude,—so rapid and unlooked for has been the progress of astronomy.—ED.

results their gravity, and the weight of every one in particular, but likewise toward the sun, and toward all the other heavenly bodies; and that more or less, according to the mass of these bodies and their distance.

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

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

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

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

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

It is this alternate increase and diminution of the water of the sea which we call its *flux* and *reflux*, or its flowing and ebbing; and more particularly, the flux denotes the time during which it increases or rises, and the reflux the time of its decrease or falling. The flux and reflux together likewise go by the name of *tide*. This alternation, then, is to be the subject of our present disquisition.

It is first of all to be remarked, that the difference between rising and falling keeps pace with the variations of the moon. At full and new moon the water rises higher than at the quarters; and about the time of the vernal and autumnal equinoxes, in the

months of March and September, this alternate motion of the sea is most considerable. A great difference is likewise observed, according to the situation of the coasts. The flux, in some places, is never more than a few feet, while, in others, the rise is forty feet and upwards. Such are the tides in the ports of *St. Malo* in France, and of *Bristol* in England.

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

26*th September* 1760.

Letter LXIII.—Different Opinions of Philosophers respecting the Flux and Reflux of the Sea.

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

In order to have a clearer comprehension of this, you must consider that in the vast extent of the ocean

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

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

Descartes, that great French philosopher, endeavoured to introduce a more rational philosophy; and remarked, that the flux and reflux of the sea was principally regulated by the moon's motion; which was indeed a very important discovery, though the ancients had already suspected a connexion between these two phenomena. For if high water or the top of the flux happen to-day at noon, it will be low water at 11 minutes after six in the evening: it will

rise till 22 minutes after midnight; and the next low water will be 33 minutes after six in the morning of the day after; and the ensuing high water, or flux, will be three quarters of an hour after noon: so that from one day to another the same tides are later by three quarters of an hour.

And as the same thing precisely takes place in the moon's motion, which rises always three quarters of an hour later than the preceeding day, it was presumable that the tides followed the course of the moon. If at any given place, for example, on the day of new moon high water happen to be at three of the clock, afternoon, you could rest assured, that ever after, on the first day of the moon, the flux would invariably be at the height at three o'clock afternoon, and that every following day it would fall later by three quarters of an hour.

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

Descartes accordingly believed that the moon, in passing over us, pressed the atmosphere, or the air which surrounds the earth, and that the air pressing on the water, in its turn, forced it to subside. Had this been the case, the water must have been depressed at the places over which the moon was, and the same effect should be produced 12 hours after, in the

ensuing tide; which, however, does not happen. Besides, the moon is too distant from the earth, and the atmosphere too low to be impressed by the moon; and admitting that the moon, or any other great body, were to pass along the atmosphere, it would be very far from undergoing any pressure from it, and still less would the sea feel this pretended pressure.

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

30*th September* 1760.

LETTER LXIV.—EXPLANATION OF THE FLUX AND REFLUX, FROM THE ATTRACTIVE POWER OF THE MOON.

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

The attractive power of the heavenly bodies having been already sufficiently established by so many other phenomena, as I have shown, it could not be doubted that the flux and reflux of the sea must be an effect of it. As soon as it is demonstrated that the moon, as well as the other heavenly bodies, is endowed with the property of attracting all bodies in the direct ratio of their mass, and in the inverse ratio of the square of their distance, it is easily com-

prehended that its action must extend to the sea; and the more so, as you must frequently have observed, that the smallest force is capable of agitating a fluid. All that remains, therefore, is to inquire, Whether the attractive power of the moon, such as we suppose it, is capable of producing in the sea the agitation known to us by the name of flux and reflux.

Let the annexed figure (PLATE II. *Fig.* 1.) represent the earth and the moon. A is the place where we see the moon over the earth; B that which is directly opposite, or the antipodes of A; and C is the centre of the earth. As the point A is nearer the moon than the point B, a body at A is more powerfully attracted toward the moon than a similar body at B. And if we suppose a third similar body to be placed at the centre of the earth C, it is evident that the body A will be more powerfully attracted toward the moon than the body C, and this last than the body B, because the body A is nearer to the moon, and the body B more remote than the body C. But similar bodies placed at E and F, are almost as much attracted by the moon as that which is at the centre of the earth C, as they are all three nearly equidistant from the moon.

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

To these differences in the action of the moon on bodies differently situated, we must here chiefly pay attention; for if all bodies were equally attracted toward the moon, they would equally obey this

power, and no derangement could take place in their mutual situation.

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

But this is not the case with the sea, as all the particles of a fluid are easily separated from each other, and every one may obey the impressions which it receives. It is evident, then, that when the powers which act on the different parts of the sea are not equal to one another, an agitation, or derangement, must be the consequence.

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

one day to another three quarters of an hour, which is confirmed by constant experience.

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

4th October 1760.

LETTER LXV.—THE SAME SUBJECT CONTINUED.

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

But a body being at A (PLATE II. *Fig.* 1.), nearer the moon than the centre of the earth C, is more powerfully attracted to it than a body at C would be; it will approach it, then, with greater velocity than this last: from hence it necessarily follows, that the body A retires from the centre C, and approaches the moon; as if there were two chariots, the one at A, the other at C, and if the chariot A were drawn toward L with greater force than the chariot C, it would remove from C. It is thus that the power of the moon has a tendency to withdraw the point A from the centre C.

Now, to remove a body from the centre of the earth is to raise it; and the water at A being now the thing in question, it is certain that the force of the moon tends to raise the water which is at A, by a power equal to the excess of the attraction toward

the moon felt at A, above that felt at C. By this power, then, the moon raises the waters of the earth which are immediately under her.

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

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

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

According to this system, at the place of the sea, where the moon is in the zenith, its power has a tendency to raise the waters; about six hours after, when she has reached the horizon, her power has a tendency to make them fall. Twelve hours and

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

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

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

7th October 1760.

LETTER LXVI.—THE SAME SUBJECT CONTINUED.

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

to *Newton*, she acts by attraction, and forces the water to rise at these very places.

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

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

But the system of *Descartes* is overturned by this single phenomenon, that the sea is always in the same state after a period of twelve hours and twenty-two minutes, or that its state is always the same, whether the moon be above or below the horizon; and it is impossible for its supporters to show how the moon, being over the heads of our antipodes, can produce the same effect as when she is over ours. For this purpose, see PLATE II. *Fig.* 2.

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

and if she were at N, it is impossible that the water at A should undergo the same pressure.

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

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

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

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

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

11*th October* 1760.

LETTER LXVII.—THE SAME SUBJECT CONTINUED.

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

full, than when she is in her quarters, there would be no difficulty in the question, as her proximity would increase her power. But though the moon approaches the earth sometimes more, sometimes less, the difference is always too small to occasion a change so considerable in the flux and reflux of the sea.

Besides, this difference is not regulated by the new and full moon; and it may happen that the moon, in the intermediate quarters, should be nearer to us than when she is new or full. We must have recourse, therefore, to another cause capable of increasing the flux and reflux of the sea at the new and full moon, and of diminishing it at the intermediate quarters.

The system of attraction shows us at first, that it is the action of the sun which, joined to that of the moon, furnishes a complete solution of all the phenomena presented to us by the flux and reflux of the sea. Indeed, all that I have said respecting the power which the moon exercises on the sea, is equally applicable to the sun, whose attractive power acts likewise unequally on all the parts of the earth, according as they are more or less remote from him. The attraction of the sun is even much more intense than that of the moon, as it chiefly regulates the motion of the earth, and carries it round its orbit.

As to the motion which he communicates to the sea, it depends on the inequality of that action, with relation to the different points of the surface of the earth, which are more or less attracted toward the sun than its centre—as I have already showed you, in explaining the effect of the moon. If all the parts of the earth were attracted equally, no change in their mutual situation would take place. But though the power of the sun be much greater than that of the moon, the inequality, with relation to different parts

of the earth, is nevertheless smaller, on account of the great distance of the sun, which is 300 times farther from us than the moon. The difference of the power with which the centre of the earth, and the points of its surface, are attracted toward the sun, is therefore very small; and from calculations actually made, it is found to be three times less nearly, than that of the moon upon these points. The attractive power of the sun alone, then, would likewise be capable of causing the flux and reflux of the sea; but it would be about three times less than that which is the effect of the combined influence of these two luminaries.

It is evident, then, that the flux and reflux of the sea are produced by the power of both the sun and the moon, or that there are really two tides occasioned, the one by the moon, the other by the sun, and called the *Lunar tide* and the *Solar tide*. That of the moon, nearly three times greater, follows its motion, and from one day to another is retarded three quarters of an hour; that which follows the action of the sun, would constantly correspond to the same hours of the day, if it existed alone, or if there were no moon. These two tides, the lunar and the solar together, produce the flux and reflux of the sea; but as the one and the other separately make the waters of the sea alternately to rise and fall, when it happens that these two causes conjointly make the sea rise and fall, its flux and reflux become much more considerable; but when the one tends to raise the sea, and the other to lower it, at the same place, when they act in contrary directions, the one will then be diminished by the other, and the lunar tide will be weakened by the solar. According as these two tides assist or check each other, the flux and reflux will then be more or less considerable.

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

It might be still farther demonstrated by calculation, that the effect of the moon, or of the sun, is somewhat greater, when these bodies are at the equator, or equally distant from the two poles of the globe: which happens at the time of the equinoxes, toward the end of the months of March and September. It is found, too, that at that time the tides are strongest. It follows beyond all doubt, then, that the tides, or the flux and reflux of the sea, are caused by the attractive power of the moon and of the sun, in as much as these powers act unequally on the different parts of the sea. The happy explanation of this phenomenon, which had so dreadfully perplexed the ancients, is a complete confirmation of the system of attraction, or of universal gravitation, on which is founded the motion of all the heavenly bodies.

14*th October* 1760.

LETTER LXVIII.—MORE PARTICULAR ACCOUNT OF THE DISPUTE RESPECTING UNIVERSAL GRAVITATION.

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

It is supposed in this system, that all bodies mutually attract each other, in the ratio of their mass, and relatively to their distance, in conformity to a law already explained. The satisfactory manner in which most of the phenomena in nature are accounted for, proves that this supposition is founded in truth; and that the attraction which different bodies exercise upon each other, may be considered as a most undoubted fact. It now remains that we inquire into the cause of these attractive powers; but this research belongs rather to the province of metaphysics than of mathematics. I dare not therefore flatter myself with the prospect of absolute success in the prosecution of it.

As it is certain, that any two bodies whatever are attracted to each other, the question is, What is the cause of this attraction? On this point philosophers are divided. The English maintain, that attraction is a property essential to all the bodies in nature, and that these bodies, hurried along by an irresistible propensity, tend mutually to approach, as if they were impelled by feeling.

Other philosophers consider this opinion as absurd, and contrary to the principles of a rational philosophy. They do not deny the fact; they even admit that powers exist, which are the causes of the