

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.

14th October 1760.

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

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

It is supposed in this system, that all bodies mutually attract each other, in the ratio of their mass, and relatively to their distance, in conformity to a law already explained. The 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

reciprocal tendency of bodies toward each other; but they maintain, that they are foreign to the bodies; that they belong to the ether, or the subtle matter which surrounds them, and that bodies may be put in motion by the ether, just as we see that a body plunged into a fluid, receives several impressions from it. Thus, according to the first, the cause of the attraction resides in the bodies themselves, and is essential to their nature; and, according to the last, it is out of the bodies, and in the fluid which surrounds them. In this case, the term attraction would be improper; and we must rather say, that bodies are impelled toward each other. But as the effect is the same, whether two bodies are reciprocally impelled, or attracted, the word attraction need not give offence, provided it is not pretended, by that term, to determine the nature itself of the cause.

To avoid all confusion which might result from this mode of expression, it ought rather to be said, that bodies move as if they mutually attracted each other. This would not decide whether the powers which act on bodies reside in the bodies themselves, or out of them; and this manner of speaking might thus suit both parties. Let us confine ourselves to the bodies which we meet with on the surface of the earth.

Every one readily admits, that all these would fall downward, unless they were supported. Now, the question turns on the real cause of this fall. Some say, that it is the earth which attracts these bodies, by an inherent power natural to it; others, that it is the ether, or some other subtle or invisible matter, which impels the body downward: so that the effect is, nevertheless, the same in both cases. This last opinion is most satisfactory to those who are fond of clear principles in philosophy, as they do not see how two bodies at a distance can act upon each

other, if there be nothing between them. The others have recourse to the divine omnipotence, and maintain that God has endowed all bodies with a power of mutual attraction.

Though it be dangerous to venture on a dispute concerning the limits of divine power, it is nevertheless certain, that if attraction were an immediate work of that power, without being founded in the nature of bodies, this would be the same thing as saying, that God immediately impels bodies toward each other, and this would amount to a perpetual miracle.

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

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

Ancient philosophers satisfied themselves with explaining the phenomena of nature, from qualities which they called *occult*, saying, for example, that opium causes sleep, from an occult quality, which

disposes it to procure sleep. This was saying just nothing, or rather was an attempt to conceal ignorance. We ought, therefore, likewise to consider attraction as an occult quality, in as far as it is given for a property essential to bodies. But, as the idea of all occult qualities is now banished from philosophy, attraction ought not to be considered in this sense.

18th October 1760.

LETTER LXIX.—NATURE AND ESSENCE OF BODIES; OR EXTENSION, MOBILITY, AND IMPENETRABILITY OF BODY.

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

First, it is asked, What is body? However absurd this question may appear, as no one is ignorant of the difference between what is body and what is not, it is, however, difficult to ascertain the real characters which constitute the nature of bodies. The Cartesians say it consists in extension, and that whatever is extended is a body. They clearly understand, that extension has, in this case, three dimensions; and that a single dimension, or extension in length only, gives only a line; and that two dimensions, length and breadth, form only a surface, which still is not a body. To constitute a body, therefore, we must have three dimensions, and every body must have length, breadth, and depth or thick-

ness; in other words, an extension in three dimensions.

But it is asked, at the same time, if every thing which has extension is a body? This must be the case, if the definition of *Descartes* be just. The idea which the vulgar form of spectres contains extension; it is, however, denied that they are bodies. Though this idea be purely imaginary, it serves to prove, however, that something may have extension without being a body. Besides, the idea which we have of space, contains, undoubtedly, an extension with three dimensions. It is admitted, nevertheless, that space alone is not a body; it only furnishes the place which bodies occupy and fill.

Let us suppose, that all those things which are at present in my apartment, air and every thing, were annihilated by the divine Omnipotence, there would remain still in the apartment the same length, breadth, and height, but without a body in it. Here, then, is the possibility of an extension that shall not be a body. Such a space, without body in it, is called a vacuum; a vacuum, then, is extension without body.

It may likewise be said, according to the vulgar superstition, that a spectre has extension, but that body, or corporality, is wanting to it. It is clear, then, that extension is not sufficient to constitute a body—that something more is necessary; hence it follows, that the definition of the Cartesians is not exact. But what more is necessary, beside extension, to constitute a body? The answer is, mobility, or the possibility of being put in motion; for, though a body be at rest, whatever may be the causes which preserve it in that state, it would, however, be possible to move it, provided the powers applied to it were sufficient. By this, space is excluded from the class of bodies, as we see that space,

which only serves to receive bodies, remains immoveable, whatever motion the bodies that it contains may have.

It is likewise said, that, by the help of motion, bodies are transported from one place to another; by which we are given to understand, that the places and space remain unchangeable. My apartment, however, with the vacuum which I have above supposed, might undoubtedly be moved, and actually is so, as it follows the motion which carries round the earth itself; here, then, is a vacuum in motion, without being a body. The vulgar superstition, too, bestows motion on spectres; and this is sufficient to prove, that the power of being moved, and extension, alone do not constitute the nature of bodies. Something more is wanting; there must be matter to constitute a body, or rather, it is this which distinguishes a real body from simple extension, or from a spectre.

Here, then, we are reduced to explain what is to be understood by the term *matter*, without which extension cannot be body. Now, the signification of these two terms is so much the same, that all body is matter, and all matter is body; so that even now we have made no great progress. We easily discover, however, a general character, inseparable from all matter, and consequently pertaining to all bodies; it is *impenetrability*, the impossibility of being penetrated by other bodies, or the impossibility that two bodies should occupy the same place at once. In truth, impenetrability is what a vacuum wants in order to be a body.

It will perhaps be objected, that the hand may be easily moved through air and through water; which are, nevertheless, acknowledged bodies; these, then, must be penetrable bodies, and consequently impenetrability is not an inherent character of all

bodies. But it is worthy of remark, that when you plunge your hand into water, the particles of the water make way for your hand, and that there is no water in the space which your hand occupies. If the hand could move through the water, while that fluid did not make room for it, but remained in the place which the hand occupied, then it would be penetrable; but it is evident this is not the case. Bodies, then, are impenetrable: a body, therefore, always excludes, from the place which it occupies, every other body; and as soon as a body enters into any place, it is absolutely necessary that the body which occupied it before should leave it. This is the sense which we must affix to the term impenetrability.

21st October 1760.

LETTER LXX.—IMPENETRABILITY OF BODIES.

THE instance of a sponge will perhaps be produced as an objection to the impenetrability of bodies, which plunged into water appears completely penetrated by it. But the particles of the sponge are very far from being so, in such a manner as that one particle of the water should occupy the same place with one particle of the sponge. We know that sponge is a very porous body; and that before it is put into the water, its pores are filled with air; as soon as the water enters into the pores of the sponge, the air is expelled, and disengages itself under the form of little bubbles; so that in this case no penetration takes place, neither of the air by the water, nor of the water by the air, as this last always makes its escape from the place into which the water enters.

It is, then, a general and essential property of all bodies to be impenetrable; and consequently the justness of this definition must be admitted, *that a body is an impenetrable extension*; as not only all bodies are extended and impenetrable, but likewise reciprocally, as that which is at the same time extended and impenetrable is beyond contradiction a body. Vacuum is accordingly excluded from the class of bodies; for though it has extension, it wants impenetrability; and wherever we meet with a vacuum, there bodies may be introduced, without thrusting any thing out of its place.

We must attempt to remove another difficulty raised against the impenetrability of bodies. There are, say the objectors, bodies which admit of compression into a smaller space: as, for example, wool, and especially air, which it is possible to reduce into a space a thousand times smaller than what it occupies. It appears, then, that the different particles of air are reduced in the same place, and that consequently they mutually penetrate.

There is, however, nothing in this; for the air too is a body, or a substance full of empty pores, or filled with that fluid, incomparably more subtle, which we call *ether*. In the first case no penetration will ensue, as the particles of air only approach nearer to each other according as the vacuum is diminished; and in the other case, the ether finds a sufficiency of small passages by which to escape, as the particles of the air approach each other, but all the while without any mutual penetration. For this reason, it is necessary to employ a greater force when we want to compress the air more; and if the air were compressed to such a degree that its minute particles touched each other, we could not carry the compression farther, because, were it pos-

sible, the minute particles of the air must mutually penetrate.

It is, then, a necessary and fundamental law in nature, that no two bodies can penetrate each other, or occupy the same place at once; and it is in conformity to this principle that we must look for the real source of all the motions which we observe in all bodies, and of the changes which befall them. As two bodies cannot continue their motion without penetrating each other, it is absolutely necessary that the one should give place to the other. If, then, two bodies are moving in the same line, the one to the left, the other to the right, as it frequently happens at billiards, if each were to continue its motion, they must mutually penetrate; but this being impossible, as soon as they come to touch, a shock takes place, by which the motion of each body is almost instantly changed; and this shock is produced in nature only to prevent penetration. The motion of each body is precisely changed no farther than is necessary to prevent all penetration; and in this consists the real cause of all the changes which happen in the world.

When all these changes are attentively considered, they are found always to take place in order to prevent some penetration, which without these changes must have ensued. At the moment I am writing I observe, that if the paper were penetrable, the pen would pass freely into it without writing; but as the paper sustains the pressure of my pen moistened with ink, it receives from it some particles which form these letters, which could not happen if bodies penetrated each other.

This property of all bodies, known by the term *impenetrability*, is then not only of the last importance relatively to every branch of human knowledge, but we may consider it as the master-spring which

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

25th October 1760.

LETTER LXXI.—OF THE MOTION OF THE BODIES,
REAL AND APPARENT.

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

We must therefore distinguish between two kinds of rest; the one absolute, the other apparent. Absolute rest takes place when a body remains constantly in the same place, not with relation to the earth, but with relation to the universe. If the fixed stars remained always in the same place of the universe, they would be at rest, though they seem to move very rapidly; but as we are not certain of it, we must not pretend to affirm that the fixed stars are in a state of absolute rest.

A body is said to be in a state of apparent rest when it preserves the same situation on the earth. It is likewise to be presumed, that these terms, rest and motion, have been introduced into language to

* Letter II.

mark rather appearances than truth; and in this sense I affirm, without hesitation, that my table is at rest, as well as the whole earth; and that the sun and the fixed stars are in motion, and that a very rapid motion, although they are really at rest. We should, therefore, be ascribing strange and purely metaphysical ideas to these expressions, if we understood by them *absolute rest or motion*; and it is absurd to employ, as some persons do, passages of the Holy Scriptures to prove that the earth is at rest, and the sun in motion.

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

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

This hypothesis, though it never can take place, is in reality very proper to assist us in distinguishing

what is operated by the nature of body itself, from that which other bodies are capable of operating upon it.

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

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

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

They say farther, that gravity may be an intrinsic power, attached to the nature of the stone; on which it must be remarked, that gravity is produced either by a subtile matter, or by the attraction of the earth. In the first case, it certainly is that subtile matter which causes the descent of the stone; in the second, which appears favourable to our opponents, it can with no propriety be affirmed, that the stone descends by an intrinsic power; it is rather the earth which contains the cause of it, and which produces the descent of the stone by its attractive power; for if the earth did not exist, or were deprived of its attractive power, they admit that the stone would not descend.

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

28th October 1760.

LETTER LXXII.—OF UNIFORM, ACCELERATED,
AND RETARDED MOTION.

I RETURN to the case of a body placed in such a manner as to have no connexion with any other. Let us suppose it to have received some motion, from whatever cause; it remains that we inquire, What will afterwards happen to it? Will it continue to move? Or will it suddenly return to a state of rest; or after some time? You must be sensible, that this is an inquiry of some importance, and that all our researches respecting the motion of bodies depend upon it. Let us examine if, by means of reasoning, we are able to resolve it.

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

If a body, then, (PLATE II. *Fig. 3.*) moves in the curve ABC ; when it is at A , its direction is the small line Aa ; when it is at B , its direction is the small line Bb ; and at C , the small line Cc . Let these small lines be produced; the continuations of which are marked by the straight dotted lines AL , BM , CN ; and it will be affirmed, that when the

body passes through A , its direction is the straight line AL , because, if the body preserved the same direction which it had at A , it would move in the straight line AL . It is evident, then, that it moves in the curve only in so far as it is continually changing its direction. And when it arrives at B and at C , the direction from which it deviates is expressed by the straight lines BM and CN .

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

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

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

short. Now, as long as the motion lasts, it is certain that the direction will remain the same.

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

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

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

From it we deduce at once this conclusion, that as often as we see a body which was at rest put in motion, or a body moving in a curve line, or whose velocity changes, it is certain, that an external cause acts upon it. No change can possibly take place either as to direction or velocity, but what is the operation of a foreign cause.

1st November 1760.

LETTER LXXIII.—PRINCIPAL LAW OF MOTION AND REST. DISPUTES OF PHILOSOPHERS ON THE SUBJECT.

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

It is alleged by the one, That all bodies have a propensity to rest, which is their natural state, and that motion is to them a state of violence; so that when a body is put in motion, it has a tendency, from its very nature, to return to the state of rest; and that it makes every effort to destroy its motion, independently of every external or foreign cause. They allege in proof, experience so convincing, according to them, that we know of no motion in nature that does not very sensibly betray this reluc-

tance. Do we not see, say they, on the billiard table, that with whatever force we strike a ball, its motion is quickly slackened, and it soon returns to a state of rest. As soon as the motion of a clock ceases to be kept up by the external force which set it agoing, it stops. It is remarked of all machines in general, that their motion lasts no longer than the external powers by which they are agitated. Hence they conclude, that a body put in motion is so far from preserving it from any thing in its own nature, that, on the contrary, an external force must be employed to keep it up.

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

But if we attend to every thing, we shall find so many obstacles opposed to the motion, that we need no longer wonder it should be so speedily extinguished. In fact, it is first the friction on the billiard table which diminishes the motion of the ball, for it cannot advance without rubbing against the cloth. Again, the air being a substance, causes likewise a resistance capable of diminishing the motion of bodies. To be convinced of this, you have only to move your hand rapidly through the air. It is evident, then, that in the case of the billiard table, it is the friction and the resistance of the air which counteract the motion of the ball, and soon reduce it to a state of rest.

Now, these causes are external, and it is easily comprehensible, that but for these obstacles, the motion of the ball must have always continued. The same reasoning is applicable to machines of all kinds,

in which the friction which acts on the different parts is so considerable, that it is visibly a very sufficient cause of soon reducing the machine to rest.

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

The other is more formidable, for they are no less than the celebrated Wolfian philosophers. They do not indeed openly declare against our principle, nay they even express much respect for it; but they advance others which directly oppose it.

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

In fact, if it be true that a body at rest remains, in virtue of its nature, in that state, it must be undoubtedly false that it should make, in virtue of its nature, continual efforts to change its state. And

if it be true that a body in motion preserves, in virtue of its nature, this motion, in the same direction; and with the same velocity, it is impossible that the same body should, in virtue of its nature, be making continual efforts to change its motion.

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

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

4th November 1760.

LETTER LXXIV.—OF THE INERTIA OF BODIES: OF POWERS.

As we say that a body, so long as it is at rest, remains in the same state, so we likewise say of a body in motion, that as long as it moves in the same direction, and with the same velocity, it remains in the same state. To continue in the same state, their

signifies nothing more than to remain at rest, or to preserve the same motion.

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

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

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

This term was first introduced into philosophy by those who maintained that all bodies have a propensity to rest. They considered bodies as somewhat resembling indolent persons, who prefer rest to exertion, and ascribed to bodies an aversion to motion,

similar to that which sluggards have for labour; the term *inertia* signifying nearly the same thing as sluggishness. But though the falseness of this opinion has been since detected, and though it is certain that bodies remain equally in their state of motion as in that of rest, yet the term *inertia* has been still retained, to denote in general the property of all bodies to continue in the same state, whether of rest or of motion.

The exact idea of *inertia*, therefore, is a repugnance to every thing that has a tendency to change the state of bodies; for as a body, in virtue of its nature, preserves the same state of motion, or of rest, and cannot be drawn out of it but by external causes, it follows, that in order to a body's changing its state, it must be forced out of it by some external cause; without which it would always continue in the same state. Hence it is, that we give to this external cause the name of *power* or *force*. It is a term in common use, though many by whom it is employed have but a very imperfect idea of it.

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

Now, the *inertia* by which a body tends to preserve itself in the same state, exists in the body itself, and is an essential property of it; when, there-

fore, an external force changes the state of any body, the *inertia* which would maintain it in the same state, opposes itself to the action of that force; and hence we comprehend, that the *inertia* is a quality susceptible of measurement, or that the *inertia* of one body may be greater or less than that of another body.

But bodies are endowed with this *inertia* in as far as they contain matter. It is even by the *inertia*, or the resistance which they oppose to every change of state, that we judge of the quantity of a body; *inertia* of a body, accordingly, is greater in proportion to the quantity of matter which it contains. Hence we conclude, that it requires a greater force to change the state of a great body, than that of a small one; and we go on to conclude, that the great body contains more matter than the small one. It may even be affirmed that this single circumstance, the *inertia*, renders matter sensible to us.

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

To this, then, is reduced our knowledge of bodies in general. First, we know that all bodies have an extension of three dimensions; secondly, that they are impenetrable; and hence results their general property, known by the name of *inertia*, by which they preserve themselves in their state; that is, when a body is at rest, by its *inertia* it remains so; and when it is in motion, it is likewise by its *inertia* that it continues to move with the same velocity, and in the same direction; and this preservation of the same state lasts till some external cause interpose to produce change in it. As often as the state of

a body changes, we must never look for the cause of such change in the body itself; it exists always out of the body, and this is the just idea which we must form of a power or force.

8th November 1760.

LETTER LXXV.—CHANGES WHICH MAY TAKE PLACE IN THE STATE OF BODIES.

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

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

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

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

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

Gravity, then, is not an intrinsic property of body; it is rather the effect of a foreign force, the source of which must be sought for out of the body. This is geometrically true, though we know not the foreign forces which occasion gravity. It is the same when we throw a stone. We see clearly that it does not follow, in its motion, the direction of a straight line; and that its velocity does not always continue the

same. It is gravity, likewise, which changes the direction or the velocity of the body; but for it, the stone would describe a straight line in the air, and proceed forward with the same velocity; and were gravity to be suddenly annihilated, during the motion of the stone, it would continue to move in a straight line, and would preserve the same direction, and the same velocity, which it had at the instant when gravity ceased to act upon it.

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

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

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

11th November 1760.

LETTER LXXVI.—SYSTEM OF THE MONADS OF WOLFF.

BEFORE I attempt to make you sensible of the truth of the principle, that all bodies, of themselves, always preserve the same state of rest or motion, I must remark, that if we consult experience only on the subject, without thoroughly investigating it by the powers of reasoning, we would be disposed to draw the directly opposite conclusion, and to maintain, That bodies always have a propensity to be continually changing their state; as we see nothing in the whole universe but a perpetual change in the state of bodies. But we have just shown what are the causes which produce these changes, and we are assured, that they are not to be found in the bodies whose state is changed, but out of them.

The principle, then, which we have established, is so far from being contradicted by experience, that it is, on the contrary, confirmed by it. You will easily judge from this, how several great philosophers, misled by an experience not accurately understood, have fallen into the error of maintaining, That all

bodies are endowed with powers, disposing them continually to change their state.

It is thus that *Wolff* has reasoned. He says, 1. Experience shows us all bodies perpetually changing their state; 2. Whatever is capable of changing the state of bodies is called force; 3. All bodies, therefore, are endowed with a force capable of changing their state; 4. Every body, therefore, is making a continual effort to change; 5. Now, this force belongs to body, only so far as it contains matter; 6. It is therefore a property of matter to be continually changing its own state; 7. Matter is a compound of a multitude of parts, denominated the elements of matter; therefore, 8. As the compound can have nothing but what is founded in the nature of its elements, every elementary part must be endowed with the power of changing its own state.

These elements are simple beings; for if they were composed of parts, they would be no longer elements, but their parts would be so. Now, a simple being is likewise denominated *monad*; every monad, therefore, has the power of continually changing its state. Such is the foundation of the system of monads, which you may have heard mentioned, though it does not now make such a noise as it formerly did. I have marked by figures the several propositions on which it is established, for the purpose of making a more distinct reference, in the reflections I mean to make upon them.

I have nothing to say respecting the first and second; but the third is very equivocal, and altogether false, in the sense in which it is taken. Without meaning to say that the forces which change the state of bodies proceed from some spirit, I readily agree, that the force by which the state of every body is changed, subsists in body, but it being always understood that it subsists in another body, and never

in that which undergoes the change of state; which has rather the contrary quality, that of persevering in the same state. In so far, then, as these forces subsist in bodies, it ought to be said, that these bodies, as long as they have certain connexions with each other, may be capable of supplying forces by which the state of another body is changed. It follows, that the fourth proposition must be absolutely false; and the result, from all that went before, rather is, that every body is endowed with the power of remaining in the same state, which is directly the opposite of the conclusion which these philosophers have drawn.

And I must here remark, that it is rather absurd to give the name of *force* to that quality of bodies, by which they remain in their state; for if we are to understand by the term *force* every thing that is capable of changing the state of bodies, the quality by which they persevere in their state, is rather the opposite of a force. It is therefore by an abuse of language that certain authors give the name of force to the *inertia*, which is that quality, and which they denominate the *inert force*.

But, not to wrangle about terms, though this abuse may lead to very gross errors, I return to the system of monads; and as proposition 4. is false, those that follow, which are successively founded upon it, must of necessity be so too. It is false then, likewise, that the elements of matter, or monads, if such there be, are possessed of the power of changing their state. The truth is rather to be founded on the opposite quality, that of persevering in the same state: and thereby the whole system of monads is completely subverted.

These philosophers attempted to reduce the elements of matter to the class of *beings* which comprehends spirits and souls, endowed, beyond the

power of contradiction, with the faculty of changing their state; for, while I am writing, my soul continually represents other objects to itself, and these changes depend entirely on my will: I am thoroughly convinced of it, and not the less so, that I am master of my own thoughts; whereas the changes which take place in bodies, are the effect of an extraneous force.

Add to this, the infinite difference between the state of body capable only of one velocity and of one direction, and the thoughts of spirit, and you will be entirely convinced of the falsehood of the sentiments of the materialists, who pretend that spirit is only a modification of matter. These gentlemen have no knowledge of the real nature of bodies.

15th November 1760.

LETTER LXXVII.—ORIGIN AND NATURE OF POWERS.

It is undoubtedly very surprising, that if every body has a natural disposition to preserve itself in the same state, and even to oppose all change, all the bodies in the universe should nevertheless be continually changing their state. We are well assured, that this change can be produced only by a force not resident in the body whose state is changed. Where, then, must we look for those powers, which produce the incessant changes that take place in all the bodies of the universe; and which are, nevertheless, foreign to body?

Must we then suppose, besides these existing bodies, particular beings which contain those powers? or, Are the powers themselves particular substances existing in the world? We know but of two kinds of beings in it, the one which comprehends all bodies,

and the other all intellectual beings, namely, the spirits and souls of men, and those of animals. Must we establish, then, in the world, besides body and spirits, a third species of beings, under the name of power or force? or, Are they spirits which incessantly change the state of bodies?

Both of these labour under too many difficulties to be hastily adopted. Though it cannot be denied, that the souls of men, and of beasts, have the power of producing changes in their bodies, it were, however, absurd to maintain, that the motion of a ball, on the billiard table, was retarded and destroyed by some spirit; or that gravity was produced by a spirit continually pressing bodies downward; and that the heavenly bodies which, in their motion, change both direction and velocity, were subjected to the action of spirits, according to the system of certain ancient philosophers, who assigned to each of the heavenly bodies, a spirit, or angel, who directed its course.

Now, on reasoning with solidity respecting the phenomena of the universe, it must be admitted, that if we except animated bodies, that is, those of men and beasts, every change of state which befalls other bodies, is produced by merely corporeal causes, in which spirits have no share. The whole question, then, is reduced to this, Whether the forces which change the state of bodies exist separately, and constitute a particular species of beings, or whether they exist in the bodies?

This last opinion appears at first sight very unaccountable; for if all bodies have the power of preserving themselves in the same state, how can it be possible they should contain powers that have a tendency to change it? You will not be surprised to hear, that the origin of force has, in all ages, been a stumbling-block to philosophers. They have all considered it as the greatest mystery in nature, and

as likely to remain for ever impenetrable. I hope, however, I shall be able to present you with a solution of this pretended mystery, so clear, that all the difficulties which have hitherto appeared insurmountable, will wholly vanish.

I say, then, that however strange it may appear, this faculty of bodies, by which they are disposed to preserve themselves in the same state, is capable of supplying powers which may change that of others. I do not say that a body ever changes its own state, but that it may become capable of changing that of another. In order to enable you to get to the bottom of this mystery respecting the origin of force, it will be sufficient to consider two bodies, as if no others existed.

Let the body A (PLATE II. Fig. 5.) be at rest, and let the body B have received a motion in the direction B A, with a certain velocity. This being laid down, the body A is disposed to continue always at rest; and the body B to continue its motion along the straight line B A, always with the same velocity, and both the one and the other in virtue of its *inertia*. The body B will at length then come to touch the body A. What will be the consequence? As long as the body A remains at rest, the body B could not continue its motion, without passing through the body A, that is, without penetrating it; it is impossible, then, that each body should preserve itself in its state, without the one's penetrating the other. But this penetration is impossible; impenetrability being a property common to all bodies.

It being impossible, then, that both the one and the other should preserve its state, the body A must absolutely begin to move, to make way for the body B, that it may continue its motion; or, that the body B, having come close to the body A, must have its motion destroyed; or, the state of both

must be changed, as much as is necessary, to put them in a condition to continue afterward each in his proper state, without mutual penetration.

Either the one body, therefore, or the other, or both, must absolutely undergo a change of their state, and the cause of this change infallibly exists in the impenetrability of the bodies themselves; since every cause, capable of changing the state of bodies, is denominated *force*, it is then, of necessity, the impenetrability of the bodies themselves which produces the force by which this change is effected.

In fact, as impenetrability implies the impossibility that bodies should mutually penetrate, each of them opposes itself to all penetration, even in the minutest parts; and to oppose itself to penetration, is nothing else but to exert the force necessary to prevent it. As often, then, as two or more bodies cannot preserve themselves in their state, without mutual penetration, their impenetrability always exerts the force necessary to change it, as far as is requisite, to prevent the slightest degree of penetration.

The impenetrability of bodies, therefore, contains the real origin of the forces, which are continually changing their state in this world; and this is the true solution of the great mystery, which has perplexed philosophers so grievously.

18th November 1760.

LETTER LXXVIII.—THE SAME SUBJECT. PRINCIPLE OF THE LEAST POSSIBLE ACTION.

You have now made very considerable progress in the knowledge of nature, from the explanation of the real origin of the powers capable of changing the state of bodies; and you are, at present, in a condi-

tion to comprehend easily, why all those of this world are subject to an incessant change of state, from rest to motion, or from motion to rest.

First, we are certain, that the world is filled with matter. Here below, it is evident, that the space which separates the gross bodies sensible to feeling, is occupied by the air, and that, when we make a vacuum in any space, the ether instantly succeeds, and it likewise fills the space in which the heavenly bodies move. All space being thus full, it is impossible that a body in motion should continue it a single instant, without meeting others, through which it must pass, if they were not impenetrable. And, as this impenetrability of bodies exerts always, and universally, a force which prevents all penetration, it is not at all surprising, then, that we should observe perpetual changes in the state of bodies, though every one has a tendency to preserve itself in the same state.

If they could penetrate each other freely, nothing would prevent any one from remaining perseveringly in its state; but being impenetrable, there must thence necessarily result force sufficient to prevent all penetration; and no more results than what is precisely needful.

While they can continue in the same state, without any injury to impenetrability, they then exert no force, and bodies remain in their state; it is only to prevent penetration, that impenetrability becomes active, and supplies a force sufficient to oppose it. When, therefore, a small force suffices to prevent penetration, impenetrability exerts that, and no more; but when a great force is necessary for this purpose, impenetrability is ever in a condition to supply it.

Thus, though impenetrability supplies these powers, it is impossible to say that it is endowed

with a determinate force; it is rather in a condition to supply all kinds of force, great or small, according to circumstances; it is even an inexhaustible source of them. As long as bodies are endowed with impenetrability, this is a source which cannot be dried up; this force absolutely must be exerted, or bodies must mutually penetrate, which is contrary to nature.

It ought likewise to be remarked, that this force is never the effect of the impenetrability of a single body; it results always from that of all bodies at once, for if one of the bodies was penetrable, the penetration would take place, without any need of a power to effect a change in their state. When, therefore, two bodies come into contact, and when they cannot continue in their state without penetrating each other, the impenetrability of both acts equally: and it is by their joint operation that the force necessary to prevent the penetration is supplied; we then say that they act upon each other, and that the force resulting from their impenetrability produces this effect. This force acts upon both of them; for as they have a tendency toward mutual penetration, it repels both the one and the other, and thus prevents their penetration.

It is certain, then, that bodies may act upon each other; and we speak so frequently of this action, as when two billiard balls clash, it is said the one acts upon the other, that you must be well acquainted with this mode of expression. But it must be carefully remarked, that, in general, bodies do not act upon each other, but in so far as their state becomes contrary to impenetrability; from whence results a force capable of changing it, precisely so much as is necessary to prevent any penetration; so that a small force would not have been sufficient to produce this effect.

It is very true, that a greater force would likewise prevent the penetration; but when the change produced in the state of bodies is sufficient to prevent mutual penetration, the impenetrability acts no farther, and there results from it the least force that is capable of preventing the penetration. Since, then, the force is the smallest, the effect which it produces, that is, the change of state which it operates, in order to prevent penetration, will be proportional; and, consequently, when two or more bodies come into contact, so that no one could continue in its state without penetrating the others, a mutual action must take place, which is always the smallest that was capable of preventing penetration.

You will find here, therefore, beyond all expectation, the foundation of the system of the late *Mr. de Maupertuis*, so much cried up by some, and so violently attacked by others. His principle is, that of the least possible action; by which he means, that in all the changes which happen in nature, the cause which produces them is the least that can be.

From the manner in which I have endeavoured to unfold this principle to you, it is evident that it is perfectly founded in the very nature of body, and that those who deny it, are much in the wrong, though still less than those who would turn it into ridicule. You will already, perhaps, have remarked, that certain persons, no great friends to *Mr. de Maupertuis*, take every opportunity of laughing at the principle of *the least possible action*, as well as at the hole continued down to the centre of the earth; but fortunately, truth suffers nothing by their pleasantries.

22d November 1760.

LETTER LXXIX.—ON THE QUESTION, ARE THERE ANY OTHER SPECIES OF POWERS?

THE origin of powers, founded on the impenetrability of bodies, which I have been endeavouring to explain, is by no means inconsistent with the opinion of those who maintain, that the souls of men, and those of beasts, have the power of acting on their bodies. There is nothing to hinder the existence of two kinds of power, which produce all the changes that take place in the world; the one corporeal, which derives its origin from the impenetrability of bodies; and the other spiritual, which the souls of animals exercise over their bodies: but this last power operates only upon animated bodies; and the Creator has so clearly distinguished it from the other, that it is not permitted, in philosophy, to confound them.

But this distinction greatly embarrasses those who consider attraction as an inherent quality of bodies; for if they act upon each other only to maintain their impenetrability, attraction cannot be referred to this case. Two distant bodies may preserve each its state without at all interesting their impenetrability, and without there being any reason of consequence why the one should act upon the other, even by attracting it.

Attraction, therefore, ought to be referred to a third species of power, which should be neither corporeal nor spiritual. But it is always contrary to the rules of a rational philosophy, to introduce a new species of powers before their existence is incontrovertibly demonstrated. It would have been necessary, therefore, for this effect, to have proved beyond contradiction, that the powers by which bodies mutually attract could not derive their origin from the subtle matter which surrounds them; but this im-