to it or not it would be equally cold. But the atmosphere is not perfectly transparent: it is even sometimes so loaded with vapours, that it loses almost entirely its transparency, and presents only a thick fog. When the air is in this state, the rays of the sun have a more powerful influence upon it, and heat it immediately.

But these vapours rise to no great height; at the height of 24,000 feet, and beyond, the air is so subtile and so pure, that it is perfectly transparent; and for this reason the rays of the sun cannot immediately produce any effect upon it. This air is likewise too remote from terrestrial bodies to receive a communication of heat from them; they act only upon such as are adjacent. Hence you will easily perceive that the rays of the sun cannot produce any effect in regions of the air very much elevated above the surface of the earth; and that the same degree of cold must always and universally prevail in such regions, as the sun has no influence there, and as the heat of terrestrial bodies cannot be communicated so far. This is nearly the case on the summit of very high mountains, where it is always much colder than on plains and in vallies.

The city of Quito, in Peru, is almost under the equator, and were we to form our judgment from its situation on the globe, we would suppose it oppressed with intolerable heat; the air, however, is abundantly temperate, and differs very little from that of Paris. Quito is situated at a great height above the real surface of the earth. In going to it from the sea shore you have to ascend for several days; it is accordingly built at an elevation equal to that of our highest mountains, though surrounded by others still much higher, called the Cordilleras. This last circumstance would afford a reason for thinking that the air there must be as hot as at the surface of the

earth, as it is contiguous on all sides to opaque bodies, on which the rays of the sun fall. The objection is solid; and no solution can be given but this: That the air at Quito, being very elevated, must be much more subtile, and of less gravity than with us; and the barometer, which always stands considerably lower, incontestably proves it.

Air of such a quality is not so susceptible of heat as common air, as it must contain less vapour and other particles which usually float in the atmosphere; and we know by experience that air very much loaded is proportionably susceptible of heat. I must here subjoin another phenomenon no less surprising: In very deep pits, and lower still, if it were still possible to descend, the same degree of heat always and universally prevails, and nearly for the same reason.* As the rays of the sun exert their influence only on the surface of the earth, and as the heat which they there excite communicates itself up and down, this effect at very great depths is almost imperceptible. The same thing holds respecting considerable heights.

3*d June* 1760.

Letter XVII.—Of Light, and the Systems of Descartes and Newton.

Having spoken of the rays of the sun, which are the focus of all the heat and light that we enjoy, you will undoubtedly ask, What are these rays? This is beyond question one of the most important inquiries in physics, as from it an infinite number of phenomena is derived. Every thing that respects light,

* It has been recently found, that in descending deep mines, the temperature, instead of being uniform, increases considerably, amounting in some cases to about 12° of Fahrenheit at a depth of 500 feet.—En.

and that renders objects visible, is closely connected with this inquiry. The ancient philosophers seem to have taken little interest in the solution of it. They contented themselves with saying that the sun is endowed with the quality of shining, of giving heat and light. But is it not worth while to inquire, Wherein does this quality consist? Do certain portions, inconceivably small, of the sun himself, or of his substance, come down to us? Or is the transmission similar to the sound of a bell, which the ear receives? though no part of the substance of the bell be separated from it—as I observed in explaining the propagation and perception of sound.

Descartes, the first of modern philosophers, maintained this last opinion; and having filled the whole universe with a subtile matter composed of small globules, which he calls the second element, he supposes that the sun is in a state of continual agitation, which he transmits to these globules, and pretends that they again communicate their motion in an instant to every part of the universe. But since it has been discovered that the rays of the sun do not reach us instantaneously, and that they take eight minutes to fly through that immense distance, the opinion of *Descartes*, which laboured beside under other difficulties, has been given up.

The great *Newton* afterwards embraced the former system, and maintained that the luminous rays are really separated from the body of the sun, and the particles of light thence emitted with that inconceivable velocity which brings them down to us in about eight minutes. This opinion, which is that of most modern philosophers, particularly the English, is called *the system of emanation*—it being imagined that rays emanate from the sun and other luminous bodies, as water emanates or springs from a fountain.

This opinion appears at first sight very bold, and irreconcileable to reason. For were the sun emitting continually, and in all directions, such floods of luminous matter, with a velocity so prodigious, he must speedily be exhausted; or at least some alteration must, after the lapse of so many ages, be perceptible. This, however, is contradicted by observation. It cannot be a matter of doubt, that a fountain which should emit streams of water in all directions, would be exhausted in proportion to the velocity of the emission; much more the sun, whose rays are emitted with a velocity so inconceivable. Let the particles of which rays of light are formed be supposed as subtile as you please, nothing will be gained; the system will ever remain equally untenable. It cannot be affirmed that this emanation is not made in all directions; for wherever you are placed, the whole sun is visible, which proves incontestably, that rays from every point of the sun are emitted towards the spot which you occupy. The case is very different from that of a fountain, which should emit streams of water in all directions. For one point in the fountain could furnish only one stream directed to a particular spot; but every point of the sun's surface must emit an infinite number, diffusing themselves in all directions. This circumstance alone infinitely increases the expenditure of luminous matter, which the sun would have to make.

Another difficulty, and which appears equally insuperable, is, that the sun is not the only body which emits rays, but that all the stars have the same quality; and as every where the rays of the sun must be crossing the rays of the stars, their collision must be violent in the extreme. How must their direction be changed by such collision! This collision must take place with respect to all luminous bodies visible at the same time. Each, however, appears distinct-

ly, without suffering the slightest derangement from any other—a certain proof that many rays may pass through the same point without disturbing each other, which seems irreconcileable to the system of emanation. Let two fountains be set a playing upon each other, and you will immediately perceive their different streams disturbed and confounded: it must of consequence be concluded, that the motion of the rays of light is very essentially different from that of a *jet d'eau*, and in general from all substances forcibly emitted.

Considering afterwards transparent bodies through which rays are freely transmitted in all directions, the supporters of this system are under the necessity of affirming, that these bodies contain pores, disposed in straight lines, which issue from every point of the surface, and proceed in all directions; it being inconceivable how there could be any line through which a ray of the sun might be transmitted with such amazing velocity, and even without the slightest collision. Here then are bodies wonderfully porous, which have the appearance nevertheless of being extremely solid.

Finally, in order to enjoy vision, the rays must enter into the eye, and penetrate its substance with the same velocity. All these difficulties taken together will, I doubt not, sufficiently convince you, that the system of emanation has in no respect a foundation in nature; and you will certainly be astonished that it could have been conceived by so great a man, and embraced by so many enlightened philosophers. But it is long since Cicero remarked, that nothing so absurd can be imagined as to find no supporter among philosophers. For my own part, I am too little a philosopher to adopt the opinion in question.

7th June 1760.

Letter XVIII.—Difficulties attending the System of Emanation.

However strange the doctrine of the celebrated *Newton* may appear, that rays proceed from the sun by a continual emanation, it has, however, been so generally received, that it requires an effort of courage to call it in question. What has chiefly contributed to this is, no doubt, the high reputation of the great English philosopher, who first discovered the true laws of the motions of the heavenly bodies; and it is this very discovery which led him to the system of emanation.

Descartes, in order to support his theory, was under the necessity of filling the whole space of the heavens with a subtile matter, through which all the celestial bodies move at perfect liberty. But it is well known, that if a body moves in air it must meet with a certain degree of resistance; from which *Newton* concluded, that however subtile the matter of the heavens may be supposed, the planets must encounter some resistance in their motions. But, said he, this motion is not subject to any resistance: the immense space of the heavens, therefore, contains no matter. A perfect vacuum, then, universally prevails. This is one of the leading doctrines of the Newtonian philosophy, that the immensity of the universe contains no matter in the spaces not occupied by the heavenly bodies. This being laid down, there is between the sun and us, or at least from the sun down to the atmosphere of the earth, an absolute vacuum. In truth, the farther we ascend, the more subtile we find the air to be; from whence it would apparently follow, that at length the air would be entirely lost. If the space between the sun and the earth be an absolute vacuum, it is impossible

that the rays should reach us in the way of communication, as the sound of a bell is transmitted by means of the air. For if the air, intervening between the bell and our ear, were to be annihilated, we should absolutely hear nothing, let the bell be struck ever so violently.

Having established, then, a perfect vacuum between the heavenly bodies, there remains no other opinion to be adopted but that of emanation; which obliged *Newton* to maintain, that the sun and all other luminous bodies emit rays which are always particles, infinitely small, of their mass, darted from them with incredible force. It must be such to a very high degree, in order to impress on rays of light that inconceivable velocity with which they come from the sun to us in the space of eight minutes. But let us see whether this theory be consistent with *Newton's* leading doctrine, which requires an absolute vacuum in the heavens, that the planets may encounter no manner of resistance to their motions. You must conclude, on a moment's reflection, that the space in which the heavenly bodies revolve, instead of remaining a vacuum, must be filled with the rays, not only of the sun, but likewise of all the other stars which are continually passing through it from every quarter, and in all directions, with incredible rapidity. The heavenly bodies which traverse these spaces, instead of encountering a vacuum, will meet with the matter of luminous rays in a terrible agitation, which must disturb these bodies in their motions much more than if it were in a state of rest.

Thus *Newton*, apprehensive lest a subtile matter, such as *Descartes* imagined, should disturb the motions of the planets, had recourse to a very strange expedient, and quite contradictory to his own intention, as, on his hypothesis, the planets must be exposed to a derangement infinitely more considerable. I have already submitted to you several other insuperable objections to the system of emanation; and we have now seen that the principal, and indeed the only reason which could induce *Newton* to adopt it, is so self-contradictory as wholly to overturn it. All these considerations united, leave us no room to hesitate about the rejection of this strange system of the emanation of light, however respectable the authority of the philosopher who invented it.

Newton was without doubt one of the greatest geniuses that ever existed. His profound knowledge, and his acute penetration into the most hidden mysteries of nature, will be a just object of admiration to the present, and to every future age. But the errors of this great man should serve to admonish us of the weakness of the human understanding, which, after having soared to the greatest possible heights, is in danger of plunging into manifest contradiction.

If we are liable to weaknesses and inconsistencies so humiliating, in our researches into the phenomena of this visible world, which lies open to the examination of our senses, how wretched must we have been had God left us to ourselves with respect to things invisible, and which concern our eternal salvation? On this important article a revelation was absolutely necessary to us; and we ought to avail ourselves of it with the most profound veneration. When it presents to us things which may appear inconceivable, we have but to reflect on the imperfection of human understanding, which is so apt to be misled, even as to sensible objects. Whenever I hear a pretended Freethinker inveighing against the truths of religion, and even sneering at it with the most arrogant self-sufficiency, I say to myself—poor weak mortal, how inexpressibly more noble and sublime are the sub-

jects which you treat so lightly, than those respecting which the great *Newton* was so grossly mistaken! I could wish your Highness to keep this reflection ever in remembrance; occasions for making it occur but too frequently.

10*th June* 1760.

LETTER XIX.—A DIFFERENT SYSTEM RESPECTING THE NATURE OF RAYS AND OF LIGHT, PROPOSED.

YOU have seen that the system of the emanation of the rays of light labours under insuperable difficulties, and that the doctrine of a vacuum for the heavenly bodies to range in, is equally untenable, as the rays of light would completely fill it. Two things, then, must be admitted: first, the space through which the heavenly bodies move is filled with a subtile matter; secondly, rays are not an actual emanation from the sun and other luminous bodies, in virtue of which, part of their substance is violently emitted from them, according to the doctrine of *Newton*.

That subtile matter which fills the whole space in which the heavenly bodies revolve, is called *Ether*. Of its extreme subtilty no doubt can be entertained. In order to form an idea of it, we have only to attend to the nature of air, which, though extremely subtile, even on the surface of the earth, becomes more and more so as we ascend; and entirely ceases, if I may use the expression, when it comes to be lost in the ether. The ether, then, is likewise a fluid as the air is, but incomparably finer and more subtile, as we are assured that the heavenly bodies revolve freely through it, without meeting any perceptible resistance. It is also without doubt possessed of elasticity, by means of which it has a tendency to

expand itself in all directions, and to penetrate into spaces where there would otherwise be a vacuum; so that if by some accident the ether were forced out of any space, the surrounding fluid would instantly rush in and fill it again.

In virtue of this elasticity, the ether is to be found not only in the regions which are above our atmosphere, but it penetrates the atmosphere universally, insinuates itself by the pores of all bodies, and passes irresistibly through them. Were you, by the help of the air-pump, to exhaust the air from a receiver, you must not imagine that you have produced an absolute vacuum; for the ether, forcing itself through the pores of the receiver, completely fills it in an instant. Having filled a glass tube of the proper length with mercury, and immerged it, when inverted, in the cistern, in order to make a barometer, it might be supposed that the part of the tube which is higher than the mercury is a vacuum, because the air is completely excluded, as it cannot penetrate the pores of glass; but this vacuum, which is apparent only, is undoubtedly supplied by the ether, insinuating itself without the smallest difficulty.

It is by this subtilty and elasticity of ether that I shall by and by explain to you the remarkable phenomena of electricity. It is even highly probable that ether has an elasticity much superior to that of air, and that many of the phenomena of nature are produced by means of it. For my own part, I have no doubt that the compression of the air in gunpowder is the effect of the elastic power of ether. And as we know by experiment that the air in it is condensed almost 1000 times more than common air, and that in this state its elasticity is likewise 1000 times greater, the elasticity of the ether must in this case be so too, and consequently 1000 times greater than that of common air. We shall then

have a just idea of ether, in considering it as a fluid in many respects similar to air, with this difference, that ether is incomparably more subtile, and more elastic.

Having seen then that the air, by these very qualities, is in a proper state for receiving the agitations or shakings of sonorous bodies, and to diffuse them in all directions, as we find in the propagation of sound, it is very natural to suppose that ether may in the same circumstances likewise receive agitations in the same manner, and transmit them to the greatest distances. As the vibrations of the air produce *sound*, what will be the effect of those of ether? You will undoubtedly guess at once *light*. It appears in truth abundantly certain, that light is with respect to ether, what sound is with respect to air; and that the rays of light are nothing else but the shakings or vibrations transmitted by the ether, as sound consists in the shakings or vibrations transmitted by the air.

The sun, then, loses nothing of his substance in this case, any more than a bell in vibrating; and, in adopting this system, there is no reason to apprehend that the mass of this orb should ever suffer any diminution. What I have said of the sun must also be extended to all luminous bodies, such as fire, a wax taper, a candle, &c.

It will undoubtedly be objected, that these terrestrial luminaries evidently waste, and that unless they are continually fed and kept up, they will be speedily extinguished; that consequently the sun must in time be wasted away, and that the parallel of a bell is not accurate. But it is to be considered, that these fires, besides their light, throw out smoke, and a great deal of exhalation, which must be carefully distinguished from the rays of light. Now the smoke and exhalation evidently occasion a considerable diminution, which must not be imputed to the rays of light; for were it possible to separate them from the smoke and other exhalations, the luminous quality alone would occasion no expenditure. Mercury may, by means of art, be rendered luminous, as you have probably seen, and that without any diminution of its substance, which proves that light alone produces no waste of luminous bodies. Thus, though the sun illuminates the whole world by his rays, he loses nothing of his own substance, his light being only the effect of a certain agitation, or violent concussion of his minute particles, communicated to the adjoining ether, and thence transmitted in all directions by means of this fluid to the remotest distances, as a bell when struck communicates its own agitation to the circumambient air. The more we consider this parallel between sonorous and luminous bodies, the more we shall find it conformable to nature, and justifiable by experience; whereas the more we attempt to reconcile the phenomena of nature to the system of emanation, the more difficulties we encounter.

14*th June* 1760.

Letter XX.—Of the Propagation of Light.

The propagation of light in the ether is produced in a manner similar to that of sound in the air; and just as the vibrations occasioned in the particles of air constitutes sound, in like manner the vibration of the particles of ether constitutes light or luminous rays; so that *light is nothing else but an agitation or concussion of the particles of ether*, which is every where to be found, on account of its extreme subtilty, in virtue of which it penetrates all bodies.

These bodies, however, modify the rays of light in many different ways, by transmitting or stopping the propagation of the concussions. Of this I shall treat at large in the sequel. I confine myself at present to the propagation of rays in the ether itself, which fills the immense space in which the heavenly bodies revolve. There the propagation takes place in perfect liberty. The first thing which here presents itself to the mind is the prodigious velocity of the rays of light, which is about 900,000 times more rapid than that of sound, though this last travels no less than 1100 feet in a second.

This amazing velocity would be sufficient of itself to overturn the system of emanation; but in that which I am attempting to establish, it is a natural consequence, from the principles laid down, as I hope to demonstrate. They are the same with those on which is founded the propagation of sound in the air; and this depends at once on its density and elasticity. It is evident, that if the density of air were diminished, sound would be accelerated; and if the elasticity of the air were increased, the same thing would happen. If the density of the air diminished, and its elasticity increased at once, we should have a two-fold reason for the increase of the velocity of sound. Let us conceive, then, the density of the air diminished, and its elasticity increased, till its density and elasticity became equal to those of ether, and we should then no longer be surprised that the velocity of sound had become many thousands of times greater than it actually is. For you will be pleased to remember, that according to the first ideas we formed of ether, this fluid must be inconceivably rarer, and more elastic than air. Now both of these qualities equally contribute to accelerate the velocity of vibrations. From this explanation, the prodigious

velocity of light is so far from presenting any thing irreconcileable to reason, that it rather perfectly harmonizes with the principles laid down; and the parallel between light and sound is in this respect so firmly established, that we may confidently maintain, that if air should become as subtile and as elastic as ether, the velocity of sound would become as rapid as that of light.

The subtilty of ether, then, and its great elasticity, are the reason which we assign for the prodigious velocity of the motion of light; and so long as the ether preserves this same degree of subtilty and elasticity, this velocity must continue the same. Now it cannot be doubted that the ether has, through the whole universe, the same subtilty and the same elasticity. For were the ether less elastic in one place than in another, it would force itself into it till the equilibrium was perfectly restored. The light of the stars, therefore, moves with as great velocity as that of the sun; and as the stars are at a much greater distance from us than the sun, a much greater quantity of time is requisite to transmit their rays to us. However great the distance of the sun may appear, whose rays, nevertheless, reach the surface of our globe in eight minutes, the fixed star nearest to us is at least 400,000 times more distant than the sun; a ray of light issuing from that star will employ then 400,000 times eight minutes in travelling to us, that is 53,333 hours, or 2,222 days, or six years nearly.

It is then upwards of six years since the rays of light issued from that fixed star, the least remote, and probably the most brilliant, in order to render it visible to us; and these rays have employed a period so considerable to fly through the space which separates us from that star. Were God just now to create a new fixed star at the same distance,

it could not become visible to us till more than six years had elapsed, as its rays require that length of time to travel this distance. Had one been created at the beginning of the world a thousand times more distant than that which I have mentioned, it could not yet be visible to us, however brilliant, as 6000 years are not yet elapsed since the creation. The first preacher of the court of Brunswick, Mr. Jerusalem, has happily introduced this thought in one of his sermons. The passage runs thus:—

"Raise your thoughts from the earth which you inhabit, to all the bodies of the vast universe, which are so far above you; launch into the immensity of space which intervenes between the most remote which your eyes are able to discover, and those whose light, from the moment of creation till now, has not as yet, perhaps, come down to us. The immensity of the kingdom of God justifies this representation." (Sermon *on the Heavens, and Eternal Beatitude*).

I flatter myself that these reflections will excite a desire of further instruction respecting the system of light, from which is derived the theory of colours, and of vision.

17*th June* 1760.

Letter XXI.—Digression on the Distances of the Heavenly Bodies, and on the Nature of the Sun, and his Rays.

The observations which I have been making respecting the time which the light of the stars employs in making its progress down to us, convey a striking idea of the extent and greatness of the universe. The velocity of sound, which flies through

the space of 1000 feet in a second, furnishes us with nearly the first standard of measurement. It is about 2000 times more rapid than the pace of a man who is a good walker. Now the velocity of the rays of light is 900,000 times still more rapid than that of sound: these rays accordingly perform every second a course of 900 millions of feet, or 170,000 English miles.

What astonishing velocity! Yet the nearest fixed star is so remote, that its rays, notwithstanding this prodigious velocity, would take more than six years in descending to us. And were it possible for a great noise, such as that of the firing of a cannon, issuing from that star, to be conveyed to our ears, it would require a period of 5,400,000 years to reach us. And this is applicable only to those stars which are the most brilliant, and are probably nearest to us. Those which appear the smallest are very probably ten times still farther remote, and more. A whole century, then, at least, must elapse before the rays of these stars could possibly reach us. How prodigious must that distance be which cannot be passed through in less than 100 years, by a velocity which flies at the rate of 170,000 English miles every second!

Were, then, one of these stars to be just now annihilated, or eclipsed only, we should still continue to see it for 100 years to come, as the last rays which it emitted could not reach us in less time.

The generality of mankind is very far from having any thing like just ideas respecting the vast extent of the universe. Many consider it as a work of little importance, which chance alone might have produced. But what must be the astonishment of one who reflects, on observing, that all these immense bodies are arranged with the most consummate wisdom; and that the more knowledge we acquire on the sub-

ject, though it must ever be very imperfect, the more we must be disposed to admire their order and magnificence!

I return to the great luminous bodies, and particularly the sun, which is the principal source of the light and heat which we enjoy on the earth. It will be asked, in the first place, wherein consists the light which the sun is incessantly diffusing through the whole universe, without ever suffering the smallest diminution? The answer is obvious, according to the system which I have been endeavouring to establish. But that of emanation furnishes no satisfactory solution. The whole universe being filled with that extremely subtile and elastic fluid which is called ether, we must suppose, in all the parts of the sun, an incessant agitation, by which every particle is in a constant motion of vibration; and this, by communicating itself to the circumambient ether, excites in that fluid a similar agitation, and is thence transmitted to regions the most remote with the rapidity which I have been describing.

And to keep up the parallel between sound and light, the sun would be in a state similar to that of a bell which should be ringing continually. The particles of the sun must consequently be kept in this incessant agitation, to produce in the ether the undulations which we call rays of light. But it is still no easy matter to explain by what power this agitation in the particles of the sun is constantly kept up, as we observe that a match does not long continue burning, but presently goes out, unless it be supplied with combustible matter. But it must be remarked, that as the sun is a mass many thousand times greater than our whole globe, if it is once thoroughly inflamed, it may continue in that state for several ages without suffering any sensible diminution. Besides, the case is not the same with the sun and our

fires and candles, a considerable part of whose substance is dissipated in smoke and exhalations, from which a real waste results. Whereas, though perhaps some particles may be forced from the sun in form of smoke, they cannot remove to a great distance, but speedily fall back into its mass, so that there cannot be any real expenditure to occasion a diminution of his substance.

The only thing of which we are still ignorant respecting this subject, is the power which incessantly maintains all the particles of the sun in this agitation. But as it contains nothing inconsistent with good sense, and as we are under the necessity of acknowledging our ignorance of many other things much less remote than the sun, we ought to be satisfied if our ideas are not involved in contradiction.

21*st June* 1760.

LETTER XXII.—ELUCIDATIONS ON THE NATURE OF LUMINOUS BODIES, AND THEIR DIFFERENCE FROM OPAQUE BODIES ILLUMINED.

THE sun being a luminous body, whose rays are universally diffused in all directions, you can no longer be at a loss to account for this wonderful phenomenon, which consists in the shaking or vibration with which all the particles of the sun are agitated. The parallel of a bell lends considerable assistance toward the explanation of this fact. But it is obvious, that the vibrations produced by light must be much more vehement and rapid than those produced by sound, ether being incomparably more subtile than air. A feeble agitation not being capable of shaking the air so as to produce sound in it, that of a bell, and that of all other sonorous bodies, are too fee-

ble relatively to ether to produce in it the vibration which constitutes light.

You will recollect, that in order to excite a perceptible sound, more than 30, and less than 7552 vibrations must be produced in a second; the air being too subtile to admit of a sensible effect from a sound consisting of less than 30 vibrations in a second, but not sufficiently so to receive one of more than 7552 vibrations in the second. A note higher than this could not be at all heard. It is the same with respect to ether: 7552 vibrations, produced in a second, could not possibly act upon it, because of its greater subtilty. It requires vibrations much more frequent. An agitation so rapid could not take place but in the minutest particles of bodies which elude our senses. The light of the sun, then, is produced by a very violent agitation, which affects all his infinitely minute particles, each of which must shake many thousands of times every second.

It is a similar agitation which likewise produces the light of the fixed stars, and of all fires, such as candles, tapers, torches, &c. which give us light, and supply the place of the sun during the night. On attentively observing the flame of a wax-light, you will easily perceive, that in the minutest particles, there is a constant and surprising agitation; and I do not apprehend that my system is liable on this side to any contradiction, while that of Newton requires a most enormous agitation, capable of launching the minutest particles with the velocity of 170,000 English miles in a second.

This, then, is the explanation of the nature of bodies luminous of themselves: for there are luminous bodies which are not so immediately, such as the moon and the planets, which are similar to our globe. We see the moon only when, and in as far as she is illuminated by the sun; and this is the

case of all terrestrial bodies, fires excepted, which have a light of their own. But other bodies, which are denominated opaque, become visible to us only when they are illuminated by some luminous body.

In a very dark night, or in an apartment, so closely shut on every side that no light can find admission, to no purpose will you turn your eyes toward the objects which surround you in the dark: you perceive nothing. But the moment a taper is introduced, you immediately see, not the taper only, but the other bodies which were before invisible. We have here, then, a very essential difference between luminous and opaque bodies. I have already employed the term *opaque* to denote bodies which are not transparent; but it comes to almost the same thing; and we must accommodate ourselves to the common modes of expression, though they are not perfectly accurate. Luminous bodies are visible by their own light, and never affect our organs of sight more than when the darkness is otherwise most profound. Those which I here denominate opaque, are rendered visible to us only by means of a light that is foreign to them. We perceive them not while they remain in darkness; but as soon as they are exposed to a luminous body, whose rays strike upon them, they become visible; and they disappear the moment that foreign light is withdrawn. It is not even necessary that the rays of a luminous body should fall upon them immediately; another opaque body, when well illuminated, produces nearly the same effect, but in a feebler manner.

The moon is an excellent instance. We know that the moon is an opaque body; but when she is illuminated by the sun, and we see her during the night, she diffuses a feeble light over all opaque bodies, and renders visible to us those which we could not have perceived without her assistance.

Placed in the day time in an apartment whose aspect is toward the north, and into which, of course, the rays of the sun cannot enter, it is, however, perfectly clear, and I am able to distinguish every object. What can be the cause of this clearness, but that the whole heaven is illuminated by the sun? What we call the azure sky, and, besides, the walls opposite to my apartment, and the other surrounding objects, are likewise illuminated, either immediately by the sun, or mediately by other opaque bodies, exposed to the action of that focus of light; and the light of all these opaque, but illuminated bodies, as far as it has admission into my apartment, renders it luminous, and that in proportion as the windows are high, wide, and well placed. The glass is little or no interruption, being, as I have already remarked, a transparent body, which freely transmits the rays of light.

When I completely exclude the light from the apartment by closing the window-shutters, I am reduced to a state of darkness, and discern no object, unless I call for a candle. Here then is an essential difference between luminous and opaque bodies; and likewise a very striking resemblance, namely, that opaque bodies, when illuminated, illuminate other opaque bodies, and produce in this respect nearly the same effect as bodies luminous of themselves. The explanation of this phenomenon has hitherto greatly perplexed philosophers; but I flatter myself that my solution of it has been clear and satisfactory.

24th June 1760.

LETTER XXIII.—HOW OPAQUE BODIES BECOME VISIBLE. NEWTON'S SYSTEM OF THE REFLECTION OF RAYS PROPOSED.

BEFORE I attempt an explanation of the phenomenon of opaque bodies becoming visible when they are illuminated, it must be remarked in general, that we see nothing but by means of the rays which enter into our eyes. When we look at any object whatever, rays issuing from every point of that object, and entering into the eye, paint upon it, if I may use the expression, the image of the object. This is not mere conjecture, but may be demonstrated by experiment. Take, for example, the eye of an ox, or of any animal recently killed, and, after having uncovered the bottom, you find all the objects which were before it painted there. As often then as we see an object, the image of it is painted on the bottom of our eyes; and this is produced by the rays which proceed from the object to us. I shall afterwards take occasion to go into a more minute detail on the subject of vision, and explain in what manner the images of objects are formed on the bottom of the eye: let this general remark suffice for the present.

As we see opaque bodies only when they are illuminated, this is a proof that there must proceed from every point of these bodies rays of light which subsist only during the illumination. The moment they are placed in the dark these rays disappear. They are not proper then to opaque bodies; their origin must be sought in the manner in which other bodies illuminate them. And this is the great question, how illumination alone is capable of producing rays on opaque bodies, or of putting them in nearly the same state as luminous bodies are, which, by an

agitation in their minutest particles, produce rays of light?

The great *Newton*, and other philosophers who have examined the subject, assign *reflection* as the cause of this phenomenon: it is therefore of the highest importance that you should form a just idea of what is called reflection.

This name is given to the repulsion of one body struck against another, as may be seen in the game of billiards. When the ball is struck against the cushion or ledge of the billiard table, it recoils again; and this retrograde motion is termed reflection. It is necessary here to attend to a distinction between two cases. Let us suppose A B (PLATE I. *Fig.* 7.) to be the ledge of a billiard table. The first case is this: When you play the ball D perpendicularly against the ledge, in the direction of D C, perpendicular to A B, and consequently the adjacent angles A C D and B C D are right angles: in this case, the ball will be driven back or reflected in the same line D C. The other case is, when the ball is played obliquely against the ledge, suppose in the line E C, forming with A B an acute angle A C E, this is called the angle of incidence. The ball will in this case be repelled from the ledge in the direction of the line C F, so that this line shall make on the other side, with the ledge B C, an angle B C F, exactly equal to the angle of incidence A C E. This angle B C F, formed by the line in which the ball recoils, is called the angle of reflection. And this law always takes place when a body in motion meets with an obstacle.

A cannon ball shot against a wall sufficiently strong to resist it, is reflected conformably to this law. It extends, in like manner, to sounds which are frequently reflected from certain bodies; and you know that this reflection of sound is called echo.

It cannot be doubted, that the same thing frequently takes place with respect to the rays of light. The objects which we see in mirrors are represented to us by the reflection of rays, and every well polished surface reflects the rays of light which fall upon it. It is undoubtedly certain, therefore, that there are cases without number in which the rays that fall on certain bodies are reflected; and philosophers have thence taken occasion to maintain, that opaque bodies are rendered visible by means of reflected rays.

I see just now houses opposite to my windows which are illuminated by the sun. According, then, to the opinion of those philosophers, the rays of the sun falling on the surface of these houses, are reflected from them; they enter into my apartment, and render these houses visible to me. In the same manner, if we believe those philosophers, the moon and the planets become visible, and these are unquestionably opaque bodies. The rays of the sun which fall on these bodies, and illuminate the parts which are exposed to them, are reflected, and are thence transmitted to us, just as if the bodies were luminous of themselves. According to this opinion, we see the moon and the planets only by the rays of the sun which they reflect; and you must frequently have heard it affirmed, that the light of the moon is a reflection of the light of the sun. In the same manner, say they, the rays of the sun are reflected by the first opaque bodies which are exposed to them, on other bodies of the same nature, and undergo a series of similar reflections, till they are entirely weakened.

But however plausible this opinion may at first sight appear, it involves so many absurdities when closely examined, that it is absolutely untenable, which I hope to demonstrate, as a preparation for the true solution of this phenomenon.

28*th June* 1760.

Letter XXIV.—Examination and Refutation of Newton's System.

I affirm, then, that when we see an opaque body illuminated by the sun, it is impossible to maintain that it reflects luminous rays, and that by means of such rays it is rendered visible to us. The example of a mirror, which undoubtedly reflects the rays, and is employed to support this opinion, rather confutes it. The mirror, beyond contradiction, sends back the rays which fall upon it; but when these reflected rays enter into our eyes, what do they represent? You will readily answer, that it is not the mirror, but the objects from which they originally proceeded; and the reflection does nothing else but enable us to see these objects in another place. Besides, we see those objects not on the surface of the mirror, but rather within it; and it may be said with truth, that the mirror itself remains invisible to us.

But, on looking at an opaque body illuminated by the sun, we do not see in it the image of that glorious orb; we see only the surface of the bodies, with all the variations to be found on them. We perceive, then, a very essential difference between the rays which are reflected from a mirror, and those by means of which opaque bodies are rendered visible. But there is, besides, another difference equally palpable in the mirror; for on changing the place of the objects, or our own situation, the appearance will always change, and the rays, reflected from the mirror, will continually represent to our eyes other images, corresponding to the nature and position of the objects, and to the place where we are stationed; but, as I have already said, these reflected rays never represent to us the mirror itself.

Now, let a body be illuminated by the sun, or other bodies, whether luminous or opaque, already illuminated; in whatever manner this body may change its place, or we change ours relatively to it, its appearance is always the same; we see always the same object, and remark in it no change relative to the different circumstances above mentioned. This furnishes a new proof, that we do not see opaque bodies by means of the rays reflected from their surface.

An objection will perhaps be started, drawn from the dove's neck, and certain kinds of stuff, which present different objects, according as our point of view changes. But this in no respect weakens my conclusion with regard to ordinary opaque bodies, which are not subject to this change. The objection only proves, that these singular objects are endowed with certain qualities; as, for example, that their minuter particles are finely polished, and that a real reflection takes place, beside the usual and ordinary manner in which bodies are rendered visible to us.

Now, it is easy to comprehend, that this reflection must be clearly distinguished from the manner in which ordinary opaque bodies are illuminated.

Finally, the rays reflected from a mirror always represent to us, likewise, the colours of the bodies from which they originally proceed; and the mirror, which reflects, makes no change in this respect. One opaque body, illuminated by any other body, in whatever manner, always presents the same colours; and every body may be said to have its proper colour. This circumstance absolutely overturns the opinion of all those who maintain, that we see opaque bodies by means of the rays which their surface reflects.

Putting together all the reasons which I have now submitted to your consideration, there can be no

hesitation in pronouncing, that this opinion is totally untenable in philosophy, or rather, in physics. I cannot, however, flatter myself with the hope, that philosophers, wedded to opinions once adopted, should yield to these reasons. But the naturalist, who is more nearly related to the mathematician, will have less difficulty in resigning an opinion, overthrown by reasons so convincing. You will again recollect what Cicero has said on this subject: That nothing so absurd can be conceived, as not to be supported by some philosopher. In fact, however strange the system which I have been refuting may appear to you, it has hitherto been propagated and defended with much warmth.

It is impossible to say, to what a degree the difficulties and contradictions which I have been endeavouring to expose, were unknown to, or overlooked by, the partisans of this system. The great *Newton* himself strongly felt their force; but as he rested in a very untenable idea respecting the propagation of light, it is not to be wondered at, that he should overlook these great difficulties; and, in general, depth of understanding does not always prevent a man from falling into absurdity in supporting an opinion once embraced.

But if this system, that opaque bodies are rendered visible by reflected rays, be false—say, its partisans, what then is the true one? They even think it impossible to imagine another explanation of this phenomenon. It is, besides, rather hard and humiliating for a philosopher to acknowledge ignorance of any subject whatever. He would rather maintain the grossest absurdities; especially if he possesses the secret of involving them in mysterious terms, which no one is capable of comprehending. For in this case, the vulgar are the more disposed to admire the learned; taking it for granted, that what

is obscurity to others, is perfectly clear to them. We ought always to exercise a little mistrust, when very sublime knowledge is pretended to—knowledge too sublime to be rendered intelligible. I hope I shall be able to explain the phenomenon in question, in such a way as to remove every difficulty.

1*st July* 1760.

LETTER XXV.—A DIFFERENT EXPLANATION OF THE MANNER IN WHICH OPAQUE BODIES ILLUMINATED BECOME VISIBLE.

ALL the phenomena of opaque bodies, which I have unfolded in the preceding letter, incontestably demonstrate, that when we see an opaque body illuminated, it is not by rays reflected from its surface that it becomes visible, but because its minuter particles are in an agitation similar to that of the minuter particles of luminous bodies; with this difference, however, that the agitation in opaque bodies is far from being so strong as in bodies luminous of themselves; for an opaque body, however much illuminated, never makes on the eye an impression so lively as luminous bodies do.

As we see the opaque bodies themselves, but by no means the images of the luminous bodies which enlighten them, as must be the case if we saw them by the reflection of their surface, it must follow, that the rays emitted by opaque bodies are proper to them, just as the rays of a luminous body are peculiar to itself. As long as an opaque body is illuminated, the minuter particles of its surface are in a state of agitation proper to produce in the ether a motion of vibration, such as is necessary for forming rays, and for painting in our eyes the image of the body from which they proceed. For this effect,