the contrary, the more it is rarefied, the more this quality is diminished. Experimental philosophers have invented one machine for rarefying air, and another for condensing it: the former is called the *air-pump*, the latter the *condenser*. These machines serve to perform many curious experiments, with which you are already well acquainted. I reserve to myself, however, the liberty of recapitulating some of them, because they are necessary to elucidate and explain the nature and properties of air, which, as they powerfully contribute to the preservation of animals, and the production of plants, press upon us the importance of forming a just idea of them.

14*th May* 1760.

Letter XI.—Gravity of the Air.

I HAVE endeavoured to demonstrate that the air is a fluid, endowed with the particular property of suffering compression into a smaller space, and of expanding into a greater, when no obstacle interposes. This property of air, known by the name of spring, or elasticity, from its resemblance to a spring, which it requires an effort to unbend, and which resumes its form as soon as the effort ceases, is accompanied by another, in common to it with all bodies in general, namely, gravity or weight, in virtue of which all bodies tend toward the centre of the earth, and by which they are under the necessity of falling down, unless supported. The learned are very much divided, and very uncertain, respecting the primary and mechanical cause of this power; but its existence is indubitable. Daily experience evinces it. We know even the quantity of it, and can measure it exactly. For the weight of a body is nothing else but the power which constrains it to descend; and as the weight of every body may be exactly measured, we know perfectly well the effect of gravity, though the cause, or that invisible power which acts upon all bodies, forcing them to descend, may be absolutely unknown to us. It follows, that the more matter any body contains, the heavier it is. Gold and lead are heavier than wood or a feather, as they contain more matter in the same bulk, or in the same extent. But as air is a very subtile and thin substance, and its gravity of consequence very little, this property usually escapes our senses. Experiments, however, may be made capable of producing full conviction that it possesses gravity. You have seen how the air may be rarefied in a vessel or a tube; and by means of the air-pump, this rarefaction may be carried so far as almost entirely to exhaust the air, and to leave the receiver sensibly a vacuum. Or you may take a tube A B C D (Plate I. *Fig* 4.), into which you introduce the piston F E, so as perfectly to touch the bottom, and to leave no air between the two surfaces. To perform the experiment with more advantage, let there be at the bottom of the tube a little aperture G, through which the air may escape as the piston is pushed forward. Let the aperture then be closely stopped, that not a particle of air may be included between the piston and the bottom of the tube. Having made this arrangement, draw back the piston; and the external air not being able to force its way into the tube, there will remain between the bottom of the tube and the piston a perfect vacuum, which may be increased at pleasure by continuing to draw back the piston. You may thus exclude the air contained in a vessel; and such vessel, reduced to a vacuum, being tried in accurate scales, will be found to weigh less than when filled with air. Hence we deduce this very important conclusion, that the air contained in an empty vessel increases its weight, and that the air itself possesses

gravity. Were the vessel large enough to contain 800 pounds weight of water, we might discover by this experiment, that the body of air which fills it would weigh nearly one pound. Hence we conclude, that air is 800 times lighter than water. I must be understood as speaking of the common air which surrounds us, and which we breathe; for you know, that with the assistance of art, air may be compressed by forcing it into a smaller space, and its gravity thereby increased. Were the vessel which I have mentioned to be filled with air compressed to twice the consistency of common air, it would weigh two pounds more than when empty. Were it filled with air 800 times more compressed than common air, it would weigh 800 pounds more than when empty, that is, as much as if it were filled with water. The air, then, possessing a certain degree of gravity, though in the natural state of this fluid its gravity is extremely small, it must, however, as well as all other bodies, tend towards the centre of the earth, and consequently it presses on every thing which opposes this tendency. For this reason the superior air presses downward on the inferior, and this last undergoes a compression from the weight of the whole mass of air which is above it. Hence it comes to pass, that in these regions the air has a certain degree of compression or density, which is the effect of the gravity of the superior air; and that if the superior air had more or less gravity, the air which surrounds us would likewise become more or less dense. It is thus that the air below supports the weight of the superior air, and that the more we ascend the more it loses its density, and rarefies; so that were it possible to continue to ascend, the air would at length be totally lost, or would become so subtile and so rarefied as to be no longer perceptible. Were you to descend, on the contrary, into a very deep pit, you would find the density of the air continually increasing, from the increase of the mass of air pressing downward upon it.

17th May 1760.

LETTER XII.—OF THE ATMOSPHERE, AND THE BAROMETER.

HAVING demonstrated that air is a fluid, elastic, and possessed of gravity, I proceed to remark, that the earth is surrounded on all sides by this fluid, and that the space which it fills is called the *atmosphere*. It would be absolutely impossible for a perfect vacuum to exist on any part of the earth's surface; for the air of the adjoining regions, compressed by the weight of the superior air, and making incessant efforts to dilate, would force itself into the empty space and fill it. The atmosphere, therefore, occupies the whole region which surrounds the earth; the inferior air is continually compressed by the weight of the superior air, and that until the degree of elasticity which results from this compression is able to form an equilibrium to the compressing power. Then, although this air is compressed only in a downward direction, it produces, in virtue of its elasticity, efforts to expand itself not only downwards, but sideways also. For this reason, the air in a chamber is as much compressed as the external, which appeared a paradox to certain philosophers. For they reasoned thus: In a chamber, the inferior air is compressed only by the small quantity of superior air included in that chamber; whereas the external air is compressed by the weight of the whole atmosphere, the height of which is immense. But the difficulty is at once removed, by the property which air possesses of expanding itself when com-

pressed in all directions. Now the air in the chamber is at first reduced by the external air to the same degree of compression and elasticity with itself; hence, whether I am in my chamber, or in the open air, I feel the same compression; being always understood, that I mean at the same height, or at the same distance from the centre of the earth. For I have already remarked, that on getting to the summit of a high tower, or of a lofty mountain, the compression of the air is less, because the weight of the superior air is then diminished. Various phenomena confirm this state of the compression of the air.

Take, for instance, (PLATE I. *Fig* 5.) a tube A B, close at the end A, and having filled it with water, or any other fluid, invert it so that the open end B may be undermost, and you will find that the fluid does not run out. The elasticity of the air acting at B, in opposition to the fluid, supports it in the tube. But if you make an aperture into the tube at A, the fluid immediately descends: the air which is admitted by the aperture acts then from above, by its pressure upon the water, and forces it downward; which demonstrates, that while the tube was close at top, it was the external air which supported the water in it. And were such a tube to be placed in a receiver, from which the air was extracted by the air-pump, the fluid would instantly descend. The ancients, to whom this property of air was unknown, alleged, that nature supported the water in the tube, from the horror which it has of a vacuum. For, said they, were the fluid to descend, there must be a vacuum at the upper end of the tube, as the air could find no admission into it. According to them, therefore, it was the horror of a vacuum which kept the fluid suspended in the tube. It is now demonstrated, that it is the force of the air which supports the weight of the fluid in the tube; and as this force has

a determinate quantity, the effect cannot exceed a certain limit.

It is found by experiment, that if the tube A B is more than 33 feet in length, water will no longer remain suspended in it, but will run out till it comes to the height of 33 feet; the space left at the top will, of course, be a real vacuum. The force of the air then cannot support water in the tube at more than the height of 33 feet; and as the same force supports the whole atmosphere, it is concluded that a column of the atmosphere is of equal weight, the base being equal with a column of water 33 feet high. If, instead of water, you were to use mercury, which is 14 times heavier, the force of the air could support it in the tube at the height of only 28 inches; and if you go beyond that, the mercury descends till its height corresponds to the pressure of the atmosphere, leaving the space at the top of the tube a vacuum. Such a tube close above, and open below, being filled with mercury, forms the instrument called the *Barometer*, by means of which it has been discovered that the atmosphere is not always of equal gravity. For its real gravity is ascertained by the barometer from the height of the mercury, which, as it rises or falls, indicates that the density of the air, or the pressure of the atmosphere, is increasing or diminishing.

20*th May* 1760.

LETTER XIII.—OF AIR-GUNS, AND THE COMPRESSION OF AIR IN GUNPOWDER.

HAVING explained that remarkable property of air which is denominated compressibility, by means of which it is reducible into a smaller space, we are enabled to give an account of several productions of both nature and art. I shall begin with an explana-

tion of the *air-gun*, though I have no doubt but you are well acquainted with that instrument. Its construction is similar to that of the common gun; but instead of powder, we employ condensed air to discharge the bullet.

In order to comprehend the process of this operation, it must be observed, that air can be compressed only by a force proportional to the degree of condensation which you wish to obtain; in this state it strives to extend itself, and the efforts which it makes are precisely equal to the force necessary to reduce it to the size which it actually occupies. The more, then, that the air is condensed, the more violent are its efforts to dilate; and if the air is raised to a density twice as great as when it is free, which is the case when we reduce it to half the space which it occupies in its natural state, the force with which it endeavours to expand is equal to the pressure of a column of water 33 feet high. Figure to yourself a great cask of this height filled with water; this fluid will undoubtedly make a stronger pressure on the bottom of the vessel. If you make a hole in it, near the bottom, the water will force itself out with considerable violence; and on stopping the aperture with your finger, you will be abundantly sensible of this pressure of the water. The bottom of the cask sustains throughout a similar pressure. Now a vessel containing air twice as dense as that of the atmosphere, must undergo precisely such a pressure; and if it were not sufficiently strong to sustain it, would burst. The sides, then, of this vessel must be as strong as the bottom of the cask I have mentioned. If in the same vessel the air were three times as dense as common air, the force with which it would act upon the sides must be increased in the proportion of one more, and would be the same which is sustained by the bottom of a cask full of water of 66

feet in height. You will easily conceive that this force must be very great, and that it must go on increasing in the same ratio, according to the different degrees of condensation of the air. This being laid down, there is, at the bottom of the air-gun, a cavity strongly fortified on all sides, into which the air is more and more compressed, in order to reduce it to as high a degree of density as the force employed for that purpose can admit. The air confined in this cavity will thereby acquire a prodigious power to force itself out; and if an aperture is made, it will fly off with a velocity proportional to that power. Now there is such an aperture which terminates in the cavity of the tube into which the ball is put. It is closely stopped; but when you wish to discharge the piece, you open, for an instant, the valve which shuts it; and the air rushing forth, forces out the ball with all the velocity which we remark in shooting. Every time you discharge, the valve is kept open only a single moment; a certain quantity of air, therefore, and no more, can escape, and enough still will remain for several shots. But on discharge, its density and corresponding elasticity diminish; and for this reason, the latter discharges are less forcible than the former, till the force is at length entirely exhausted. Were the valve to remain open any considerable time, more air would make its escape, which would all go to waste; for this force acts upon the ball only while it is in the barrel of the gun; as soon as it is shot off, it is useless to leave a passage for the air. Hence it appears, that were it possible to carry the condensation of this fluid a great deal farther, you would produce from the wind-gun the same effects as from the guns and cannons in common use.

The effect of artillery is accordingly founded on the same principle. Gunpowder is only a substance,

which contains in its pores an air extremely condensed. Nature produces here the same operations which we employ for compressing the air, but carries the condensation to a much higher degree. All that is necessary is to open the little cavities in which this dense air is confined, that it may have liberty to escape. This is performed by means of fire, which bursts open these little envelopes: the air then suddenly flies off with incredible velocity, and forces before it bullets and balls in a manner entirely similar to that which we have remarked in the case of the wind-gun, but with much greater impetuosity. Here, then, are two very surprising effects produced from the condensation of air, with this single difference, that in the one it is the work of art, and in the other that of nature. We see therefore in this, as in every thing else, how infinitely the operations of human skill are surpassed by those of nature.

24th May 1760.

Letter XIV.—The Effect produced by Heat and Cold on all Bodies, and of the Pyrometer and Thermometer.

Beside the properties already mentioned, air has another very remarkable quality in common to it with all bodies, not excepting such as are solid; I mean the change produced on it by heat and cold. It is observable, in general, that all bodies, being heated, dilate or increase in size. A bar of iron made very hot, is somewhat longer and thicker than when it is cold. There is an instrument called the *Pyrometer*, which accurately indicates the slightest differences of length or shortness that a bar of iron undergoes to which it is applied. You know that in a watch, some of the wheels move very slowly,

though they communicate motion to others which revolve with considerable rapidity. By a similar mechanism it is possible, from a change almost imperceptible, to produce one very considerable, as is the case of the pyrometer which I have just mentioned. It has an index, which runs over a very considerable space, on the slightest change produced in the length of the body on which the experiment is made. On applying this instrument to a bar of iron, or any other metal, placed over a burning lamp, the index is immediately put in motion, and shows that the bar is becoming longer; and as the heat increases, the bar likewise increases in length. But on extinguishing the lamp, and the bar growing cold again, the index moves in a contrary direction, and thereby shows that the bar is growing shorter. The difference, however, is so slight, that without the help of this instrument, it would be difficult to perceive it. Yet this variation is abundantly perceptible in the motion of pendulum time-pieces. The use of the pendulum is to regulate the motion. If you lengthen it, the clock goes slower; and if you shorten it, the clock goes faster. Now it is remarked, that in very hot weather all clocks lose time, and proportionably gain it in very cold weather; which clearly demonstrates, that the pendulum is lengthened or shortened, according to the temperature of the air.

All bodies undergo this alteration; but the quantity differs greatly, according to the nature of the substance of which they are composed. In fluids, especially, this variability is very perceptible. To ascertain it, take a glass tube, B C, (Plate I. *Fig.* 6.) joined at the end B to a hollow ball A, and let it be filled with any liquor you please up to M. On heating the ball A, the liquor will rise from M toward C; when it becomes cold again, the liquor will fall

toward B. This clearly proves that the same liquid occupies a greater space when it is heated, and a smaller when cold. It is likewise clear, that this variation must be more perceptible, when the ball is large, and the tube narrow. For if the whole mass of liquor increases or diminishes by a thousandth part, that thousandth part will occupy, in the tube, a space great in proportion to its narrowness. Such an instrument then is exceedingly proper to indicate to us the different degrees of heat and cold; for if the liquor rises or falls, it is a certain indication that the heat is increasing or diminishing. This instrument is called the *Thermometer*,* which points out the changes that take place in the temperature of the air, and of the bodies that surround us. It must not be confounded with the *Barometer*, whose use is to indicate the gravity of the air, or rather the force with which it is compressed. This caution is the more necessary, that the barometer and thermometer have a considerable resemblance: being both

* Of this instrument there are three kinds now in use, viz. *Fahrenheit's*, *Reaumur's*, and *Celsius'* or the *Centigrade* thermometer. In the *first* of these, which is used in Britain and North America, the freezing point is at 32°, and the boiling point at 212°, the interval being 180°. In *Reaumur's*, which is used in Switzerland, Italy, and part of Germany, the scale begins at the freezing point, and the boiling point is placed at 80°, the interval being 80°. In the *Centigrade* thermometer, which is used in France, Sweden, and Denmark, the freezing point is at 0°, and the boiling point at 100.

The freezing point of the thermometer is immoveable, unless when the bulb containing the mercury has changed its form, which has been recently supposed to take place in consequence of the vacuum above the mercury, which exposes the bulb to the pressure of the atmosphere. The boiling point is, however, variable, depending on the pressure of the atmosphere. Near the surface of the earth it varies 1° of Fahrenheit, for every 530 feet of altitude, or for 0,589 inches of the barometer. By measuring therefore the temperature at which water boils, we may determine the height of the place. This method was first suggested by Fahrenheit and Cavallo, but has been perfected by the Rev. F. J. H. Wollaston, who has given an account of this thermometrical barometer in the *Philosophical Transactions* for 1817, p. 183.—En.

glass tubes filled with mercury; but their construction, and the principles on which they are founded, are entirely different. This quality of bodies, extension by heat, and contraction by cold, belongs likewise in a very superior degree to air. I shall explain it at greater length in my next letter.

27th May 1760.

Letter XV.—Changes produced in the Atmosphere by Heat and Cold.

1. Heat and cold produce the same effect on air, as on every other body. Air is rarefied by heat, and condensed by cold. From what I have said of the elasticity of air, you easily perceive, that a certain quantity of this fluid is not determined to occupy only a certain space, as all other bodies are; but by its nature it has a perpetual tendency to dilate, and actually does expand itself, as long as it meets no obstacle.

This property of air is denominated *Elasticity*. When this fluid is confined in a vessel, it makes efforts in every direction to burst it; and these efforts are greater or less in proportion to its condensation. Hence we come to this conclusion, that the elasticity of air is in exact proportion to its density; so that when its density is doubled, its elasticity is likewise doubled; and that, in general, a certain degree of elasticity corresponds to a proportional degree of density. It must be remarked, however, that this takes place no longer than while the air preserves the same degree of heat. Whenever it becomes hotter, it acquires greater power of expansion than what corresponded to its density; and cold produces the opposite effect, by diminishing its expansive power. In order then to determine the elasticity of

a mass of air, it is not sufficient to know its density; you must likewise know its degree of heat. In order to set this in a clear light, let us suppose two chambers closely shut on all sides, but united by a door of communication: and that the heat in both is equal. In order to this the air in both chambers must have the same degree of density. For were the air more dense, and consequently more elastic, in the one than in the other, part of it would escape from the one, and force its way into the other, till the density in both were the same. But let us suppose that one of the chambers has become hotter than the other, the air thereby acquiring a greater elasticity, would of course force itself into the other, and reduce that which it found there into a smaller space, till the elasticity in both chambers was brought to the same degree. During this change there will be a current of air through the door, from the chamber which is more, into that which is less heated; and when the equilibrium is restored, the air will be more rarefied in the warm apartment, and more condensed in the cold; and yet the elasticity of both will be the same. From this it clearly follows, that two masses of air of different densities, may have the same elasticity, when the one is hotter than the other; and this circumstance taken into consideration, it may happen, that with the same degree of density, they may be endowed with different degrees of elasticity.

What I have said of two chambers may be applied to two countries; and hence it may be concluded, that when one country becomes warmer than the other, there must of necessity be a current of air from the one to the other; and from this results the wind.

Here, then, is one fruitful source of winds, though there are perhaps others, which consist in the different degrees of heat which prevail in different regions of the earth; and it is demonstrable, that the whole air which surrounds the earth could not be in a state of rest, unless that, universally, at equal heights, there were found the same degree, not only of density, but likewise of heat. And should it happen that there were no wind over the whole surface of the earth, it might with certainty be concluded, that the air would likewise be every where equally dense and warm at equal heights. Now as this never happens, there must of necessity always be winds, at least in some regions. But these winds are, for the most part, to be met with only on the surface of the earth; and the higher you rise, the less violent winds are. Winds are hardly perceptible at the summit of very high mountains; there perpetual tranquillity reigns; from which it is impossible to doubt, that at considerable elevations, the air is always in a state of rest. Hence it follows, that in regions remarkably elevated, there universally prevails all over the earth, the same degree of density and heat; for were it hotter in one place than in another, the air could not be in a state of rest. And, as there is no wind in these elevated regions, it must necessarily follow, that the degree of heat there must be always the same; which is a very surprising paradox, considering the great variations of heat and cold which we feel on the surface of the earth, during the course of a year, and even of one day; without taking into the account the difference of climate, that is, the intolerable heats felt under the equator, and the dreadful cold which constantly prevails towards the poles of the earth. Experience itself, however, confirms the truth of this astonishing fact. The snow and ice remain equally, summer and winter, on the mountains of Switzerland, and are equally unchangeable on the Cordilleras lofty mountains of Peru, situated under the very

equator, and where there perpetually reigns, nevertheless, a cold as excessive as that of the polar regions. The height of these mountains is $4\frac{5}{7}$ English miles, or 24,000 feet. From this it may be, with confidence, concluded, that were it possible for us to ascend to the height of 24,000 feet, above the earth, we should always meet with the same degree of cold, and that cold excessively severe. We should remark there no sensible difference during either summer or winter, under the equator, or near the poles. At this height, and still higher, the state of the atmosphere is universally, and at all seasons, the same; and the variations of heat and cold take place near the surface of the earth alone. It is only in these inferior regions that the effect of the rays of the sun becomes perceptible. You have, undoubtedly, some curiosity to know the reason of this. It shall be the subject of the following letter.

31*st May* 1760.

LETTER XVI.—THE COLD FELT ON HIGH MOUNTAINS AND AT GREAT DEPTHS ACCOUNTED FOR.

IT appears very surprising, that we should feel the same degree of cold in all regions, after we have risen to a certain height, say 24,000 feet; considering that the variations with respect to heat on the earth, not only in different climates, but in the same country, at different seasons of the year, are so perceptible. This variety, which takes place at the surface of the globe, is undoubtedly occasioned by the sun. It appears, at first sight, that his influence must be the same above and below, especially when we reflect, that a height of 24,000 feet, though very great with respect to us, and even far beyond the height of very lofty mountains, is a mere nothing,

compared to the distance of the sun, which is about ninety-six millions of miles. This is, therefore, a very important difficulty, which we must endeavour to solve. For this purpose I begin with remarking, that the rays of the sun do not communicate heat to any bodies, but such as do not grant them a free passage. You know that bodies, through which we can discern objects, are denominated *transparent*, *pellucid*, and *diaphanous*. These bodies are glass, crystal, diamond, water, and several other liquids, though some are more or less transparent than others. One of these transparent bodies being exposed to the sun, is not heated to such a degree as a body not transparent, as wood, iron, &c. Bodies not transparent are denominated *opaque*. A burning-glass, for example, by transmitting the rays of the sun, sets on fire opaque bodies, while the glass itself is not sensibly heated. Water exposed to the sun becomes somewhat warm, only because it is not perfectly transparent; when we see it considerably heated by the sun at the brink of rivers, it is because the bottom, being an opaque body, is heated by the rays which the water transmits. Now, every heated body communicates that heat to all adjoining bodies; the water accordingly derives heat from the bottom. If the water be very deep, so that the rays cannot penetrate to the bottom, it has no perceptible heat, though the sun bears upon it.

As air is a very transparent body to a much higher degree than glass or water, it follows that it cannot be heated by the sun, because the rays are freely transmitted through it. The heat which we frequently feel in the air is communicated to it by opaque bodies, which the rays of the sun have heated; and were it possible to annihilate all these bodies, the air would scarcely undergo any change in its temperature by the rays of the sun: exposed

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.

3d 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-