sweeper,* which was so diverting to your Highness, furnishes me with another excellent comparison. When you can guess the sense, and discover that it is perfectly expressed in the proposition of the enigma, you feel a very sensible pleasure on making the discovery; but insipid and incongruous enigmas produce none. Such are, if I may be permitted to judge, the true principles on which decisions respecting the excellency of musical compositions are founded.

6th May 1760.

Letter IX.—Compression of the Air.

The explanation of sound, which I have had the honour to present to your Highness, leads me forward to a more particular consideration of air, which, being susceptible of a movement of vibration, such as that by which musical strings, bells, and other sonorous bodies are agitated, transmits the concussion to our ears. It will be immediately asked, what is air? For it does not appear at first sight to be a material substance. As we perceive no sensible body in it, surrounding space seems to contain no matter whatever. We feel nothing; we can walk, and move every limb in it, without experiencing the slightest obstacle. But you have only to move your hand briskly to be sensible of some resistance, and even to perceive a stream of wind excited by that rapid movement. Now the wind is nothing else but air put in motion; and seeing it is capable of producing effects so surprising, how is it possible to doubt that air is a material substance, and consequently a

* A celebrated enigma of La Mothe, published in his fugitive pieces.

body? For the terms *body* and *matter* are synonymous.

Body is divided into two great classes, solid and fluid. The air, it is evident, must be referred to the class of fluids. It has several properties in common with water; but it is much more subtile and fine. Experiments have ascertained that air is about 800 times more subtile and more rarefied than water; and that if air were to be rendered 800 times denser than it is, it would have the same consistency as the other fluid. A principal property of air, by which it is distinguished from other fluids, is its quality of being compressed, or reduced into a smaller space. This is demonstrated by the following experiment: Take a tube of metal or glass A B C D (Plate I. *Fig.* 2.), close shut at the end A B, and open at the other, into which is introduced a piston P, filling exactly the cavity of the tube. On pushing the piston inwards, when it has arrived at the middle E, the air which occupied at first the cavity A B C D will be reduced one-half, and consequently will have become twice as dense. If the piston is pushed still farther in, as far as F, half way between B and E, the air will be reduced to a space four times smaller than at first; and if you continue to drive forward the piston to G, so that B G shall be the half of B F, or the eighth part of the whole length B D, the same air which in the beginning was expanded over the whole cavity of the tube, will be contracted to a space eight times smaller. Going on in the same manner to contract it into a space 800 times smaller, you will obtain an air 800 times denser than ordinary air. It would then be as dense as water, which it would be easy to prove by other experiments. Hence it appears that air is a fluid substance, capable of compression, or, in other words, of being reduced to a smaller space; and in this respect it differs entirely from water. For let the tube A B C D be filled with this last fluid, and attempt to introduce the piston, you will find it impossible to drive it forward. Employ what force you may, you will gain nothing; the tube will burst sooner than you can reduce the water to a space sensibly smaller. This then is the essential difference between air and water: the latter is susceptible of no compression, but air may be compressed to any degree you please. The more the air is compressed, the denser it becomes; thus the air which occupied a certain space, when compressed or reduced to half that space, becomes twice as dense; if reduced to a space 10 times smaller, it is rendered 10 times more dense; and so on. I have already remarked, that could it be rendered 800 times more dense, it would then be as dense as water, and consequently as heavy; for weight increases in the same proportion as density. *Gold*, the heaviest substance with which we are acquainted,* is likewise the most dense. It is found by experiment to be 19 times heaver than water; so that a mass of *gold*, in the form of a cube of one foot, would weigh 19 times a mass of *water* of the same dimensions. Now such a mass of *water* weighs 70 pounds; the mass of *gold* therefore would weigh 19 times 70, that is, 1330 pounds. It follows, that were it possible to compress air till it were reduced to a space 19 times 800, that is, 15,200 times smaller, it would become as dense and as weighty as gold.†

But it is very far from being possible to carry the compression of air to that degree. You may at first without difficulty drive forward the piston, but the

* Platinum, a metal discovered since this was written, is 22 times heavier than water.—Ed.

† Several different kinds of air, such as chlorine, sulphuretted hydrogen, nitrous oxide, sulphurous acid, carbonic acid, cyanogen and euchlorine, have been very recently converted by Mr. Faraday into liquids by pressure.—Ed.

farther you advance the resistance becomes more powerful; and before you are able to reduce the air to a space 10 times smaller, such a force must be employed as would burst the tube, unless it were of uncommon strength. And not only would such a force be necessary to drive the piston farther, but an equal force would be requisite to keep it in that state; for on the slightest relaxation of the power, the compressed air would drive it backward. The more compressed the air is, the more violent are its efforts to expand, and to recover its natural state. This is what we call the spring or elasticity of the air, of which I propose to treat in my next letter.

10*th May* 1760.

Letter X.—Rarefaction and Elasticity of the Air.

I have remarked, that air is a fluid about 800 times more subtile than water; so that could water, without being reduced to vapour, be expanded over a space so many times greater, and could it become of consequence so many times more subtile, it would be of a similar consistence with the air which we breathe. But air has a property which water has not, that of suffering compression into a smaller space, and of being proportionably condensed, as I demonstrated in the preceding letter. And we discover in air another property no less remarkable: it is capable of being expanded over a greater space, and thus rendered still more subtile. This operation is called the rarefaction of air.

You have only to take, as before, a tube A B C D (Plate I. *Fig.* 3.), at the bottom of which A C, let there be a small aperture O, so that, on introducing the piston as far as to E F, the air may escape by that aperture without being condensed. The air which now occupies the cavity A C E F will then be in its natural state; let the aperture O be closely stopped. On drawing back the piston, the air will gradually expand through the greater space, so that when the piston is brought back to the point G, the space C G being double the space C F, the same air which was contained in the space A C E F will fill a space twice as great; it will be of course only half as dense, or, which is the same thing, twice as rare. If you draw back the piston to the point H, the space C H being four times as great as the space C F, the air will become four times as rare as it was at first, as it is then expanded over a space four times as great. And could the piston be drawn back till the space became 1000 times as great, the air would still equally expand through that space, and consequently become 1000 times as rare. Here then, likewise, air differs essentially from water: for if the cavity A C E F were filled with water, to no purpose would you draw back the piston; the water would continue to occupy the same space as at first, and the rest would remain empty. Hence we see that the air possesses an intrinsic power of expanding itself more and more, which it exerts not only when it is condensed, but also when rarefied. In whatever state of condensation or rarefaction the air may be, it makes unremitting efforts to extend itself over a larger space, and is continually expanding so long as it meets no obstacle. This property is called the elasticity of air; and it has been demonstrated, by experiments which I shall presently describe, that this elastic power is in proportion to the density;—in other words, the more the air is condensed, the greater are its efforts to expand itself; and the more rarefied it is, the feebler are those efforts. It will be demanded, perhaps, why the air now in my chamber

does not make its escape by the door, being endowed with an expansibility continually impelling it to occupy a greater space? The answer is obvious. This would infallibly happen, did not the external air make equal efforts to extend itself; but the efforts of the air of the chamber to get out, and that of the external air to press in, being equal, they balance each other, and remain in a state of rest. Had the external air accidentally acquired a greater degree of density, that is, more elasticity, it would in part force its way into the chamber, where the air being compressed, would likewise acquire a greater degree of elasticity; this current would accordingly last till the elasticity of the internal became equal to that of the external air. And should the air of the chamber suddenly become more dense, and its elasticity greater than that of the external air, it would force its way out; and its density gradually diminishing, its elasticity too would diminish, till it became equal to the external air; the current would then cease, and the air in the chamber would be in equilibrium with the external. Free air, then, is in a state of rest only when it has the same degree of elasticity with that which surrounds it; and as soon as that of the one tract becomes more or less elastic than the adjoining, the equilibrium can no longer subsist; but if the elasticity is greater, the air will expand itself, and slide into spaces where it is smaller: and from this motion of the air results the wind. Hence it comes to pass that the elasticity of the air is sometimes greater, sometimes less in the same place; and this variation is indicated by the *barometer*, the description of which merits a particular consideration. I confine myself at present to these qualities of air, its *condensation* and *rarefaction*, intreating you to recollect, that the more condensed it is, the greater power of expansion or elasticity it acquires; and that, on 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 compressed 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.

20th 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 explanation 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.—Ed.

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.

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 re-

gions 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 $4\frac{3}{5}$ 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.—Ed.