colours; and that the circumstances of the one serve to elucidate those of the other. This analogy accordingly furnishes the most convincing proofs in support of my system. But I have reasons still more solid to adduce, which will secure it from every attack.

6th June 1761.

Letter XX.—Continuation.

Nothing is more adapted to the communication of knowledge respecting the nature of vision, than the analogy discoverable, almost in every particular, between it and the hearing. Colours are to the eye what sounds are to the ear. They differ from each other as flat and sharp notes differ. Now we know that flat and sharp in sounds depends on the number of vibrations whereby the organ of hearing is struck in a given time, and that the nature of each is determined by a certain number, which marks the vibrations performed in a second. From this I conclude, that each colour is likewise restricted to a number of vibrations which act on vision; with this difference, that the vibrations which produce sound reside in gross air, whereas those of light and colours are transmitted through a medium incomparably more subtile and elastic. The same thing holds as to the objects of both senses. Those of hearing are all of them bodies adapted to the transmission of sound, that is, susceptible of a motion of vibration, or of a tremulous agitation, which, communicating itself to the air, excites in the organ the sensation of a sound corresponding to the rapidity of the vibrations.

Such are all musical instruments; and, to confine myself principally to the harpsichord, we ascribe to

each string a certain sound which it produces when struck. Thus, one string is named C, another D, and so on. A string is named C, when its structure and tension are such, that being struck, it produces about 100 vibrations in a second; and if it produced less or more in the same time, it would have the name of a different note, higher or lower.

You will please to recollect, that the sound of a strings depends on three things—its length, its thickness, and the degree of tension; the more it is stretched, the sharper its sound becomes; and as long as it preserves the same disposition, it emits the same sound; but that changes as soon as the other undergoes any variation.

Let us apply this to bodies which are the objects of vision. The minuter particles which compose the tissue of their surface, may be considered as strings distended, in as much as they are endowed with a certain degree of elasticity and bulk, so that being struck they acquire a motion of vibration, of which they will finish a certain number in a second; and on this number depends the colour which we ascribe to such body. It is red, when the particles of its surface have such a degree of tension, that being agitated, they perform precisely so many vibrations in a second as are necessary to excite in us the sensation of that colour. A degree of tension which would produce vibrations more or less rapid, would excite that of a different colour, and then the body would be yellow, green, or blue, &c.

We have not as yet acquired the ability of assigning to each colour the number of vibrations which constitute its essence; we do not so much as know which are the colours that require a greater or less rapidity of vibration, or rather, it is not yet determined what colours correspond with high or low notes. It is sufficient to know, that each colour is attached to a certain number of vibrations, though it has not hitherto been ascertained; and that you have only to change the tension or elasticity of the particles which form the surface of a body, to make it change colour.

We see that the most beautiful colours in flowers quickly change and disappear, from a failure of the nutritive juices; and because their particles lose their vigour or their tension. This, too, is observable in every other change of colour.

To place this in a clearer light, let us suppose that the sensation of red requires such a rapidity of vibration, that 1000 are performed in a second; that orange requires 1125, yellow 1250, green 1333, blue 1500, and violet 1666. Though these numbers are only supposed, this does not affect the object I have in view. What I say as to these numbers, will apply in like manner to the really corresponding numbers, if ever they are discovered.

A body, then, will be red, when the particles of its surface, put in vibration, complete 1000 in a second; another body will be orange, when disposed so as to complete 1125 in a second, and so on. Hence it is obvious that there must be an endless variety of intermediate colours between the six principal which I have mentioned; and it is likewise evident, if the particles of a body, being agitated, should perform 1400 vibrations in a second, it would be of an intermediate colour between green and blue; green corresponding to number 1333, and blue to 1500.

9*th June* 1761.

Letter XXI.—How Opaque Bodies are rendered visible.

You will find no difficulty in the definition I have been giving of coloured bodies. The particles of their surface are always endowed with a certain degree of elasticity, which renders them susceptible of a motion of vibration, as a string is always susceptible of a certain sound; and it is the number of vibrations which these particles are capable of making in a second, which determines the species of colour.

If the particles of the surface have not elasticity sufficient to admit of such agitation, the body must be black, this colour being nothing else but a deprivation of light, and all bodies from which no rays are transmitted to our eyes appearing black.

I now come to a very important question, respecting which some doubts may be entertained. It may be asked, What is the cause of the motion of vibration which constitutes the colours of bodies?

Into the discovery of this, indeed, the whole is resolved; for as soon as the particles of bodies shall be put in motion, the ether diffused through the air will immediately receive a similar agitation, which, continued to our eyes, constitutes there that which we call *rays*, from which vision proceeds.

I remark, first, that the particles of bodies are not put in motion by an internal, but an external power, just as a string distended would remain for ever at rest, were it not put in motion by some external force. Such is the case of all bodies in the dark; for, as we see them not, it is a certain proof that they emit no rays, and that their particles are at rest. In other words, during the night, bodies are in the same state with the strings of an instrument that is not touched, and which emit no sound;

whereas bodies rendered visible may be compared to strings which emit sound.

And as bodies become visible as soon as they are illuminated, that is as soon as the rays of the sun, or of some other luminous body, fall upon them, it must follow, that the same cause which illuminates them, must excite their particles to generate rays, and to produce in our eyes the sensation of vision. The rays of light, then, falling upon a body, put its particles into a state of vibration.

This appears at first surprising, because on exposing our hands to the strongest light, no sensible impression is made on them. It is to be considered, that the sense of touch is in us too gross to perceive these subtile and slight impressions; but that the sense of sight, incomparably more delicate, is powerfully affected by them. This furnishes an incontestable proof that the rays of light which fall upon a body possess sufficient force to act upon the minuter particles, and to communicate to them a tremulous agitation. And in this precisely consists the action necessary to explain how bodies, when illuminated, are put in a condition themselves to produce rays, by means of which they become visible to us. It is sufficient that bodies should be luminous or exposed to the light, in order to the agitation of their particles, and thereby to their producing themselves rays which render them visible to us.

The perfect analogy between hearing and sight, gives to this explanation the highest degree of probability. Let a harpsichord be exposed to a great noise, and you will see that not only the strings in general are put into a state of vibration, but you will hear the sound of each, almost as if it were actually touched. The mechanism of this phenomenon is easily comprehended, as soon as it is known that a string agitated is capable of communicating to the

air the same motion of vibration which, transmitted to the ear, excites in it the sensation of the sound which that same string emits.

Now, as a string produces in the air such a motion, it follows, that the air reciprocally acts on the string, and gives it a tremulous motion. And as a noise is capable of putting in motion the strings of a harpsichord, and of extracting sounds from them, the same thing must take place in the objects of vision.

Coloured bodies are similar to the strings of a harpsichord, and the different colours to the different notes, in respect of high and low. The light which falls on these bodies, being analogous to the noise to which the harpsichord is exposed, acts on the particles of their surface, as that noise acts on the strings of the harpsichord; and these particles thus put in vibration will produce the rays which shall render the body visible.

This elucidation seems to me sufficient to dissipate every doubt relating to my theory of colours. I flatter myself, at least, that I have established the true principle of all colours, as well as explained how they become visible to us only by the light whereby bodies are illuminated, unless such doubts turn upon some other point which I have not touched upon.

13*th June* 1761.

Letter XXII.—The Wonders of the Human Voice.

In explaining the theory of sounds, I considered only two respects in which sounds could differ: the one regarded the force of sound, and I remarked that it is greater in proportion as the vibrations excited in the air are more violent. Thus, the noise of a discharge of cannon, or the ringing of a bell, has more force than that of a string, or of the human voice.

The other difference of sounds is totally independent of this, and refers to flat and sharp, according to which we say some are low and others high. My remark relatively to this difference, made it to depend on the number of vibrations completed in a certain given time, say a second; so that the greater such number is, the higher or sharper is the sound; and the smaller it is, the sound is lower or flatter.

You can easily comprehend how the same note may be either strong or faint; accordingly, we see that the *forte* and *piano* employed by musicians change in no respect the nature of sounds. Among the good qualities of a harpsichord, it is required that all the notes should have nearly the same degree of strength; and it is always considered as a great fault when some of the strings are wound up to a greater degree of force than the rest. Now the flat and the sharp are referable only to the simple sounds, whose vibrations follow regularly, and at equal intervals; and, in music, we employ only those sounds which are denominated simple. Accords are compound sounds, or the concourse of several produced at once, among the vibrations of which a certain order must predominate, which is the foundation of harmony. But when no relation among the vibrations is perceptible, it is a confused noise, with which it is impossible to say what note of the harpsichord is in tune, such as the report of a cannon or musket.

There is still another remarkable difference among the simple sounds, which seems to have escaped the attention of philosophers. Two sounds may be of equal force, and in accord with the same note of the harpsichord, and yet very different to the ear. The sound of a flute is totally different from that of the

French horn, though both may be in tune with the same note of the harpsichord, and equally strong; each sound derives a certain peculiarity from the instrument which emits it, but it is impossible to describe wherein this consists; the same string, too, emits different sounds, according as it is struck, touched, or pinched. You can easily distinguish the sound of the horn, the flute, and other musical instruments.

The most wonderful diversity, to say nothing of the variety of articulation in speech, is observable in the human voice, that astonishing master-piece of the Creator. Reflect but for a moment on the different vowels which the mouth simply pronounces or sings. When the vowel *a* is pronounced or sung, the sound is quite different from that of *e*, *i*, *o*, *u* or *ai* pronounced or sung, though on the same tone. We must not then look for the reason of this difference in the rapidity or order of the vibrations; no investigation of philosophers has hitherto unfolded this mystery.

You must be perfectly sensible, that in order to utter these different vowels, a different conformation must be given to the cavity of the mouth; and that in man the organization of this part is much better adapted to produce these effects than that of animals. We find, accordingly, that certain birds which learn to imitate the human voice, are never capable of distinctly pronouncing the different vowels; the imitation is at best extremely imperfect.

In many organs there is a stop which bears the name of the human voice; it usually, however, contains only the notes which express the vocal sounds *ai* or *ae*. I have no doubt, that with some change it might be possible to produce likewise the other vocal sounds *a*, *e*, *i*, *o*, *u*, *ou*; but even this would not be sufficient to imitate a single word of the human voice;—for how can we combine them with the consonants, which are so many modifications of the vowels? We are so conformed, that however common the practice, it is almost impossible to trace and explain the real mechanism.

We distinctly observe three organs employed in expressing the consonants, the lips, the tongue, and the palate; but the nose likewise essentially concurs. On stopping it, we become incapable of pronouncing the letters *m* and *n*; the sound of *b* and *d* only is then to be heard. A striking proof of the marvellous structure of our mouth for the pronunciation of the letters undoubtedly is, that all the skill of man has not hitherto been capable of producing a piece of mechanism that could imitate it. The song has been exactly imitated, but without any articulation of sounds, and without distinction of the different vowels.

The construction of a machine capable of expressing sounds, with all the articulations, would no doubt be a very important discovery. Were it possible to execute such a piece of mechanism, and bring it to such perfection, that it could pronounce all words, by means of certain stops, like those of an organ or harpsichord, every one would be surprised, and justly, to hear a machine pronounce whole discourses or sermons together, with the most graceful accompaniments. Preachers and other orators, whose voice is either too weak or disagreeable, might play their sermons or orations on such a machine, as organists do pieces of music. The thing does not seem to me impossible.*

16*th June* 1761.

* Pipes have actually been constructed of such forms, by Kratzenstein and Kempelen, as to imitate very accurately the different vowel sounds produced by the human voice. From this first attempt Kempelen proceeded to analyze the mechanism of speech, and he succeeded in constructing a speaking machine, which uttered not only words, but entire sentences. The four letters D, G, K, T, however, baffled all his ingenuity; and he was obliged to substitute for them the letter P, which was so managed as to bear a considerable resemblance to them, so much so, at least, as to deceive the auditory.—See the *Edinburgh Encyclopædia*, article Acoustics, vol. i. p. 126; and Automaton, vol. iii. p. 153, where a full account of this machine is given.—Ed.

Letter XXIII.—A Summary of the Principal Phenomena of Electricity.

The subject which I am now going to recommend to your attention almost terrifies me. The variety it presents is immense, and the enumeration of facts serves rather to confound than to inform. The subject I mean is electricity, which for some time past has become an object of such importance in physics, that every one is supposed to be acquainted with its effects.

You must undoubtedly have frequently heard it mentioned in conversation; but I know not whether you have ever witnessed any of the experiments. Natural philosophers of modern times prosecute the study of it with ardour, and are almost every day discovering new phenomena, the description of which would employ many hundreds of letters; nay, perhaps, I should never have done.

And here it is I am embarrassed. I could not bear to think of letting you remain unacquainted with a branch of natural philosophy so essential; but I would willingly save you the fatigue of wading through a diffuse detail of the phenomena, which after all would not furnish the necessary information. I flatter myself, however, that I have discovered a road which will lead so directly to the object, that you shall attain a knowledge of it much more perfect than that of most natural philosophers, who devote night and day to the investigation of these mysteries of nature.

Without stopping to explain the various appearances and effects of electricity, which would engage me in a long and tedious detail, without extending your knowledge of the causes which produce these effects, I shall pursue quite a different course, and begin with unfolding the true principle of nature on which all these phenomena are founded, however various they may appear, and from which they are all easily deducible.

It is sufficient to remark, in general, that *Electricity* is excited by the *friction of a glass tube.* It thereby becomes electrical: and then it alternately attracts and repels light bodies which are applied to it; and on the application of other bodies, *sparks of fire* are mutually extracted, which, increased in strength, kindle spirits of wine and other combustible substances. On touching such a tube with the finger, you feel, beside the spark, a puncture which may, in certain circumstances, be rendered so acute as to produce a commotion through the whole body.

Instead of a tube of glass, we likewise employ a globe of glass, which is made to turn round an axis, like a turning-wheel. During this motion it is rubbed with the hand, or with a cushion applied to it; then the globe becomes electric, and produces the same phenomena as the tube.

Besides glass, resinous bodies, such as Spanish wax, and sulphur, likewise possess the property of becoming electric by friction; but certain species of bodies only have this quality, of which glass, sealing-wax, and sulphur, are the principal.

Other bodies undergo friction without producing any such effect; no sign of electricity appears: but on applying them to the first, when rendered electric, they immediately acquire the same property. They become electric, then, by communication, as they

touch; and frequently the approximation only of electric bodies renders them such.

All bodies, therefore, are divisible into two classes; in the one are included those that become electric by friction, in the other those which are rendered such by communication, whereas friction produces no manner of effect on them. It is very remarkable, that bodies of the first class receive no electricity from communication; when you apply to a tube or globe of glass, strongly electrified, other glasses or bodies which friction renders electric, this touch communicates no electricity to them. The distinction of these two classes of bodies is worthy of attention; the one class being disposed to become electrical by friction only, and not by communication—the other, on the contrary, only by communication.

All metals belong to this last class, and the communication extends so far, that on presenting one extremity of a wire to an electric body, the other extremity becomes so likewise, be the wire ever so long; and on applying still another wire to the farther extremity of the first, the electricity is conveyed through the whole extent of that second thread—and thus electricity may be transmitted to the most remote distances.

Water is a substance which receives electricity by communication. Large pools have been electrified to such a degree, that the application of the finger has elicited sparks, and excited pain.

The prevailing persuasion now is, that lightning and thunder are the effect of the electricity which the clouds acquire, from whatever cause. A thunder storm exhibits the same phenomena of electricity, on the great scale, which the experiments of natural philosophers do in miniature.

20*th June* 1761.

LETTER XXIV.—THE TRUE PRINCIPLE OF NATURE, ON WHICH ARE FOUNDED ALL THE PHENOMENA OF ELECTRICITY.

THE summary I have exhibited of the principal phenomena of electricity, has no doubt excited a curiosity to know what occult powers of nature are capable of producing effects so surprising.

The greatest part of natural philosophers acknowledge their ignorance in this respect. They appear to be so dazzled by the endless variety of phenomena which every day present themselves, and by the singularly marvellous circumstances which accompany these phenomena, that they are discouraged from attempting an investigation of the true cause of them. They readily admit the existence of a subtile matter, which is the primary agent in the production of the phenomena, and which they denominate the electric fluid; but they are so embarrassed about determining its nature and properties, that this important branch of physics is rendered only more perplexed by their researches.

There is no room to doubt that we must look for the source of all the phenomena of electricity only in a certain fluid and subtile matter; but we have no need to go to the regions of imagination in quest of it. That subtile matter denominated *Ether*, whose reality I have already endeavoured to demonstrate,* is sufficient very naturally to explain all the surprising effects which electricity presents. I hope I shall be able to set this in so clear a light, that you shall be able to account for every electrical phenomenon, however strange an appearance it may assume.

* See Letter XV. Volume I.

The great requisite is to have a thorough knowledge of the nature of ether. The air which we breathe rises only to a certain height above the surface of the earth; the higher you ascend the more subtile it becomes, and at last it entirely ceases. We must not affirm, that beyond the region of the air there is a perfect vacuum, which occupies the immense space in which the heavenly bodies revolve. The rays of light, which are diffused in all directions from these heavenly bodies, sufficiently demonstrate that those vast spaces are filled with a subtile matter.

If the rays of light are emanations forcibly projected from luminous bodies, as some philosophers have maintained, it must follow, that the whole space of the heavens is filled with these rays—nay, that they move through it with incredible rapidity. You have only to recollect the prodigious velocity with which the rays of the sun are transmitted to us. On this hypothesis, not only would there be no vacuum, but all space would be filled with a subtile matter, and that in a state of constant and most dreadful agitation.

But I think I have clearly proved, that rays of light are no more emanations projected from luminous bodies, than sound is from sonorous bodies. It is much more certain, that rays of light are nothing else but a tremulous motion or agitation of a subtile matter, just as sound consists of a similar agitation excited in the air. And as sound is produced and transmitted by the air, light is produced and transmitted by that matter, incomparably more subtile, denominated ether, which consequently fills the immense space between the heavenly bodies.

Ether, then, is a medium proper for the transmission of rays of light; and this same quality puts us in a condition to extend our knowledge of its nature and properties. We have only to reflect on the properties of air, which render it adapted to the reception and transmission of sound. The principal cause is its elasticity or spring. You know that air has a power of expanding itself in all directions, and that it does expand the instant that obstacles are removed. The air is never at rest but when its elasticity is every where the same; whenever it is greater in one place than another, the air immediately expands. We likewise discover by experiment, that the more the air is compressed, the more its elasticity increases: hence the force of air-guns, in which the air, being very strongly compressed, is capable of discharging the ball with astonishing velocity. The contrary takes place when the air is rarefied: its elasticity becomes less in proportion as it is more rarefied, or diffused over a larger space.

On the elasticity of the air, then, relative to its density, depends the velocity of sound, which makes a progress of about 1000 feet in a second. If the elasticity of the air were increased, its density remaining the same, the velocity of sound would increase; and the same thing would take place if the air were more rare, or less dense than it is, its elasticity being the same. In general, the more that any medium, similar to air, is elastic, and at the same time less dense, the more rapidly will the agitations excited in it be transmitted. And as light is transmitted so many thousand times more rapidly than sound, it must clearly follow that the ether, that medium whose agitations constitute light, is many thousand times more elastic than air, and, at the same time, many thousand times more rare or more subtile, both of these qualities contributing to accelerate the propagation of light.

Such are the reasons which lead us to conclude that ether is many thousand times more elastic and more subtile than air; its nature being in other respects

similar to that of air, in as much as it is likewise a fluid matter, and susceptible of compression and of rarefaction. It is this quality which will conduct us to the explanation of all the phenomena of electricity.

23d June 1761.

Letter XXV.—Continuation. Different Nature of Bodies relatively to Electricity.

Ether being a subtile matter, and similar to air, but many thousand times more rare and more elastic, it cannot be at rest, unless its elasticity, or the force with which it tends to expand, be the same every where.

As soon as the ether in one place shall be more elastic than in another, which is the case when it is more compressed there, it will expand itself into the parts adjacent, compressing what it finds there, till the whole is reduced to the same degree of elasticity. It is then in equilibrio, the equilibrium being nothing else but the state of rest, when the powers which have a tendency to disturb it counterbalance each other.

When, therefore, the ether is not in equilibrio, the same thing must take place as in air, when its equilibrium is disturbed; it must expand itself from the place where its elasticity is greater, toward that where it is less; but considering its greater elasticity and subtilty, this motion must be much more rapid than that of air. The want of equilibrium in the air produces wind, or the motion of that fluid from one place to another. There must therefore be produced a species of wind, but incomparably more subtile than that of air, when the equilibrium of the ether is disturbed, by which this last fluid will pass from places where it was more compressed and more elastic, to those where it was less so.

This being laid down, I with confidence affirm, that all the phenomena of electricity are a natural consequence of want of equilibrium in the ether, so that wherever the equilibrium of the ether is disturbed the phenomena of electricity must take place; consequently, electricity is nothing else but a derangement of the equilibrium of the ether.

In order to unfold all the effects of electricity, we must attend to the manner in which ether is blended and enveloped with all the bodies which surround us. Ether, in these lower regions, is to be found only in the small interstices which the particles of the air and of other bodies leave unoccupied. Nothing can be more natural than that the ether, from its extreme subtilty and elasticity, should insinuate itself into the smallest pores of bodies, which are impervious to air, and even into those of the air itself. You will recollect that all bodies, however solid they may appear, are full of pores; and many experiments incontestably demonstrate, that these interstices occupy much more space than the solid parts; finally, the less ponderous a body is, the more it must be filled with these pores, which contain ether only. It is clear, therefore, that though the ether be thus diffused through the smallest pores of bodies, it must however be found in very great abundance in the vicinity of the earth.

You will easily comprehend, that the difference of these pores must be very great, both as to magnitude and figure, according to the different nature of the bodies, as their diversity probably depends on the diversity of their pores. There must be, therefore, undoubtedly, pores more close, and which have less communication with others; so that the ether which

they contain is likewise more confined, and cannot disengage itself but with great difficulty, though its elasticity may be much greater than that of the ether which is lodged in the adjoining pores. There must be, on the contrary, pores abundantly open, and of easy communication with the adjacent pores: in this case it is evident, that the ether lodged in them can with less difficulty disengage itself than in the preceding; and if it is more or less elastic in these than in the others, it will soon recover its equilibrium.

In order to distinguish these two classes of pores, I shall denominate the first *close*, and the others *open*. Most bodies must contain pores of an intermediate species, which it will be sufficient to distinguish by the terms *more* or *less close*, and *more* or *less open*.

This being laid down, I remark, first, that if all bodies had pores perfectly close, it would be impossible to change the elasticity of the air contained in them; and even though the ether in some of these pores should have acquired, from whatever cause, a higher degree of elasticity than the others, it would always remain in that state, and never recover its equilibrium, from a total want of communication. In this case, no change could take place in bodies; all would remain in the same state as if the ether were in equilibrio, and no phenomenon of electricity could be produced.

This would likewise be the case if the pores of all bodies were perfectly open; for then, though the ether might be more or less elastic in some pores than in others, the equilibrium would be instantly restored, from the entire freedom of communication— and that so rapidly, that we should not be in a condition to remark the slightest change. For the same reason, it would be impossible to disturb the equilibrium of the ether contained in such pores; as often as the equilibrium might be disturbed, it would be as instantaneously restored, and no sign of electricity would be discoverable.

The pores of all bodies being neither perfectly close nor perfectly open, it will always be possible to disturb the equilibrium of the ether which they contain: and when this happens, from whatever cause, the equilibrium cannot fail to re-establish itself; but this re-establishment will require some time, and this produces certain phenomena; and you will presently see, much to your satisfaction, that they are precisely the same which electrical experiments have discovered. It will then appear, that the principles on which I am going to establish the theory of electricity are extremely simple, and at the same time absolutely incontrovertible.

27th June 1761.

Letter XXVI.—On the same Subject.

I hope I have now surmounted the most formidable difficulties which present themselves in the theory of electricity. You have only to preserve the idea of ether, which I have been explaining; and which is that extremely subtile and elastic matter diffused not only through all the void spaces of the universe, but through the minutest pores of all bodies, in which it is sometimes more and sometimes less engaged, according as they are more or less close. This consideration conducts us to two principal species of bodies, of which the one has pores more close, and the other pores more open.

Should it happen, therefore, that the ether contained in the pores of bodies has not throughout the same degree of elasticity, and that it is more or less compressed in some than in others, it will make an

effort to recover its equilibrium; and it is precisely from this that the phenomena of electricity take their rise, which, of consequence, will be varied, in proportion as the pores in which the ether is lodged are various, and grant it a communication more or less free with the others.

This difference in the pores of bodies perfectly corresponds to that which the first phenomena of electricity have made us to remark in them, by which some easily become electrical by communication, or the proximity of an electrical body, whereas others scarcely undergo any change. Hence you will immediately infer, that bodies which receive electricity so easily, by communication alone, are those whose pores are open; and that the others, which are almost insensible to electricity, must have theirs close, either entirely or to a very great degree.

It is, then, by the phenomena of electricity themselves, that we are enabled to conclude what are the bodies whose pores are close or open. Respecting which, permit me to suggest the following elucidations.

First, the air which we breathe has its pores almost entirely close; so that the ether which it contains cannot disengage itself but with difficulty, and must find equal difficulty in attempting to penetrate into it. Thus, though the ether diffused through the air is not in equilibrio with that which is contained in other bodies, where it is more or less compressed, the re-establishment of its equilibrium is not to be produced without extreme difficulty; this is to be understood of dry air, humidity being of a different nature, as I shall presently remark.

Farther, we must rank in this class of bodies with close pores, *glass*, *pitch*, *resinous bodies*, *sealing-wax*, *sulphur*, and particularly *silk*. These substances have their pores so very close, that it is with extreme difficulty the ether can either escape from, or penetrate into them.

The other class, that of bodies whose pores are open, contains, first, water and other liquors, whose nature is totally different from that of air. For this reason, when air becomes humid, it totally changes its nature with respect to electricity, and the ether can enter or escape without almost any difficulty. To this class of bodies with open pores likewise must be referred those of animals, and all metals.

Other bodies, such as wood, several sorts of stones and earths, occupy an intermediate state between the two principal species which I have just mentioned; and the ether is capable of entering or escaping with more or less facility, according to the nature of each species.

After these elucidations on the different nature of bodies with respect to the ether which they contain, you will see with much satisfaction how all the phenomena of electricity, which have been considered as so many prodigies, flow very naturally from them.

All depends, then, on the state of the ether, diffused or dispersed through the pores of all bodies, in as far as it has not throughout the same degree of elasticity, or as it is more or less compressed in some than in others; for the ether not being then in equilibrio, will make an effort to recover it. It will endeavour to disengage itself, as far as the openness of the pores will permit, from places where it is too much compressed, to expand itself and enter into pores where there is less compression, till it is throughout reduced to the same degree of compression and elasticity, and is, of consequence, in equilibrio.

Let it be remarked, that when the ether passes from a body where it was too much compressed, into another where it is less so, it meets with great obstacles in the air which separates the two bodies, on account of the pores of this fluid, which are almost entirely close. It however passes through the air, as a liquid and extremely subtile matter, provided its force is not inferior, or the interval between the bodies too great. Now this passage of the ether being very much impeded, and almost entirely prevented by the pores of the air, the same thing will happen to it as to air forced with velocity through small apertures—a hissing sound is heard—which proves that this fluid is then put into an agitation which produces such a sound.

It is, therefore, extremely natural, that the ether, forced to penetrate through the pores of the air, should likewise receive a species of agitation. You will please to recollect, that as agitation of the air produces sound, a similar agitation of ether produces light. As often, then, as ether escapes from one body, to enter into another, its passage through the air must be accompanied with light; which appears sometimes under the form of a spark, sometimes under that of a flash of lightning, according as its quantity is more or less considerable.

Here, then, is the most remarkable circumstance which accompanies most electrical phenomena, explained to a demonstration, on the principles I have laid down. I shall now enter into a more particular detail, which will furnish me with a very agreeable subject for some following letters.

30*th June* 1761.

Letter XXVII.—Of Positive and Negative Electricity. Explanation of the Phenomenon of Attraction.

You will easily comprehend, from what I have above advanced, that a body must become electrical whenever the ether contained in its pores becomes more or less elastic than that which is lodged in adjacent bodies. This takes place when a greater quantity of ether is introduced into the pores of such body, or when part of the ether which it contained is forced out. In the former case, the ether becomes more compressed, and consequently more elastic; in the other, it becomes rarer, and loses its elasticity. In both cases, it is no longer in equilibrio with that which is external; and the efforts which it makes to recover its equilibrium, produce all the phenomena of electricity.

You see, then, that a body may become electric in two different ways, according as the ether contained in its pores becomes more or less elastic than that which is external; hence result two species of electricity: the one, by which the ether is rendered more elastic, or more compressed, is denominated *increased* or *positive electricity*; the other, in which the ether is less elastic, or more rarefied, is denominated *diminished* or *negative electricity*. The phenomena of both are nearly the same; a slight difference only is observable, which I shall mention.

Bodies are not naturally electrical—as the elasticity of the ether has a tendency to maintain it in equilibrio, it must always require a violent operation to disturb this equilibrium, and to render bodies electrical; and such operations must act on bodies with close pores, that the equilibrium, once deranged, may not be instantly restored. We accordingly

find, that glass, amber, sealing-wax, or sulphur, are the bodies employed to excite electricity.

The easiest operation, and, for some time past, the most universally known, is to rub a stick of sealing-wax with a piece of woollen cloth, in order to communicate to that wax the power of attracting small slips of paper and of other light bodies. Amber, by means of friction, produces the same phenomena; and as the ancients gave to this body the name of *electrum*, the power excited by friction obtained, and preserves, the name of *electricity*—natural philosophers of the remotest ages having remarked, that this substance acquired by friction the faculty of attracting light bodies.

This effect undoubtedly arises from the derangement of the equilibrium of the ether by means of friction. I must begin, therefore, with explaining this well-known experiment. Amber and sealing-wax have their pores abundantly close, and those of wool are abundantly open; during the friction, the pores of both the one and the other compress themselves, and the ether which is contained in them is reduced to a higher degree of elasticity. According as the pores of the wool are susceptible of a compression greater or less than those of amber or sealing-wax, it must happen, that a portion of ether shall pass from the wool into the amber, or reciprocally, from the amber into the wool. In the former case, the amber becomes *positively* electric, and in the other *negatively*—and its pores being close, it will remain in this state for some time; whereas the wool, though it has undergone a similar change, will presently recover its natural state.

From the experiments which electric sealing-wax furnishes, we conclude that its electricity is *negative*, and that a part of its ether has passed during the friction into the wool. Hence you perceive how a stick of sealing-wax is, by friction on woollen cloth, deprived of part of the ether which it contained, and must thereby become electric. Let us now see what effects must result from this, and how far they correspond with observation and experience.

Let A B (See PLATE II. Vol. I. *Fig.* 6.) be a stick of sealing-wax, from which, by friction, part of the ether contained in its pores has been forced out; that which remains, being less compressed, will therefore have less force to expand itself, or, in other words, will have less elasticity than that contained in other bodies in the circumambient air: but as the pores of air are still closer than those of sealing-wax, this prevents the ether contained in the air from passing into the sealing-wax, to restore the equilibrium: at least this will not take place till after a considerable interval of time.

Let a small and very light body *C*, whose pores are open, be now presented to the stick of sealing-wax, the ether contained in them finding a free passage, because it has more force to expand itself than is opposed to it by the ether shut up in the stick at *c*, will suddenly escape, will force a passage for itself through the air, provided the distance is not too great, and will enter into the sealing-wax. This passage, however, will not be effected without very considerable difficulty, as the pores of the sealing-wax have only a very small aperture, and consequently it will not be accompanied with a vehemence capable of putting the ether in a motion of agitation, to excite a sensible light. A faint glimmering only will be perceptible in the dark, if the electricity is sufficiently strong.

But another phenomenon will be observable, which is no less surprising—the small body *C* will spring toward the sealing-wax, as if attracted by it. To explain the cause of this, you have only to consider, that the small body *C*, in its natural state, is equally pressed on all sides by the air which surrounds it; but as in its present state the ether makes its escape, and passes through the air in the direction *C c*, it is evident, that this last fluid will not press so violently on the small body on this side than on any other, and that the pressure communicated to it toward *c*, will be more powerful than in any other direction, impelling it toward the sealing-wax as if attracted by it.

Thus are explained, in a manner perfectly intelligible, the attractions observable in the phenomena of electricity. In this experiment, the electricity is too feeble to produce more surprising effects. I shall have the honour of presenting you with a more ample detail in the following letters.

4th July 1761.

LETTER XXVIII.—ON THE SAME SUBJECT.

SUCH were the faint beginnings of the electrical phenomena; it was not till lately that they were carried much farther. At first a tube of glass was employed, similar to that of which barometers are made, but of a larger diameter, which was rubbed with the naked hand, or with a piece of woollen cloth, and electrical phenomena more striking were observed.

You will readily comprehend, that on rubbing a tube of glass, part of the ether must pass, in virtue of the compression of the pores of the glass, and of the rubbing body, either from the hand into the glass, or from the glass into the hand, according as the pores of the one or of the other are more susceptible of compression in the friction. The ether, after this operation, easily recovers its equilibrium in the hand, because its pores are open; but those of the glass being abundantly close, this fluid will preserve its state in it, whether the glass is surcharged or exhausted, and consequently will be electric, and will produce phenomena similar to those of sealing-wax, but undoubtedly much stronger, as its electricity is carried to a higher degree, as well from the greater diameter of the tube, as from the very nature of glass.

Experiments give us reason to conclude, that the tube of glass becomes, by these means, surcharged with ether, whereas sealing-wax is exhausted of it; the phenomena however are nearly the same.

It must be observed, that the glass tube retains its electricity as long as it is surrounded only with air, because the pores of the glass, and those of the air, are too close to allow a communication sufficiently free to the ether, and to exhaust the glass of what it has, more than in its natural state; superfluity of ether always increasing elasticity. But the air must be very dry, for only when in that state are its pores sufficiently close; when it is humid or loaded with vapours, experiments do not succeed, whatever degree of friction you bestow on the glass. The reason is obvious; for water, which renders the air humid, having its pores very open, receives every instant the superfluous ether which was in the glass, and which of course remains in its natural state. Experiments succeed, then, in only very dry air: let us now see what phenomena a glass tube will in that case produce, after having undergone considerable friction.

It is clear, that on presenting to it a small light body C (Plate II. Vol. I. *Fig.* 7.), with open pores, such as gold leaf, the ether in the tube, more elastic at the nearest parts D, E, will not make ineffectual efforts to discharge itself and pass into the pores of the body C. It will force a path through the air, provided the distance be not too great; and you will even see a light between the tube and the body, occasioned by the agitation excited in the ether, which passes with difficulty from the tube into the body. When, instead of the body C, the finger is applied to it, you feel a pricking, occasioned by the rapid entrance of the ether; and if you expose your face to it, at some distance, you feel a certain agitation in the air, excited by the transition of the ether. These circumstances are likewise accompanied sometimes with a slight cracking, produced undoubtedly by the agitation of the air, which the ether traverses with such rapidity.

I must entreat you to keep in mind, that an agitation in the air always produces a sound, and that the motion of ether produces light; and then the explanation of these phenomena will become abundantly easy.

Let the small light body C, be replaced in the vicinity of our electric tube; as long as the ether is escaping from the tube, to enter into the pores of the body C, the air will be in part expelled from it, and consequently will not press so strongly on the body on that side, as in every other direction; it will happen, then, as in the preceding case, that the body C will be impelled toward the tube, and being light, will come close up to it. We see, then, that this apparent attraction equally takes place, whether the ether in the tube be too much or too little elastic, or whether the elasticity of the tube be positive or negative. In both cases, the passage of the ether stops the air, and by its pressure hinders it from acting.

But while the small body C is approaching the tube, the passage of the ether becomes stronger, and the body C will soon be as much surcharged with ether as the tube itself. Then the action of the ether, which arises from its elasticity only, entirely ceases, and the body C will sustain on all sides an equal pressure. The attraction will cease, and the body C will remove from the tube, as nothing detains it, and its own gravity puts it in motion. Now, as soon as it removes, its pores being open, its superfluous ether presently escapes in the air, and it returns to its natural state. The body will then act as at the beginning, and you will see it again approach the tube, so that it will appear alternately attracted and repelled by it; and this play will go on till the tube has lost its electricity. For as, on every attraction, it discharges some portion of its superfluous ether, besides the insensible escape of part of it in the air, the tube will soon be re-established in its natural state, and in its equilibrium; and this so much the more speedily as the tube is small, and the body C light; then all the phenomena of electricity will cease.

7th July 1761.

Letter XXIX.—On the Electric Atmosphere.

I had almost forgotten to bring forward a most essential circumstance, which accompanies all electric bodies, whether *positively* or *negatively* such, and which supplies some very striking elucidations for explaining the phenomena of electricity.

Though it be indubitably true that the pores of air are very close, and scarcely permit any communication between the ether that they contain, and what is in the vicinity, it undergoes, however, some change when near to an electric body.

Let us first consider an electric body *negatively* so, as a stick of *sealing-wax A B* (Plate IV. *Fig.* 1.), which has been deprived by friction of part of the ether contained in its pores, so that what it

now contains has less elasticity than that of other bodies, and consequently than that of the air which surrounds the wax. It must necessarily happen, that the ether contained in the particles of the air which immediately touch the wax, as at m, having greater elasticity, should discharge itself, in however small a degree, into the pores of the wax, and will consequently lose somewhat of its elasticity. In like manner, the particles of air more remote, suppose at n, will likewise suffer a portion of their ether to escape into the nearer at m, and so on to a certain distance, beyond which the air will no longer undergo any change. In this manner, the air round the stick of wax, to a certain distance, will be deprived of part of its ether, and become itself electric.

This portion of the air, which thus partakes of the electricity of the stick of wax, is denominated the *electric atmosphere*; and you will see from the proofs which I have just adduced, that every electric body must be surrounded with an atmosphere. For if the body is *positively* electric, so as to contain a superfluity of ether, it will be more compressed in such a body, and consequently more elastic, as is the case with a tube of glass when rubbed; this ether, more elastic, then discharges itself, in a small degree, into the particles of air which immediately touch it, and thence into particles more remote, to a certain distance; this will form another electric atmosphere round the tube, in which the ether will be more compressed, and consequently more elastic than elsewhere.

It is evident that this atmosphere which surrounds such bodies must gradually diminish the electricity of them, as in the first case there passes almost continually a small portion of ether from the surrounding air, into the electric body, and which, in the other case, issues from the electric body, and passes into the air. This is likewise the reason why electric bodies at length lose their electricity; and this so much the sooner, as the pores of the air are more open. In a humid air, whose pores are very open, all electricity is almost instantly extinguished; but in very dry air it continues a considerable time.

This electric atmosphere becomes abundantly sensible on applying your face to an electrified body; you have a feeling similar to the application of a spider's web, occasioned by the gentle transition of the ether from the face into the electric body, or reciprocally, from this last into the face, according as it is negative or positive, to use the common expression.

The electric atmosphere serves likewise more clearly to explain that alternate attraction and repulsion of light bodies placed near to electric bodies, which I mentioned in the preceding letter; in which you must have remarked, that the explanation of repulsion there given is incomplete; but the electric atmosphere will supply the defect.

Let *A B* (Plate IV. *Fig.* 2.) represent an electric tube of glass surcharged with ether, and let *C* be a small light body, with pores sufficiently open, in its natural state. Let the atmosphere extend as far as the distance *D E*. Now, as the vicinity of *C* contains already an ether more elastic, this will discharge itself into the pores of the body *C*; there will immediately issue from the tube a new ether, which will pass from *D* into *C*, and it is the atmosphere chiefly which facilitates this passage. For if the ether contained in the air had no communication with that in the tube, the corpuscle *C* would not feel the vicinity of the tube; but while the ether is passing from *D* to *C*, the pressure of the air between *C* and *D* will be diminished, and the corpuscle *C* will no longer be pressed equally in all directions; it will therefore be impelled toward *D*, as if attracted by it. Now, in proportion as it approaches, it will be likewise more and more surcharged with ether, and will become electric as the tube itself, and consequently the electricity of the tube will no longer act upon it.

But as the corpuscle, being now arrived at *D*, contains too much ether, and more than the air at *E*, it will have a tendency to escape, in order to make its way to *E*. The atmosphere in which the compression of the ether continues to diminish from *D* to *E* will facilitate this passage, and the superfluous ether will in effect flow from the corpuscle toward *E*. By this passage, the pressure of the air on the corpuscle will be smaller on that side than every where else, and consequently the corpuscle will be carried toward *D*, as if the tube repelled it. But as soon as it arrives at *E*, it discharges the superfluous ether, and recovers its natural state; it will then be again attracted toward the tube, and having reached it, will be again repelled, for the reason which I have just been explaining.

It is the electric atmosphere then chiefly which produces these singular phenomena, when we see electrified bodies alternately attract and repel small light bodies, such as little slips of paper, or particles of metal, with which this experiment best succeeds, as the substances have very open pores.

You will see, moreover, that what I have just now said respecting *positive* electricity, must equally take place in *negative*. The transition of the ether is only reversed, by which the natural pressure of the air must always be diminished.

11*th July* 1761.

Letter XXX.—Communication of Electricity to a Bar of Iron, by means of a Globe of Glass.

After the experiments made with glass tubes, we have proceeded to carry electricity to a higher degree of strength. Instead of a tube, a globe or round ball of glass has been employed, which is made to turn with great velocity round an axis, and on applying the hand to it, or a cushion of some matter with open pores, a friction is produced, which renders the globe completely electric.

Figure 4. of Plate IV. represents this globe, which may be made to move round an axis AB, by a mechanism similar to that employed by turners. C is the cushion strongly applied to the globe, on which it rubs as it turns round. The pores of the cushion being, in this friction, compressed more than those of the glass, the ether contained in it is expelled, and forced to insinuate itself into the pores of the glass, where they continue to accumulate, because the open pores of the cushion are continually supplying it with more ether, which it is extracting, at least in part, from surrounding bodies; and thus the globe may be surcharged with ether to a much higher degree than glass tubes. The effects of electricity are accordingly rendered much more considerable, but of the same nature with those which I have described, alternately attracting and repelling light bodies; and the sparks which we see on touching the electric globe are much more lively.

But naturalists have not rested satisfied with such experiments, but have employed the electrical globe in the discovery of phenomena much more surprising.

Having constructed the machine for turning the globe round its axis AB, a bar of iron FG (Plate IV. *Fig.* 3.) is suspended above, or on one side of the globe, and toward the globe is directed a chain of iron or other metal ED, terminating at D, in metallic filaments, which touch the globe. It is sufficient that this chain be attached to the bar of iron in any manner whatever, or but touch it. When the globe is turned round, and in turning made to rub on the cushion at C, in order that the glass may become surcharged with ether, which will consequently be more elastic, it will easily pass from thence into the filaments D, for, being of metal, their pores are very open; and from thence, again, it will discharge itself by the chain DE, into the bar of iron FG. Thus, by means of the globe, the ether extracted from the cushion C will successively accumulate in the bar of iron FG, which likewise, of consequence, becomes electric; and its electricity increases in proportion as you continue to turn the globe.

If this bar had a farther communication with other bodies whose pores too are open, it would soon discharge into them its superfluous ether, and thereby lose its electricity; the ether extracted from the cushion would be dispersed over all the bodies which had an intercommunication, and its greatest compression would not be more perceptible. To prevent this, which would prove fatal to all the phenomena of electricity, the bar must of necessity be supported or suspended by props of a substance whose pores are very close; such as glass, pitch, sulphur, sealing-wax, and silk. It would be proper, then, to support the bar on props of glass or pitch, or to suspend it by cords of silk. The bar is thus secured against the transmission of its accumulated ether, as it is surrounded on all sides only by bodies with close pores, which permit hardly any admission to the ether in the bar. The bar is then said to be *insulated*, that is, deprived of all contact which could communicate, and thereby diminish its electricity. You must be sensible, however, that it is not possible absolutely to prevent all waste; for this reason, the electricity of such a bar must continually diminish, if it were not kept up by the motion of the globe.

In this manner electricity may be communicated to a bar of iron, which never could be done by the most violent and persevering friction, because of the openness of its pores. And, for the same reason, such a bar rendered electric by communication, produces phenomena much more surprising. On presenting to it a finger, or any other part of the body, you see a very brilliant spark dart from it, which entering into the body, excites a pungent and sometimes painful sensation. I recollect having once presented to it my head, covered with my peruke and hat, and the stroke penetrated it so acutely, that I felt the pain next day.

These sparks, which escape from every part of the bar on presenting to it a body with open pores, set on fire at once spirit of wine, and kill small birds whose heads are exposed to them. On plunging the end of the chain DE into a bason filled with water, and supported by bodies with close pores, such as glass, pitch, silk, the whole water becomes electric; and some authors assure us that they have seen considerable lakes electrified in this manner, so that on applying the hand you might have seen even very pungent sparks emitted from the water. But it appears to me, that the globe must be turned a very long time indeed, to convey such a portion of ether into a mass of water so enormous; it would be likewise necessary, that the bed of the lake, and every thing in contact with it, should have their pores close.

The more open, then, the pores of a body are, the more disposed it is to receive a higher degree of electricity, and to produce prodigious effects. You must admit that all this is perfectly conformable to the principles which I at first established.

14th July 1761.

Letter XXXI.—Electrisation of Men and Animals.

As electricity may be communicated from glass to a bar of iron, by means of a chain which forms that communication, it may likewise be conveyed into the human body; for the bodies of animals have this property in common with metals and water, that their pores are very open; but the man who is to be the subject of the experiment, must not be in contact with other bodies whose pores are likewise open.

For this purpose, the man is placed on a large lump of pitch, or seated on a chair supported by glass columns, or a chair suspended by cords of silk, as all these substances have pores sufficiently close to prevent the escape of the ether, with which the body of the man becomes surcharged by electricity.

This precaution is absolutely necessary, for were the man placed on the ground, the pores of which are abundantly open, as soon as the ether was conveyed into his body to a higher degree of compression, it would immediately discharge itself into the earth; and we must be in a condition to surcharge it entirely with ether before the man could become electric. Now you must be sensible, that the cushion by which the globe of glass is rubbed could not possibly supply such a prodigious quantity of ether, and that were you to extract it even out of the earth