they very indecisive in their answer? Some of them very frankly allow, that the extent of the universe may very probably be infinite, without our being able, however far our ideas are carried, to determine its limits. Here then is one infinity more, which they do not deem heretical.

For a still stronger reason, divisibility in infinitum ought not to give them the least offence. To be divisible to infinity is not surely an attribute which any one could ever think of ascribing to the Supreme Being, and does not confer on bodies a degree of perfection which would not be far from that which these philosophers allow them, in compounding them of monads, which, on their system, are beings endowed with qualities so eminent, that they do not hesitate to give to God himself the denomination of monad.

In truth, the idea of a division which may be continued without any bounds, contains so little of the character of the Deity, that it rather places bodies in a rank far inferior to that which spirits and our souls occupy; for it may well be affirmed that a soul, in its essence, is infinitely more valuable than all the bodies in the world. But, on the system of monads, every body, even the vilest, is compounded of a vast number of monads, whose nature has a great resemblance to that of our souls. Each monad represents to itself the whole world as easily as our souls; but, say they, their ideas of it are very obscure, though we have already clear, and sometimes also distinct ideas of it.

But what assurance have they of this difference? Is it not to be apprehended that the monads which compose the pen wherewith I am writing, may have ideas of the universe much clearer than those of my soul? How can I be assured of the contrary? I ought to be ashamed to employ a pen in conveying

my feeble conceptions, while the monads of which it consists possibly conceive much more sublimely; and you might have greater reason to be satisfied, should the pen commit its own thoughts to paper, instead of mine.

In the system of monads, that is not necessary; the soul represents to itself beforehand, by its inherent powers, all the ideas of my pen, but in a very obscure manner. What I am now taking the liberty to suggest, contributes absolutely nothing to your information. The partisans of this system have demonstrated that simple beings cannot exercise the slightest influence on each other; and your own soul derives from itself what I have been endeavouring to convey, without my having any concern in the matter.

Conversation, reading and writing, therefore, are merely chimerical and deceptive formalities, which illusion would impose upon us as the means of acquiring and extending knowledge. But I have already had the honour of pointing out to you the wonderful consequences resulting from the system of the pre-established harmony; and I am apprehensive that these reveries may have become too severe a trial of your patience, though many persons of superior illumination consider this system as the most sublime production of human understanding, and are incapable of mentioning it but with the most profound respect.

30*th May* 1761.

Letter XVIII.—Elucidation respecting the Nature of Colours.

I am under the necessity of acknowledging, that the ideas respecting colour, which I have already taken the liberty to suggest,* come far short of that degree of evidence to which I could have wished to carry them. This subject has hitherto proved a stumbling-block to philosophers, and I must not flatter myself with the belief that I am able to clear it of every difficulty. I hope, at the same time, that the elucidations which I am going to submit to your examination, may go far toward removing a considerable part of them.

The ancient philosophers ranked colours among the bodies of which we know only the names. When they were asked, for example, why such a body was red, they answered, it was in virtue of a quality which made it appear red. You must be sensible that such an answer conveys no information, and that it would have been quite as much to the purpose to confess ignorance.

Descartes, who first had the courage to plunge into the mysteries of nature, ascribes colours to a certain mixture of light and shade, which last being nothing else but a want of light, as it is always found where the light does not penetrate, must be incapable of producing the different colours we observe.

Having remarked that the sensations of the organ of sight are produced by the rays which strike that organ, it necessarily follows, that those which excite in it the sensation of red, must be of quite a different nature from those which produce the sensation of the other colours; hence it is easily comprehended that each colour is attached to a certain quality of the rays which strike the organ of vision. A body appears to us red, when the rays which it emits are of a nature to excite in our eyes the sensation of that colour.

* See Letters XXVII. XXVIII. and XXXI. in Volume I.

The whole, then, results in an inquiry into the difference of the rays which variety of colours produces. This difference must be great, to produce so many particular sensations in our eyes. But wherein can it consist? This is the great question, toward the solution of which our present research is directed.

The first difference between rays which presents itself is, that some are stronger than others. It cannot be doubted that those of the sun, or of any other body very brilliant, or very powerfully illuminated, must be much stronger than those of a body feebly illuminated, or endowed with a slender degree of light; our eyes are assuredly struck in a very different manner by the one and by the other.

Hence it might be inferred, that different colours result from the force of the rays of light; so that the most powerful rays should produce, for example, red; those which are less so, yellow; and in progression, green, and blue.

But there is nothing more easy than to overturn this system, as we know from experience that the same body always appears to be of the same colour, be it less or more illuminated, or whether its rays be strong or feeble. A red body, for example, appears equally red, exposed to the brightest lustre of the sun, and in the shade, where the rays are extremely faint. We must not, then, look for the cause of the difference of colour in the different degrees of the force of rays of light, it being possible to represent the same colour as well by very forcible as by very faint rays. The feeblest glimmering serves equally well to discover to us difference of colours, as the brightest effulgence.

It is absolutely necessary, therefore, that there should be another difference of rays discovered, which may characterise their nature relatively to the different colours. You will undoubtedly conclude, that in order to discover this difference, we must be better acquainted with the nature of luminous rays; in other words, we must know what it is that, reaching our eyes, renders bodies visible; this definition of a ray must be the justest, as in effect it is nothing else but that which enters into the eye by the pupil, and excites the sensation in it.

I have already informed you, that there are only two systems or theories which pretend to explain the origin and nature of rays of light. The one is that of *Newton*, who considers them as emanations proceeding from the sun and other luminous bodies; and the other, that which I have endeavoured to demonstrate, and of which I have the reputation of being the author, though others have had nearly the same ideas of it. Perhaps I may have succeeded better than they, in carrying it to a higher degree of evidence. It will be of importance, then, to show, in both systems, on what principle the difference of colours may be established.

In that of emanation, which supposes the rays to issue from luminous bodies, in the form of rivers, or rather of fountains, spouting out a fluid in all directions, it is alleged that the particles of light differ in size or in substance, as a fountain might emit wine, oil, and other liquids; so that the different colours are occasioned by the diversity of the subtile matter which emanates from luminous bodies. Red would be, accordingly, a subtile matter issuing from the luminous body, and so of yellow and the other colours. This explanation would exhibit clearly enough the origin of the different colours, if the system itself had a solid foundation. I shall enter into the subject more at large in my next letter.

2d June 1761.

Letter XIX.—Reflections on the Analogy between Colours and Sounds.

You will be pleased to recollect the objections I offered to the system of the emanation of light.* They appear to me so powerful, as completely to overturn that system. I have accordingly succeeded in my endeavours to convince certain natural philosophers of distinction, and they have embraced my sentiments of the subject with expressions of singular satisfaction.

Rays of light, then, are not an emanation from the sun and other luminous bodies, and do not consist of a subtile matter emitted forcibly by the sun, and transmitted to us with a rapidity which may well fill you with astonishment. If the rays employed only eight minutes in their course from the sun to us, the torrent would be terrible, and the mass of that luminary, however vast, must speedily be exhausted.

According to my system, the rays of the sun, of which we have a sensible perception, do not proceed immediately from that luminary; they are only particles of ether floating around us, to which the sun communicates nearer and nearer a motion of vibration, and consequently they do not greatly change their place in this motion.

This propagation of light is performed in a manner similar to that of sound. A bell, whose sound you hear, by no means emits the particles which enter your ears. You have only to touch it when struck, to be assured that all its parts are in a very sensible agitation. This agitation immediately communicates itself to the more remote particles of air,

* See Letters XVII. and XVIII. in Volume I.

so that all receive from it successively a similar motion of vibration, which, reaching the ear, excite in it the sensation of sound. The strings of a musical instrument put the matter beyond all doubt; you see them tremble, go and come. It is even possible to determine by calculation how often in a second each string vibrates; and this agitation, being communicated to the particles of air adjacent to the organ of hearing, the ear is struck by it precisely as often in a second. It is the perception of this tremulous agitation which constitutes the nature of sound. The greater the number of vibrations produced by the string in a second, the higher or sharper is the sound. Vibrations less frequent produce lower notes.

We find the circumstances which accompany the sensation of hearing, in a manner perfectly analagous, in that of sight.

The medium only, and the rapidity of the vibrations differ. In sound, it is the air through which the vibrations of sonorous bodies are transmitted. But with respect to light, it is the ether, or that medium incomparably more subtile and more elastic than air, which is universally diffused wherever the air and grosser bodies leave interstices.

As often, then, as this ether is put into a state of vibration, and is transmitted to the eye, it excites in it the sentiment of vision, which is, in that case, nothing but a similar tremulous motion, whereby the small nervous fibres at the bottom of the eye are agitated.

You easily comprehend, that the sensation must be different, according as this tremulous agitation is more or less frequent; or according as the number of vibrations performed in a second is greater or less. Hence there must result a difference similar to that which takes place in sounds, when the vibrations are more or less frequent. This difference is clearly

perceptible by the ear, as the character of sounds in respect of flat and sharp depends on it. You will recollect that the note marked C in the harpsichord performs about 100 vibrations in a second; note D 112; note E 125; note F 133; note G 150; note A 166; note B 187; and *C* 200. Thus the nature of sounds depends on the number of vibrations performed in a second.

It cannot be doubted that the sense of seeing may be likewise differently affected, according as the number of vibrations of the nervous fibres of the bottom of the eye is greater or less. When these fibres vibrate 1000 times in a second, the sensation must be quite different from what it would be did they vibrate 1200 or 1500 times in the same space.

True it is, that the organ of vision is not in a condition to reckon numbers so great, still less than the ear is to reckon the vibrations which constitute sound; but it is always in our power to distinguish between the greater and the less.

In this difference, therefore, we must look for the cause of difference of colour; and it is certain that each of them corresponds to a certain number of vibrations, by which the fibres of our eyes are struck in a second, though we are not as yet in a condition to determine the number corresponding to each particular colour, as we can do with respect to sounds.

Much research must have been employed before it was possible to ascertain the numbers corresponding to all the notes of the harpsichord, though there was an antecedent conviction that their difference was founded on the diversity of those numbers. Our knowledge respecting these objects is nevertheless considerably advanced, from our being assured that there prevails a harmony so delightful between the different notes of the harpsichord and the different 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.

9th 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.