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.

14*th 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

itself, you could gain no ground, for you would just take away as much on the one hand as you gave on the other.

Having then placed the man whom you mean to electrify, in the manner which I have indicated, you have only to make him touch with his hand the globe of glass while it turns, and the ether accumulated in the globe will easily pass into the open pores of the hand, and diffuse itself over the whole body, from whence it cannot so easily escape, as the air and all the bodies with which he is surrounded have their pores close. Instead of touching the globe with his hand, it will be sufficient for him to touch the chain, or even the bar, which I described in the preceding letter; but in this case, not only the man himself must be surcharged with ether, but likewise the chain with the bar of iron; and as this requires a greater quantity of ether, it would be necessary to labour longer in turning the globe, in order to supply a sufficient quantity.

In this manner the man becomes entirely electric, or, in other words, his whole body will be surcharged with ether; and this fluid will consequently be found there in the highest degree of compression and electricity, and will have a violent tendency to escape.

You must be abundantly sensible, that a state so violent cannot be indifferent to the man. The body is in its minutest parts wholly penetrated with ether, and the smallest fibres, as well as the nerves, are so filled with it, that this ether, without doubt, pervades the principal springs of animal and vital motion. It is accordingly observed, that the pulse of a man electrified beats faster—he is thrown into a sweat—and the motion of the more subtile fluids with which the body is filled becomes more rapid. A certain change is likewise felt over the whole body, which it

is impossible to describe; and there is every reason to believe, that this state has a powerful influence on the health, though sufficient experiments have not yet been made to ascertain in what cases this influence is salutary, or otherwise. It may sometimes be highly beneficial to have the blood and humours raised to a more lively circulation; certain obstructions, which threaten dangerous consequences, might thereby be prevented; but on other occasions an agitation too violent might prove injurious to health. The subject certainly well deserves the attention of medical gentlemen. We have heard of many surprising cures performed by electricity, but we are not yet enabled sufficiently to distinguish the occasions on which we may promise ourselves success.

To return to our electrified man; it is very remarkable, that in the dark we see him surrounded with a light similar to that which painters throw round the heads of saints. The reason is abundantly obvious; as there is always escaping from the body of that man some part of the ether with which he is surcharged, this fluid meets with much resistance from the close pores of the air; it is thereby put into a certain agitation, which is the origin of light, as I have had the honour to demonstrate.

Phenomena of a very surprising nature are remarked in this state of a man electrified. On touching him, you not only see very brilliant sparks issue from the part which you touch, but the man feels besides a very pungent pain. Farther, if the person who touches him be in his natural state, or not electrified, both sensibly feel this pain, which might have fatal consequences, especially if he were touched in the head, or any other part of the body of acute sensibility. You will readily comprehend, then, how little indifferent it is to us, that a part of the ether contained in our body escape from it, or that new

ether is introduced, especially as this is done with such amazing rapidity.

Moreover, the light with which we see the man surrounded in the dark, is an admirable confirmation of my remarks respecting the electric atmosphere which is diffused round all bodies; and you will no longer find any difficulty in the greater number of electrical phenomena, however inexplicable they may at first appear.

18*th July* 1761.

Letter XXXII.—Distinctive Character of the two Species of Electricity.

You will please to recollect, that not only glass becomes electric by friction, but that other substances, such as sealing-wax and sulphur, have the same property, in as much as their pores are likewise close; so that whether you introduce into them an extraordinary quantity of ether, or extract a part of it, they continue for some time in that state; nor is the equilibrium so soon restored.

Accordingly, instead of a globe of glass, globes of sealing-wax and sulphur are employed, which are likewise made to revolve round an axis, rubbing at the same time against a cushion, in the same manner which I described respecting a globe of glass. Such globes are thus rendered equally electric; and on applying to them a bar of iron, which touches them only by slender filaments or fringes of metal, incapable of injuring the globe, electricity is immediately communicated to that bar, from which you may afterwards transmit it to other bodies at pleasure.

Here, however, a very remarkable difference is observable. A globe of glass rendered electric in this manner, becomes surcharged with ether; and the

bar of iron, or other bodies brought into communication with it, acquire an electricity of the same nature. This electricity is denominated *positive* or *augmented* electricity. But when a globe of sealing-wax or sulphur is treated in the same manner, an electricity directly opposite is the result, which is denominated *negative* or *diminished* electricity, as it is perceived that by friction these globes are deprived of part of the ether contained in their pores.

You will be surprised to see that the same friction is capable of producing effects altogether opposite; but this depends on the nature of the bodies which undergo the friction, whether by communicating or receiving it, and of the rigidity of their particles which contain the pores. In order to explain the possibility of this difference, it is evident, at first sight, that when two bodies are rubbed violently against each other, the pores of the one must in most cases undergo a greater compression than those of the other, and that then the ether contained in the pores is extruded, and forced to insinuate itself into those of the bodies which are less compressed.

It follows, then, that in this friction of glass against a cushion, the pores of the cushion undergo a greater compression than those of the glass, and consequently the ether of the cushion must pass into the glass, and produce in it a positive or *increased* electricity, as I have already showed. But on substituting a globe of sealing-wax or of sulphur in place of the glass, these substances being susceptible of a greater degree of compression in their pores than the substance of the cushion with which the friction is performed, a part of the ether contained in these globes will be forced out, and constrained to pass into the cushion; the globe of sealing-wax or sulphur will thereby be deprived of part of its ether, and of course receive a negative or *diminished* electricity.

The electricity which a bar of iron, or of any other metal, receives from communication with a globe of sealing-wax or sulphur, is of the same nature; as is also that which is communicated to a man placed on a lump of pitch, or suspended by cords of silk. When such a man, or any other body with open pores electrified in the same manner, is touched, nearly the same phenomena are observable as in the case of positive electricity. The touch is here likewise accompanied with a spark, and a puncture on both sides. The reason is obvious; for the ether which in this case escapes from bodies in their natural state, to enter into electrified bodies, being under constraint, must be under an agitation which produces light. A sensible difference is, however, to be remarked in the figure of the spark, according as the electricity is positive or negative. See that of positive electricity, PLATE IV. *Fig.* 5.

If the bar A B possesses positive electricity, and the finger C is presented to it, the light which issues out of the bar appears under the form of rays diverging from the bar toward the finger *m n*, and the luminous point is seen next the finger.

But if the bar A B (PLATE IV. *Fig.* 6.) is negatively electric, and the finger C is presented to it, the luminous rays *m n* diverge from the finger, and you see the luminous point *p* next the bar.

This is the principal character by which positive is distinguished from negative electricity. From whence soever the ether escapes, the spark is emitted in the figure of rays diverging from that point; but when the ether enters into a body, the spark is a luminous point toward the recipient body.*

21*st July* 1761.

* Professor Hildebrand has lately found, that the size and luminousness of the spark depends upon the nature, as well as upon the form of the metal from which the sparks are taken. The pieces of metal which he used were of a conical form. They had all the same shape and dimensions, and were fixed in the same manner, at the end of an insulated conductor. The sparks differed very much in extent, as shown in the following list;—those at the top of the list giving the greatest sparks, and those at the bottom the least.

Regulus of Antimony.	Sulphuret of Copper.	Steel.
Gold.	Tin.	Tempered Steel.
Silver.	Zinc.	
Brass.	Iron. Lead.	

A cone with an angle of 52° gave a much more luminous spark than one with an angle of 86°. The parabolic rounding of the summit, or slight inequalities of surface, were found to be particularly favourable to the production of a strong light.—ED.

LETTER XXXIII.—HOW THE SAME GLOBE OF GLASS MAY FURNISH AT ONCE THE TWO SPECIES OF ELECTRICITY.

YOU will be enabled to see still more clearly the difference between positive and negative electricity, after I have explained how it is possible to produce, by one and the same globe of glass, both the species; and this will serve, at the same time, farther to elucidate these wonderful phenomena of nature.

Let A B (PLATE IV. *Fig.* 7.) be the globe of glass turning round its axis C, and rubbed against the cushion D, in an opposite direction to which the globe is touched by the metallic filaments F, attached to the bar of iron FG, which is suspended by cords of silk H and I, that it may no where touch bodies with open pores.

This being laid down, you know that, by friction against the cushion D, the ether passes from the cushion into the glass, from which it becomes more compressed, and consequently more elastic: it will pass, therefore, from thence, by the metallic filaments F, into the bar of iron F G; for though the pores of glass are abundantly close, as the ether in the

globe is continually accumulating by the friction, it soon becomes so overcharged, that it escapes by the metallic filaments, and discharges itself into the bar, by which this last becomes equally electric.

Hence you perceive, that all this superfluity of ether is supplied by the cushion, which would speedily be exhausted, unless it had a free communication with the frame which supports the machine, and thereby with the whole earth, which is every instant supplying the cushion with new ether; so that as long as the friction continues, there is a quantity sufficient farther to compress that which is in the globe and in the bar. But if the whole machinery is made to rest on pillars of glass, as M and N, or if it is suspended by cords of silk, that the cushion may have no communication with bodies whose pores are open, which might supply the deficiency of ether, it would soon be exhausted, and the electricity could not be conveyed into the globe and the bar beyond a certain degree, which will be scarcely perceptible, unless the cushion be of a prodigious size. To supply this defect, the cushion D is put in communication with a large mass of metal E, the ether of which is sufficient to supply the globe and the bar, and to carry it to such a high degree of compression.

You will thus procure to the globe and to the bar a positive electricity, as has been already explained. But in proportion as they become surcharged with ether, the cushion and the metallic mass E will lose the same quantity, and thereby acquire a negative electricity: so that we have here at once the two species of electricity; the positive in the bar, and the negative in the metallic mass. Each produces its effect conformably to its nature. On presenting a finger to the bar, a spark with divergent rays will issue from the bar, and the luminous point will be seen toward the finger; but if you present the finger to the metallic mass, the spark with divergent rays will issue from the finger, and you will see the luminous point toward the mass.

Let us suppose two men placed on lumps of pitch, to cut off all communication between them and bodies with open pores; let the one touch the bar, and the other the metallic mass, while the machine is put in motion: it is evident that the former will become positively electric, or surcharged with ether; whereas the other, he who touches the metallic mass, will acquire a negative electricity, and lose his ether.

Here, then, are two electric men, but in a manner totally different, though rendered such by the same machine. Both will be surrounded by an electric atmosphere, which in the dark will appear like the light that painters throw about the figures of saints. The reason is, that the superfluous ether of the one insensibly escapes into the circumambient air; and that, with respect to the other, the ether contained in the air insensibly insinuates itself into his body. This transition, though insensible, will be accompanied with an agitation of ether, which produces light.

It is evident, that these two species of electricity are directly opposite; but in order to have a thorough conviction of it, let these two join hands, or only touch each other, and you will see very vehement sparks issue from their bodies, and they themselves will feel very acute pain.

If they were electrified in the same manner, which would be the case if both touched the bar or the metallic mass, they might safely touch each other; no spark and no pain would ensue, because the ether contained in both would be in the same state;

whereas, in the case laid down, their state is directly opposite.

25*th July* 1761.

Letter XXXIV.—The Leyden Experiment.

I now proceed to describe a phenomenon of electricity which has made a great deal of noise, and which is known by the name of *the Leyden experiment*, because *Mr. Muschenbroeck*, professor at Leyden, is the inventor of it. What is most astonishing in this experiment, is the terrible stroke resulting from it, by which several persons at once may receive a very violent shock.

Let C (Plate IV. *Fig.* 8.) be a globe of glass, turned round by means of the handle E, and rubbed by the cushion D D, which is pressed upon the globe by the spring O. At Q are the metallic filaments, which transmit the electricity into the bar of iron F G, by the metallic chain P.

Hitherto there is nothing different from the process already described. But in order to execute the experiment in question, to the bar is attached another chain of metal H, one extremity of which I, is introduced into a glass bottle K K, filled with water; the bottle too is placed in a basin L L, likewise filled with water. You plunge, at pleasure, into the water in the basin another chain A, one end of which drags on the floor.

Having put the machine in motion for some time, that the bar may become sufficiently electric, you know that if the finger were to be presented to the extremity of the bar at *a*, the usual stroke of electricity would be felt, from the spark issuing out of it. But were the same person at the same time to

put the other hand into the water in the basin at A, or were he but to touch with any part of his body the chain plunged in that water, he would receive a stroke incomparably more violent, by which his whole frame would undergo a severe agitation.

This shock may be communicated to many persons at once. They have only to join hands, or to touch each other, were it but by the clothes; then the first puts his hand into the water in the basin, or touches the chain only, one end of which is plunged into it; and as soon as the last person applies his finger to the bar, you will see a spark dart from it much more vehement than usual, and the whole chain of persons feel, at the same instant, a very violent shock over their whole body.

Such is the famous Leyden experiment, which is so much the more surprising, that it is difficult to see how the bottle and the water in the basin contribute to increase so considerably the effect of the electricity. To solve this difficulty, permit me to make the following reflections.

1. While by the action of the machine the ether is compressed in the bar, it passes by the chain H into the water contained in the bottle I, and there meeting a body with open pores, the water in the bottle will become as much surcharged with ether as the bar itself.

2. The bottle, being glass, has its pores close, and therefore does not permit the ether compressed within it to pierce through the substance of the glass, to discharge itself into the water in the basin; consequently, the water in the basin remains in its natural state, and will not become electric; or even on the supposition that a little of the ether might force its way through the glass, it would presently be lost in the basin and pedestal, the pores of which are open.

3. Let us now consider the case of a man with one hand in the water in the basin, or only in contact with the chain A, one extremity of which is immersed in that water; let him present the other hand to the bar at *a*, the result will be, as the first effect, that with the spark which issues from the bar, the ether will make its escape with great velocity, and meeting every where, in the body of the man, open pores, will without obstruction be diffused over it.

4. Hitherto we see only the usual effect of electricity; but while the ether with such rapidity flies over the body of the man, it discharges itself with equal rapidity, by the other hand, or by the chain A, into the water in the basin; and as it enters this with such impetuosity, it will easily overcome the obstacle opposed by the glass, and penetrate into the water which the bottle contains.

5. Now the water in the bottle containing already an ether too much compressed, it will acquire from this increase new force, and will diffuse itself with impetuosity, as well through the chain I H, as through the bar itself; it will of consequence make its escape thence at *a* with new efforts; and as this is performed in an instant, it will enter into the finger with increased force, to be diffused over the whole body of the man.

6. Passing thence anew into the water in the basin, and penetrating the bottle, it will increase still farther the agitation of the ether compressed in the water of the bottle, and in the bar; and this will continue till the whole is restored to equilibrium, which will quickly take place, from the great rapidity with which the ether acts.

7. The same thing will happen if you employ several persons instead of one man. And now, I flatter myself, you fully comprehend whence arises the surprising increase of force in the electricity which is produced by this experiment of *Mr. Muschenbroeck*, and which exhibits effects so prodigious.

8. If any doubt could remain respecting what I have advanced, that the ether compressed in the water of the bottle could not penetrate through the glass, and that afterwards I have allowed it a passage abundantly free—such doubt will vanish when it is considered, that, in the first case, every thing is in a state of tranquillity, and, in the last, the ether is in a terrible agitation, which must undoubtedly assist its progress through the closest passages.

28*th July* 1761.

LETTER XXXV.—REFLECTIONS ON THE CAUSE AND NATURE OF ELECTRICITY, AND ON OTHER MEANS PROPER TO PRODUCE IT.

AFTER these elucidations, you can be at no loss respecting the cause of the prodigious effects observable in the phenomena of electricity.

Most authors who have treated the subject, perplex the experiments in such a manner, that they are rendered absolutely unintelligible, especially when they attempt an explanation. They have recourse to a certain subtile matter, which they denominate *the electric fluid*, and to which they ascribe qualities so extravagant, that the mind rejects them with contempt; and they are constrained to acknowledge, at length, that all their efforts are insufficient to furnish us with a solid knowledge of these important phenomena of nature.

But you are enabled to conclude, from the principles which I have unfolded, that bodies evidently become electric, only so far as the elasticity, or the state of the compression of the ether in the pores of

bodies, is not the same as every where else; in other words, when it is more or less compressed in some than in others. For, in that case, the prodigious elasticity with which the ether is endowed, makes violent efforts to recover its equilibrium, and to restore every where the same degree of elasticity, as far as the nature of the pores which, in different bodies, are more or less open, will permit; and it is the return to equilibrium which always produces the phenomena of electricity.

When the ether escapes from a body where it is more compressed, to discharge itself into another where it is less so, this passage is always obstructed by the close pores of the air; hence it is put into a certain agitation, or violent motion of vibration, in which, as we have seen, light consists; and the more violent this motion is, the more brilliant the light becomes, till it is at length capable of setting bodies on fire, and of burning them.

While the ether penetrates the air with so much force, the particles of air are likewise put into a motion of vibration, which occasions sound; it is accordingly observed, that the phenomena of electricity are accompanied with a cracking noise, greater or less, according to the diversity of circumstances.

And as the bodies of men and animals are filled with ether in their minutest pores, and as the action of the nerves seems to depend on the ether contained in them, it is impossible that men and animals should be indifferent with respect to electricity: and when the ether in them is put into a great agitation, the effect must be very sensible, and, according to circumstances, sometimes salutary, and sometimes hurtful. To this last class, undoubtedly, must be referred the terrible shocks of the Leyden experiment; and there is every reason to believe that it might be carried to a degree of force capable of killing men, for by means of it many small animals, such as mice and birds, have actually been killed.

Though friction usually is employed in the production of electricity, you will easily comprehend that there may be other means besides this. Whatever is capable of carrying the ether contained in the pores of a body to a greater or less degree of compression than ordinary, renders it electric: and if its pores are close, there the electricity will be of some duration; whereas, in bodies whose pores are open, it cannot possibly subsist, unless surrounded by air, or other bodies with close pores.

Hence it has been observed, that heat frequently supplies the place of friction. When you heat or melt sealing-wax or sulphur in a spoon, you discover a very sensible electricity in these substances, after they are cooled. The reason is no longer a mystery, as we know that heat enlarges the pores of all bodies, for they occupy a greater space when hot than when they are cold.

You know that in a thermometer the mercury rises in heat, and falls in cold; because it occupies a greater space when it is hot, and fills the tube more than when it is cold. We find, for the same reason, that a bar of iron very hot is always somewhat longer than when cold—a property common to all bodies with which we are acquainted.

When, therefore, we melt by fire a mass of sealing-wax or sulphur, their pores are enlarged, and probably more open; a greater quantity of ether must of course be introduced to fill them. When, afterwards, these substances are suffered to cool, the pores contract and close, so that the ether in them is reduced to a smaller space, and consequently carried to a higher degree of compression, which increases its elasticity: these masses will acquire, therefore, a

positive electricity, and must consequently exhibit the effects of it.

This property of becoming electric by heat is remarked in most precious stones. Nay, there is a stone named *Tourmaline*, which, when rubbed or heated, acquires at once the two species of electricity. The ether in one part of the stone is expelled to compress more that which is in the other part; and its pores are too close to permit the re-establisment of the equilibrium.*

1*st August* 1761.

* Very important discoveries have been made since the time of Euler, respecting the production of Electricity by *Friction*, *Pressure*, and *Heat*. A very brief notice of these will be interesting to the reader.

Electricity by Friction.—Rock crystal, and almost all the precious stones, acquire *positive* or *vitreous* electricity, with whatever substances they are rubbed; and, on the other hand, resin, sulphur, bitumen, &c. acquire negative or resinous electricity when rubbed with any non-conducting substance. Glass, however, when polished, gives vitreous electricity by friction, whereas it gives resinous electricity when it is rough. Among the metals, *Zinc* and *Bismuth* always acquire vitreous electricity when rubbed with a piece of woollen cloth, while *Tin* and *Antimony* always acquire resinous electricity. In many of the other metals, and in various other substances, the results are often irregular and anomalous, sometimes one kind of electricity being developed, and sometimes another. The most striking example of this is in the mineral called *Kyanite*, some crystals of which always acquire resinous electricity by friction, while other crystals always acquire vitreous electricity. In some of these crystals, indeed, vitreous electricity is obtained by rubbing one face, and resinous electricity by rubbing the other. For farther information on this subject, see Haüy's *Traité de Mineralogie*, Paris, 1822, vol. i. p. 186; and the *Edinburgh Encyclopædia*, Article ELECTRICITY, vol. viii. p. 430.

Electricity by Pressure.—The Abbé Haüy discovered the method of producing electricity by pressure. He found that if a rhomb of Iceland spar is held in one hand by two of its opposite edges, and if with two fingers of the other hand two of its opposite faces are merely *touched*, it gives out vitreous electricity. When pressure is applied in place of contact, the effect is greatly increased. Haüy found the same property in Topaz, Euclase, Arragonite, Fluate of Lime, Carbonate of Lead, and Hyalin Quartz, all of which give vitreous electricity, both by friction and pressure. Sulphate of Barytes and Sulphate of Lime give no electricity by pressure. Elastic Bitumen, which is negatively electrified by friction, is also negatively electrified by pressure.

LETTER XXXVI.—NATURE OF THUNDER: EXPLANATIONS OF THE ANCIENT PHILOSOPHERS, AND OF DESCARTES: RESEMBLANCE OF THE PHENOMENA OF THUNDER TO THOSE OF ELECTRICITY.

I HAVE hitherto considered electricity only as an object of curiosity and speculation to naturalists; but

Electricity by Heat.—The property possessed by *Tourmaline* of becoming electrical by heat, seems to have been known to the ancients. When Tourmaline, Oxide of Zinc, Borate of Magnesia, Auvergne Mesotype, Greenland Mesotype, Scolezite and Mesolite, are heated, one extremity of the crystal developes resinous, and the other vitreous electricity, the intensity of electricity diminishing rapidly from the extremities to the middle or neutral point of the crystal. In the Boracite there are eight electrical poles, one at each solid angle of the cube.

When these minerals again reach the ordinary temperature, the electricity disappears; but M. Haüy has lately found, that it then passes, by a reduction of temperature, to the opposite state. With Oxide of Zinc and Tourmaline he invariably found, that the opposite electricity could be developed by cold, so that the pole which possessed vitreous electricity when it was hot, developed resinous electricity when it was cold. When the opposite electricity is beginning to show itself, the two poles have sometimes at once both vitreous and resinous electricity. The disappearance of the opposite electricity produced by cold takes place generally below the freezing point.—See Haüy's *Traité de Mineralogie*, tom. i. p. 200.

In examining the electricity of the Tourmaline, I have found that it may be shown in a very satisfactory manner, by means of a thin slice taken from any part of the prism, and having its surfaces perpendicular to the axis of the prism. It must then be placed upon a piece of well polished glass, and the glass heated to a considerable degree. At the proper temperature, which is about that of boiling water, the slice will adhere to the glass so firmly, that even when the glass is above the Tourmaline, the latter will adhere to it for six or eight hours. By this means slices of a very considerable breadth and thickness develope as much electricity as is capable of supporting their own weight. The slice of Tourmaline adheres equally to all bodies whatever. Mr. Sivright has fitted up a Tourmaline so as to bring the action of its two poles very near to one another. It resembles the letter D, with an opening in its curved part. The straight part is the Tourmaline, and the two curved parts are pieces of silver wire rising out of two silver caps; one of which embraces each pole of the Tourmaline. A pith ball suspended at the opening vibrates between the extremities of the wires. Sir H. Davy (*Elements of Chemical Philosophy*, vol. i. p. 130.), states, that when the slice is of considerable size, flashes of light may be seen along its surface.—See *Edinburgh Philosophical Journal*, vol. i. p. 205.—ED.

you will presently see, not without some degree of surprise, that thunder and lightning, as well as all the terrible phenomena which accompany them, derive their origin from the same principle; and that in these nature executes on the great scale what naturalists do in miniature by their experiments.

Those philosophers who thought they saw some resemblance between the phenomena of thunder and those of electricity, were at first considered as visionaries; and it was imagined that they made use of this pretence merely as a cover to their ignorance respecting the cause of thunder: but you will soon be convinced, that every other explanation of these grand operations of nature is destitute of foundation.

In truth, every thing advanced on the subject previous to the knowledge of electricity was a mass of absurdity, and little calculated to convey instruction respecting any of the phenomena of thunder.

Ancient philosophers attributed the cause of it to sulphureous and bituminous vapours, which, ascending from the earth into the air, mixed with the clouds, where they caught fire from some unknown cause.

Descartes, who quickly perceived the insufficiency of this explanation, imagined another cause in the clouds themselves, and thought that thunder might be produced by the sudden fall of more elevated clouds on others in a lower region of the air; that the air contained in the intermediate space was compressed by this fall to such a degree as was capable of exciting a noise so loud, and even of producing lightning and thunder, though it was impossible for him to demonstrate the possibility of it.

But without fixing your attention on false explanations, which lead to nothing, I hasten to inform you, that it has been discovered by incontestable proofs, that the phenomena of thunder are always

accompanied by the most indubitable marks of electricity.

Let a bar of metal, say of iron, be placed on a pillar of glass, or any other substance whose pores are close, that when the bar acquires electricity it may not escape or communicate itself to the body which supports the bar; as soon as a thunder-storm arises, and the clouds which contain the thunder come directly over the bar, you perceive in it a very strong electricity, generally far surpassing that which art produces; if you apply the hand to it, or any other body with open pores, you see bursting from it, not only a spark, but a very bright flash, with a noise similar to thunder; the man who applies his hand to it receives a shock so violent that he is stunned. This surpasses curiosity; and there is good reason why we should be on our guard and not approach the bar during a storm.

A professor at Petersburgh, named *Richmann*, has furnished a melancholy example. Having perceived a resemblance so striking between the phenomena of thunder and those of electricity, this unfortunate naturalist, the more clearly to ascertain it by experiment, raised a bar of iron on the roof of his house, cased below in a tube of glass, and supported by a mass of pitch. To the bar he attached a wire, which he conducted into his chamber, that as soon as the bar should become electric, the electricity might have a free communication with the wire, and so enable him to prove the effects in his apartment. And it may be proper to inform you, that this wire was conducted in such a manner as no where to be in contact but with bodies whose pores are close, such as glass, pitch, or silk, to prevent the escape of the electricity.

Having made this arrangement, he expected a thunder-storm, which, unhappily for him, soon came.

The thunder was heard at a distance: *Mr. Richmann* was all attention to his wire, to see if he could perceive any mark of electricity. As the storm approached, he judged it prudent to employ some precaution, and not keep too near the wire; but happening carelessly to advance his chest a little, he received a terrible stroke, accompanied with a loud clap, which stretched him lifeless on the floor.

About the same time, the late *Dr. Lieberkuhn* and *Dr. Ludolf* were preparing to make similar experiments in this city, and with that view had fixed bars of iron on their houses; but being informed of the disaster which had befallen *Mr. Richmann*, they had the bars of iron immediately removed; and, in my opinion, they acted wisely.

From this you will readily judge, that the air or atmosphere must become very electric during a thunder-storm, or that the ether contained in it must then be carried to a very high degree of compression. This ether, with which the air is surcharged, will pass into the bar, because of its open pores; and it will become electric, as it would have been in the common method, but in a much higher degree.

4th August 1761.

Letter XXXVII.—Explanation of the Phenomena of Lightning and Thunder.

The experiments now mentioned incontestably demonstrate, therefore, that stormy clouds are extremely electrical, and that consequently their pores are either surcharged with ether, or exhausted, as both states are equally adapted to electricity. But I have very powerful reasons for believing that this electricity is positive, that the ether in them is compressed to the highest degree, and consequently so much the more elastic than elsewhere.

Such storms usually succeed very sultry weather. The pores of the air, and of the vapours floating in it, are then extremely enlarged, and filled with a prodigious quantity of ether, which easily takes possession of all the empty spaces of other substances. But when the vapours collect in the superior regions of our atmosphere, to form clouds, they have to encounter excessive cold. Of this it is impossible to doubt, from the hail which is frequently formed in these regions; this is a sufficient proof of a congelation, as well as the snow which we find on the tops of very high mountains, such as the Cordilleras, while extreme heat prevails below.

Nothing then is more certain, or better established by proof, than the excessive cold which universally prevails in the upper regions of the atmosphere, where clouds are formed. It is equally certain, that cold contracts the pores of bodies, by reducing them to a smaller size: now, as the pores of the vapours have been extremely enlarged by the heat, as soon as they are formed aloft into clouds, the pores contract, and the ether which filled them, not being able to escape, because those of the air are very close, it must needs remain there: it will be of course compressed to a much higher degree of density, and consequently its elasticity will be so much the greater.

The real state of stormy clouds, then, is this—the ether contained in their pores is much more elastic than usual, or in other words, the clouds have a positive electricity. As they are only an assemblage of humid vapours, their pores are very open; but being surrounded by the air whose pores are close, this ether could not escape but very imperceptibly. But if any person, or any body whatever with open pores, were to approach it, the same phenomena which electricity exhibits would present themselves;

a very vehement spark, or rather a real flash, would burst forth. Nay more, the body would undergo a very violent shock by the discharge, from the impetuosity with which the ether in the cloud would rush into its pores. This shock might be indeed so violent as to destroy the structure; and, finally, the terrible agitation of the ether which bursts from the cloud, being not only light, but a real fire, it might be capable of kindling and consuming combustible bodies.

Here, then, you will distinguish all the circumstances which accompany thunder; and as to the noise of thunder, the cause is very obvious, for it is impossible the ether should be in such a state of agitation, without the air itself receiving from it the most violent concussions, which forcibly impel the particles, and excite a dreadful noise. Thunder, then, bursts forth, as often as the force of ether contained in the clouds is capable of penetrating into a body where the ether is in its natural state, and whose pores are open: it is not even necessary that such body should immediately touch the cloud.

What I have said respecting the atmosphere of electrified bodies, principally takes place in clouds; and frequently, during a storm, we are made sensible of this electric atmosphere by a stifling air, which is particularly oppressive to certain persons. As soon as the cloud begins to dissolve into rain, the air becoming humid by it, is charged with an electricity, by which the commotion may be conveyed to bodies at a very great distance.

It is observed that thunder usually strikes very elevated bodies, such as the summits of church-spires, when they consist of substances with open pores, as all metals are; and the pointed form contributes not a little to it. Thunder frequently falls likewise on water, the pores of which are very open; but bodies

with close pores, as glass, pitch, sulphur, and silk, are not greatly susceptible of the thunder stroke, unless they are very much moistened. It has been accordingly observed, that when thunder passes through a window, it does not perforate the glass, but always the lead or other substances which unite the panes. It is almost certain, that an apartment of glass cemented by pitch, or any other substance with close pores, would be an effectual security against the ravages of thunder.

8*th August* 1761.

Letter XXXVIII.—Continuation.

Thunder, then, is nothing else but the effect of the electricity with which the clouds are endowed; and as an electrified body, applied to another in its natural state, emits a spark with some noise, and discharges into it the superfluous ether with prodigious impetuosity, the same thing takes place in a cloud that is electric, or surcharged with ether, but with a force incomparably greater, because of the terrible mass that is electrified, and in which, according to every appearance, the ether is reduced to a much higher degree of compression than we are capable of producing in it by our machinery.

When, therefore, such a cloud approaches bodies prepared for the admission of its ether, this discharge must be made with incredible violence: instead of a simple spark, the air will be penetrated with a prodigious flash, which, exciting a commotion in the ether contained in the whole adjoining region of the atmosphere, produces a most brilliant light; and in this lightning consists.

The air is at the same time put into a very violent motion of vibration, from which results the noise

of thunder. This noise must, no doubt, be excited at the same instant with the lightning; but you know that sound always requires a certain quantity of time, in order to its transmission to any distance, and that its progress is only at the rate of about eleven hundred feet in a second; whereas light travels with a velocity inconceivably greater. Hence we always hear the thunder later than we see the lightning; and from the number of seconds intervening between the flash and the report, we are enabled to determine the distance of the place where it is generated, allowing eleven hundred feet to a second.

The body itself, into which the electricity of the cloud is discharged, receives from it a most dreadful stroke; sometimes it is shivered to pieces—sometimes set on fire and consumed, if combustible—sometimes melted, if it be of metal; and, in such cases, we say it is thunder-struck, the effects of which, however surprising and extraordinary they may appear, are in perfect consistency with the well-known phenomena of electricity.

A sword, it is known, has sometimes been by thunder melted in the scabbard, while the last sustained no injury: this is to be accounted for from the openness of the pores of the metal, which the ether very easily penetrates, and exercises over it all its powers; whereas the substance of the scabbard is more closely allied to the nature of bodies with close pores, which do not permit the ether so free a transmission.

It has likewise been found, that of several persons on whom the thunder has fallen, some only have been struck by it; and that those who were in the middle suffered no injury. The cause of this phenomenon likewise is manifest. In a group exposed to a thunder storm, they are in the greatest danger who stand in the nearest vicinity to the air that is surcharged with ether; as soon as the ether is discharged upon one, all the adjoining air is brought back to its natural state, and consequently those who were nearest to the unfortunate victim feel no effect; while others, at a greater distance, where the air is still sufficiently surcharged with ether, are struck with the same thunder-clap.

In a word, all the strange circumstances so frequently related of the effects of thunder, contain nothing which may not be easily reconciled with the nature of electricity.

Some philosophers have maintained, that thunder does not come from the clouds, but from the earth, or from bodies. However extravagant this sentiment may appear, it is not so absurd, as it is difficult to distinguish, in the phenomena of electricity, whether the spark issues from the body which is electrified, or from that which is not so, as it equally fills the space between the two bodies; and if the electricity is negative, the ether and the spark are in reality emitted from the natural or non-electrified body. But we are sufficiently assured, that in thunder the clouds have a positive electricity, and that the lightning is emitted from the clouds.

You will be justifiable however in asking, if by every stroke of thunder some terrestrial body is affected? We see, in fact, that it very rarely strikes buildings, or the human body; but we know, at the same time, that trees are frequently affected by it, and that many thunder-strokes are discharged into the earth and into the water. I believe, however, it might be maintained, that a great many do not descend so low, and that the electricity of the clouds is very frequently discharged into the air or atmosphere.

The small opening of the pores of the air no longer opposes any obstruction to it, when vapours or rain

have rendered it sufficiently humid; for then we know the pores are open.

It may very possibly happen in this case, that the superfluous ether of the clouds should be discharged simply into the air; and when this takes place, the strokes are neither so violent, nor accompanied with so great a noise, as when the thunder bursts on the earth, when a much greater extent of atmosphere is put in agitation.

11*th August* 1761.

Letter XXXIX.—The possibility of preventing, and of averting, the Effects of Thunder.

It has been asked, Whether it might not be possible to prevent, or to avert, the fatal effects of thunder? You are well aware of the importance of the question, and under what obligation I should lay a multitude of worthy people, were I able to indicate an infallible method of finding protection against thunder.

The knowledge of the nature and effects of electricity, permits me not to doubt that the thing is possible. I corresponded some time ago with a Moravian priest, named *Procopius Divisch*, who assured me that he had averted, during a whole summer, every thunder-storm which threatened his own habitation and the neighbourhood, by means of a machine constructed on the principles of electricity. Several persons since arrived from that country, have assured me that the fact is undoubted, and confirmed by irresistible proof.

But there are many respectable characters, who, on the supposition that the thing is practicable, would have their scruples respecting the lawfulness

of employing such a preservative. The ancient pagans, no doubt, would have considered him as impious, who should have presumed to interfere with Jupiter in the direction of his thunder. Christians, who are assured that thunder is the work of God, and that Divine Providence frequently employs it to punish the wickedness of men, might with equal reason allege, that it were impiety to attempt to oppose the course of sovereign justice.

Without involving myself in this delicate discussion, I remark that conflagrations, deluges, and many other general calamities, are likewise the means employed by Providence to punish the sins of men; but no one surely ever will pretend, that it is unlawful to prevent or resist the progress of a fire or an inundation. Hence I infer, that it is perfectly lawful to use the means of prevention against the effects of thunder, if they are attainable.

The melancholy accident which befell *Mr. Richmann* at Petersburg, demonstrates, that the thunder-stroke which this gentleman unhappily attracted to himself, would undoubtedly have fallen somewhere else, and that this place thereby escaped; it can therefore no longer remain a question whether it be possible to conduct thunder to one place in preference to another; and this seems to bring us near our mark.

It would no doubt be a matter of still greater importance to have it in our power to divest the clouds of their electric force, without being under the necessity of exposing any one place to the ravages of thunder; we should, in that case, altogether prevent these dreadful effects, which terrify so great a part of mankind.

This appears by no means impossible; and the Moravian priest whom I mentioned above unquestionably effected it; for I have been assured, that his

machinery sensibly attracted the clouds, and constrained them to descend quietly in a distillation, without any but a very distant thunder-clap.

The experiment of a bar of iron, in a very elevated situation, which becomes electric on the approach of a thunder-storm, may lead us to the construction of a similar machine, as it is certain, that in proportion as the bar discharges its electricity, the clouds must lose precisely the same quantity; but it must be contrived in such a manner, that the bars may immediately discharge the ether which they have attracted.

It would be necessary, for this purpose, to procure for them a free communication with a pool, or with the bowels of the earth, which, by means of their open pores, may easily receive a much greater quantity of ether, and disperse it over the whole immense extent of the earth, so that the compression of the ether may not become sensible in any particular spot. This communication is very easy, by means of chains of iron, or any other metal, which will with great rapidity carry off the ether with which the bars are surcharged.

I would advise the fixing of strong bars of iron, in very elevated situations, and several of them together, their higher extremity to terminate in a point, as this figure is very much adapted to the attraction of electricity. I would afterwards attach long chains of iron to these bars, which I would conduct under ground into a pool, lake, or river, there to discharge the electricity; and I have no doubt, that after making repeated essays, the means may be certainly discovered of rendering such machinery more commodious, and more certain in its effect.*

* As buildings are often struck laterally, the main thunder-rod, especially in monumental pillars and elevated buildings, should have various lateral branches diverging from it, and extending to the air through openings in the building. By this means it is secured much more effectually than when there is only one conductor, which can do no more than protect the summit of the building.—Ed.

It is abundantly evident, that on the approach of a thunder-storm, the ether with which the clouds are surcharged would be transmitted in great abundance into these bars, which would thereby become very electric, unless the chains furnished to the ether a free passage, to spend itself in the water, and in the bowels of the earth.

The ether of the clouds would continue, therefore, to enter quietly into the bars, and would by its agitation produce a light, which might be visible on the pointed extremities.

Such light is, accordingly, often observed during a storm, on the summit of spires—an infallible proof that the ether of the cloud is there quietly discharging itself; and every one considers this as a very good sign of the harmless absorption of many thunder-strokes.

Lights are likewise frequently observed at sea, on the tops of the masts of ships, known to sailors by the name of *Castor and Pollux*;* and when such signs are visible, they consider themselves as safe from the stroke of thunder.

Most philosophers have ranked these phenomena among vulgar superstitions; but we are now fully assured, that such sentiments are not without foundation; indeed, they are infinitely better founded than many of our philosophical reveries.†

15*th August* 1761.

* This phenomenon is also called the Fire of St. Elmo. A very interesting account of it will be found in the *Edinburgh Philosophical Journal*, vol. ix. p. 85.—Ed.

† A very copious account of the recent discoveries in electricity will be found in the article on that subject, in the *Edinburgh Encyclopædia*, vol. viii. p. 411.—Ed.