charge is passed through it, though with a large discharge in proportion to the conducting power of the rod, the outward pressure may become so great as to throw off the stratum of sealing-wax. This point is of some importance in regard to the question of painting lightning-rods. If the metal is of sufficient size to freely transmit an ordinary discharge from the clouds, the condition of the exterior surface can have but little effect, and we see no objection to coating it with black paint, the basis of which is carbon, a good conducting material.

It is also to the same repulsive energy that we may attribute the spreading of a discharge when it passes through partial conductors, as in the case in which a spark from an electrical machine is transmitted over a pane of glass on which particles of iron filings are sparsely scattered. It is probable that drops of rain and partially condensed vapor in the atmosphere in some cases are connected with a similar appearance of discharge of electricity in the heavens.

A much longer spark of electricity can be drawn through rarified air than through that of ordinary density. The light which accompanies a discharge in this case assumes different colors, the violet predominating. This is a fact of interest in connection with the color exhibited by lightning, and we may infer that the discharges of a violet hue take place between clouds at a great elevation in the atmosphere.

The electric spark, when passed through a confined portion of atmospheric air, is found to produce a chemical combination of its component parts, namely, nitrogen and oxygen, and to form nitric acid. The same result is produced on a grand scale in the heavens during thunder-storms; hence the rain water which falls, in the summer season especially, always contains a considerable quantity of nitric acid, which is considered by the chemist as furnishing a portion of the nitrogen essential to the growth and development of the plant, and to the same source is referred the nitric acid in the nitrate of lime and potash which is found in the form of efflorescence on damp ground and the walls of old buildings. Indeed, all the nitrate of potash from which gunpowder is manufactured is supposed to have its origin in this way, and the explosion from the thunder-cloud, and that from the cannon, are the counterparts of each other.

Again, during the transmission of electricity from an ordinary electrical machine, a pungent odor is perceived, something analogous to that produced by the slow combustion of phosphorous, which, by a long-continued series of researches, Professor Schönbein has shown to result from a change in the oxygen of the air. He supposes that this substance is composed of two atoms, which, by their combination, partly neutralize each other, but which are separated by the repulsion of the electric spark, and thus free have a much greater tendency to combine with other substances than in their ordinary state of union. Oxygen, thus changed, according to Schönbein, is called ozone, and, as it would appear, performs an important part in many of the molecular and chemical phenomena of the atmosphere. To this increased combining power of oxygen may be attributed the formation of the nitric acid we have mentioned, and without such an explanation, it would be difficult to conceive how particles of oxygen and nitrogen, which are rendered

mutually repulsive by the electrical discharge, should enter into chemical combination.

We have seen that though metals are generally good conductors, yet when electricity falls upon a rod of iron or copper explosively, the energetic repulsion, which must always accompany these explosions, tends to throw the particles off on all sides, and when the discharge is sufficiently great, the conductor itself is dissipated in vapor. Water is a much inferior conductor to iron, and though a large mass of it will silently discharge a conductor, yet it offers great resistance to the transmission of electricity explosively, and hence the electricity is sometimes seen to leave a conductor, and pass a considerable distance over the surface of water, rather than to force its passage through the interior of the mass. It is, therefore, highly important in arranging lightning rods that they should be connected at the lower end with a large surface of conducting matter, to prevent, as far as possible, the fluid from leaving the rod in the case of an explosive discharge.

ELECTRICITY OF THE ATMOSPHERE.

Having given in the preceding sections a brief exposition of the general principles of electricity, we are now prepared to apply these to an exposition of the phenomena of atmospheric electricity.

The origin of the electricity of the atmosphere has long occupied the attention of physicists, and at different times they have apparently settled down on some plausible hypothesis, which merely offered a probable explanation of the phenomena without leading to new facts or pointing out new lines of research.

The earth, as is now well known, is almost a perfect conductor for the most feeble currents of electricity, provided the contact with it of the electrified body be sufficiently broad. The ærial covering which surrounds it, however, is a non-conductor which is capable of confining electricity in a condition of accumulation or of diminution, and of preventing the restoration of the equilibrium which, without the existence of this isulator would otherwise take place.

The hypothesis was at first advanced that the earth attracted the ethereal medium of celestial space and condensed it in a hollow stratum around the whole globe; that the electricity of the atmosphere was due to the action of this exterior envelope. Dr. Hare, our countryman, has presented this hypothesis with considerable distinctness. Without denying the possibility or even probability of such a distribution of electrical excitement, we may observe that, if this electrical shell were of uniform thickness, and we see no reason to suppose it should vary in different parts in this respect, it would follow from the law of central forces, that it could have no effect in disturbing the equilibrium on the surface or in the interior of the earth; a particle of matter remaining, as we have seen, at rest or unaffected at any point within a hollow sphere. This fact appears to militate against the truth of this assumption.

Another hypothesis attributed the electricity of the atmosphere to the friction of the winds on each other and on the surface of the earth, but careful experiments have shown that the friction of dry air on air or of air on solids or liquids does not develop electrical phenomena.

The next hypothesis was advanced by Pouillet; which referred the electricity of the atmosphere to the evaporation of water, particularly that which contained saline ingredients. But when pure water is carefully evaporated in a space not exposed to the sky, no electricity is produced except by the friction of the sides of the vessel in the act of rapid ebullition; and when the experiment is made with salt water, the electrical effects observed are found to be produced by an analogous friction of the salt against the interior of the vessel. When pure water is evaporated under a clear sky, the vapor produced is negatively electrified; but this state is contrary to that in which the atmosphere is habitually found.

Pouillet also supposed that the process of vegetation was a source of disturbance of the electrical equilibrium, but this has not been supported by critical experiments.

The discovery accidentally made a few years ago of the great amount of electricity evolved in blowing off steam from the boiler of a locomotive, seemed to afford a ready explanation of the electrical state of the atmosphere. It was then attributed to the condensation of the ærial vapor. Faraday, however, conclusively proved by one of his admirable series of model experiments, that this effect was due entirely to the friction of the water which escaped in connection with the steam on the side of the orifice through which the discharge took place. When dry steam, or that which is so heated as to contain no liquid water, was blown out, all electrical excitement disappeared; and when condensed air, even at elevated temperatures, was discharged from an insulated fountain, no electricity was produced.

The celebrated physicist of Geneva, Professor De la Rive, refers the electricity of the atmosphere to thermal action. It is well known that if the lower end of a bar of iron, or of any other metal not readily melted, be plunged into a source of heat while the upper end remains cool a current of electricity will flow from the heated to the cooled end, the former becoming negative and the latter positive, and that these different states will continue as long as the difference of temperature is maintained. Now, according to Professor De la Rive, a column of the air is in the same condition as the bar of metal—its lower end is constantly heated by the earth, and its upper cooled by the low temperature of celestial space. Unfortunately, however, for this ingenious hypothesis, a column of air is a non-conductor of electricity, while a bar of metal is a good conductor, and it still remains to be proved that such a distribution of electricity as that we have described relative to the bar of metal can be produced in a column of air.

The foregoing are the principal hypotheses which have been advanced to account for what has been considered the free electricity of the atmosphere. After an attentive study of the whole subject, we have been obliged to reject them all as insufficient, and compelled, in the present state of science, to adopt the only conclusion which appears to offer a logical explanation of all the phenomena, namely, that of Peltier, which refers them not to the excitement of the air, but to the inductive action of the earth primarily electrified.

The author of this theory, we are sorry to say, did not receive that attention which his merits demanded, nor his theory that consideration to which so logical and so fruitful a generalization was justly entitled. Arago, in his great work on the phenomena of atmospheric electricity, does not allude to the labors of Peltier, but perhaps the reason of this is that this work was not intended as a scientific exposition of the principles of the phenomena, but merely a collection and classification of observed facts.

Peltier commenced the cultivation of science late in life, and, since the untutored mind of the individual, like that of the race, passes through a series of obscure and complex imaginings before it arrives at clear and definite conceptions of truth, it is not surprising that his first publications were of a character to command little attention, or, indeed, to excite prejudice, on account of their apparent indefinite character and their want of conformity with established principles. His theory of atmospheric electricity requires to be translated into the ordinary language of science before it can be readily comprehended even by those best acquainted with the subject, and hence his want of appreciation may be attributed more to the peculiarities of the individual than to the fault of the directors of the science of the French Academy.

According to the theory of Peltier, the electrical phenomena of the atmosphere are entirely due to the induction of the earth, which is constantly negative, or what, in the theory of Du Fay, is called resinous. He offers no explanation, as far as we know, of this condition of the earth, which, at first sight, would appear startling, but, on a little reflection, is not found wanting in analogy to support it. The earth is a great magnet, and possesses magnetic polarity in some respects similar to that which is exhibited in the case of an ordinary loadstone or artificial magnet. This magnetism, however, is of an unstable character, and is subjected to variations in the intensity and in the direction of its polar force. In like manner we may consider the earth as an immense prime conductor negatively charged with electricity, though its condition in this respect may, like that of its magnetical state, be subject to local variations of intensity, and perhaps to general as well as partial disturbance. It may be said that this merely removes the difficulty of the origin of the electricity of the atmosphere to an unexplained cosmical condition of the earth, but even this must be considered an important step in the progress of scientific investigation. The hypothesis of Peltier has since his death been rendered still more probable by the labors of Sabin, Lloyd, La Mont, Bache, and others, in regard to certain perturbations of the magnetism of the earth, which are clearly referable to the sun and moon. It must now be admitted that magnetism is not confined to our earth, but is common to other, and, probably, to all the bodies of our system; and, from analogy, we may also infer that electricity, a coördinate if not an identical principle, is also cosmical in its presence and the extent of its operation. That the earth is negatively electrified was proved by Volta at the close of the last century. For this purpose he received the spray from a cascade on the balls of a sensitive electrometer; the leaves diverged with negative electricity.

This experiment has been repeated in various parts of the globe, and always with the same result. That it indicates the negative condition of the earth is evident, when we reflect that the upper level from which the water falls must be considered as the exterior of the charged globe, and hence must be more intensely electrified than points nearer the center. Since the earth is, as a whole, a good conductor of electricity, as shown by the operations of the telegraph, the electrical tension of it cannot differ much in different parts, and we are at present unacquainted with any chemical, thermal, or mechanical action on land of sufficient magnitude to produce this constant electrical state. We are therefore induced to adopt the conclusion that the earth, in relation to space around it, is permanently electrical; that perhaps the ethereal medium, which has been assumed as the basis of electricity, as was supposed by Newton, becomes rarer in the vicinity and within bodies of ponderable matter. Be this as it may, all the phenomena observed in the atmosphere, and which have so long perplexed the physicist, can be reduced apparently to order, and their dependencies and associations readily understood, in accordance with the foregoing assumption. This is not a mere vague supposition, serving to explain in a loose way certain phenomena, but one which enables us not only to group at once a large class of facts which, from any other point of view, would appear to have no connection with each other, but also to devise means for estimating the relative intensity of action, and to predict, both in mode and measure, changes of atmospheric electricity before they occur. It follows, as a logical consequence from this theory, that salient points, such as the tops of mountains, trees, spires, and even vapors, if of conducting materials, will be more highly excited than the general surface of the globe, in a manner precisely similar to the more intense excitement of electricity at the summit of a point projecting from the surface of the prime conductor of an ordinary electrical machine.

It also follows, from the same principle, that if a long metallic conductor be insulated in the atmosphere, its lower end, next the earth, will be *positive*, and the upper end *negative*. The natural electricity will be drawn down by the unsaturated matter of the earth into the lower end of the wire, which will thence become redundant, while the upper end will be rendered negative, or under saturated. That this condition really takes place in the atmosphere was proved in a striking manner by the experiment of Guy Lussac and Biot, in their celebrated ærial voyage, which consisted in lowering from the balloon an insulated copper wire, terminated at each end by a small ball. The upper end of this was found to be negative, and consequently the lower end must have been positive, since the whole apparatus, including the balloon, was insulated. The experiments should be repeated at different elevations by some of our modern æronauts, since the results obtained would have an important bearing on the theory of atmospheric electricity.

The same results may be shown in a simpler manner by the method invented by Saussure. This consists in attaching a leaden ball to a long wire covered with silk or varnish, connected by means of a

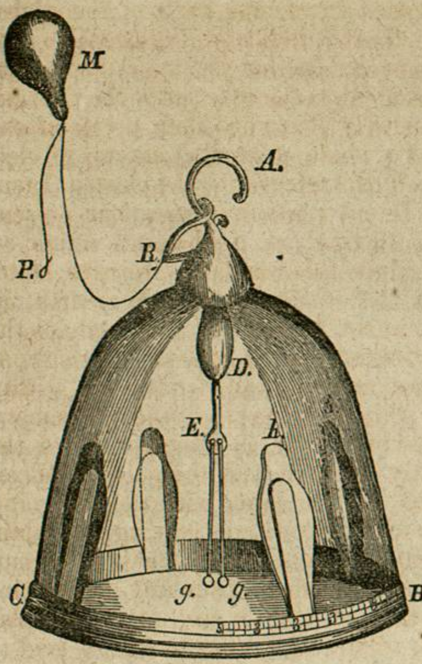

Fig. 12.

slight spring to the hook of an electrometer. When this bulb is thrown upward so as to rise to a considerable height in the air, by means of a string and handle *p*, the wire is disconnected from the electrometer, and the pith balls of the latter diverge with positive electricity. That this effect is not due to the friction of the bulb and the air, is shown by whirling it in a horizontal circle round the head—not the least sign of electricity in this case will be exhibited; and that it is not charged by absorbing free electricity from the air is proved by the fact that when the ball is thrown horizontally no excitement is manifest. The result is, however, just such as would be produced by the induction of the earth acting on the natural electricity of the wire and drawing it down to its lower extremity. A precisely similar effect would also be produced if the upper surface of the atmosphere were charged with this electricity. The intensity of the charge which the electrometer receives will depend upon the elevation to which the ball ascends, or, in other words, on the perpendicular component of the wire.

The method employed by Saussure in observing the variations of the electricity of the atmosphere,


Fig. 13.


Fig. 14

illustrates the same principle. For this purpose he made use of one of his own electrometers, which is shown in Fig. 12. It consists of a bell-glass with a brass stem, D E, surrounded with sealing-wax, and two small pith balls, *g g*, suspended by very fine wires. C B is a metallic foot, and *h h* slips of tin-foil pasted on the inside and outside of the glass to discharge the pith balls when the electricity is so strong as to cause them