the writer of this article adopted during his electrical investigations at Princeton.

The roof of the house which he occupied in the college campus was covered with tinned iron, and this covering was therefore in the condition of an insulated plate, on account of the imperfect conduction of the wood and brick-work which intervened between it and the ground. To one of the lower edges of this covering was soldered a copper wire, which was continued downwards to the first story and passed through a gimlet-hole in the window-frame into the interior of the author's study, and was then passed out of the lower side of the same window, and thence into a well, in which it terminated in a metallic plate below the surface of the water. Within the study the wire was cut in two, and the two ends thus formed were joined by a spiral of finer wire *a* covered with silk thread. Into the axis of this spiral a large-sized sewing-needle *d* was inserted, the point having been previously attached to a cork, which served as a handle for removing it. With this arrangement, the needle was found to become magnetic whenever a flash of lightning was perceived, though it might be at the distance of several miles. The intensity of magnetism and the direction of the current were ascertained by presenting the end of the needle to a small compass represented by *c*. In several instances the inductive action took place at such a distance that, after seeing the flash, the needle was removed, its magnetic condition observed, and another needle put in its place, before the noise of the thunder reached the ear. In this experiment, the inductive action of the electrical discharge in the heavens was exerted on the natural electricity of a surface of about 1,600 square feet, and a considerable portion of this passed down through the wire into the well. The arrangement served to indicate an action which would otherwise be too feeble to produce sensible effects.

It must be observed that the effect here described was not produced by the actual transfer of any electricity from the cloud, but was simply the result of induction at a distance, and would probably have been nearly the same had the intervening space been filled with glass or any other solid non-conducting substance. We say probably, very nearly the same, because Mr. Faraday has shown that the inductive effect at a distance is modified by a change in the intervening medium.

It is also proper to mention, in this place, although we cannot stop to give the full explanation of the means by which the result was obtained, that the electricity along the wire was not that due to a single discharge into the well, but to a series of oscillations up and down in alternate directions, until the equilibrium was restored.

ELECTRICITY IN MOTION.

The phenomena we have thus far described relate principally to electricity at rest. Those which relate to ordinary or frictional electricity in motion have not been so minutely investigated as the other class, and present much more difficulty in ascertaining the laws to which they are subjected. The discharge of electricity from the clouds, or from an ordinary electrical machine, is so instantaneous that we are principally confined in our investigations to the effects which remain along its path after its transfer.

The electricity, however, which is developed by chemical action in a galvanic battery, is of sufficient quantity to produce a continuous stream, or at least a series of impulses in such rapid succession that they may be considered continuous. By employing electricity of this kind, it has been supposed that we can study the fluid while it is actually in motion, and from the results deduce inferences as to the mode in which some of the effects are produced in the discharge of frictional electricity. The two classes of phenomena, however, though referable to the same cause, are, in many respects, so different in character that considerable caution is required in regard to inferences from analogy. The phenomena of ordinary electricity are characterized by an intensity of action which indicates a repulsive force between the atoms of the hypothetical fluid, which, in some way is, at least, partially neutralized in the case of galvanism.

Ordinary electricity in a state of equilibrium appears to produce but a very feeble effect upon bodies in which it is accumulated. However great may be the quantity present, no perceptible effect is perceived in the pulse when a person is insulated on a glass stool, and charged either positively or negatively, so long as the electricity remains at rest. If, however, it is drawn from him in the form of a spark, then a disagreeable pricking sensation is experienced at the point of rupture. Dr. Faraday constructed a small metallic house or room, which he suspended by silk ropes in mid air, and charged it so strongly that long sparks could be drawn from the outside, yet not the least effect was perceived by the persons within; even when the air of the interior of the house was strongly electrified, the excitement was only perceptible on the outside.

It is fully established by the most satisfactory experiments that, in all cases in which a discharge of electricity takes place by breaking through a stratum of non-conducting substance like air, there is an actual transfer of matter each way between the two ends or sides of the opening in the conductor along the path which the spark traverses. If an opening be made in a rod, and each end terminated by a brass ball, one of which is covered with gold leaf, and the other with silver, a transfer in opposite directions of these two metals will be observed. A similar effect is produced in the discharge of lightning from the clouds, and there are several well authenticated cases on record, in which a picture as it were of one body has been impressed on another between which the electrical discharge took place.

Another effect produced by the discharge which has an important bearing upon the explanation of some of the mechanical results of electricity, is a sudden and violent repulsive energy given to the atoms of air and other substances through which it passes, and which causes them to separate with an explosive violence.

This may be shown by transmitting a discharge from an electrical battery between two brass balls projecting into the inside of a glass bulb, to the lower side of which is joined an air-tight tube containing a small quantity of water, and opening at the end into a cup of water, the arrangement with the exception of the balls being similar to that of an air thermometer. The moment the discharge takes place, the water will be driven down the tube, exhibiting a great enlargement of the volume of air in the bulb. This experiment was communicated by Mr. Kinnersley, of Philadelphia, to Dr. Franklin. The effect was attributed at first to heat produced by the discharge of electricity through the air in the bulb, but although there is heat evolved in this case, as is proved by the fact that if a number of sparks be passed in succession, the water does not return to its first altitude, and thus indicates an increase of temperature, yet the principal cause is evidently due to the sudden repulsive energy given to the air at the moment of the passage of the discharge, as may readily be shown by inclosing a thermometer within the bulb. The increase of temperature which this indicates, will be far too small to account for the great and sudden expansion produced. A similar exhibition of force is exhibited when a strong discharge of electricity is passed through a vessel like the one we have described, filled with water. In this arrangement a thick glass bulb may be broken with violence into pieces.

The mechanical effects produced by lightning must be attributed principally to this cause. When a powerful discharge from a cloud passes through a confined space filled with air, and surrounded by partial non-conductors, a tremendous energy is exerted. In the case of a house examined by the writer of this article, the discharge fell upon the top of a chimney at the west end of the building and passing through a stovepipe hole, traversed the space under the rafters called the cockloft, to the chimney at the east end, and thence down to the ground; the force exerted was sufficiently great to lift up the whole roof from the top of the walls on which it rested. In like manner, when the discharge takes place along the upright timbers of a house, the clapboards are frequently blown off outwards, and the plaster inwards, as if by the explosion of gunpowder.

We must ascribe to a similar action the splintering of trees by lightning. At the moment of the passage of the discharge, the sap or moisture is suddenly endowed with a repulsive energy which resembles in its effects the action of an explosive compound, separating the fibers longitudinally, and projecting parts of the body of the tree to a distance. When a tree is struck by lightning the greatest effect is usually produced on the main stem just below the branches. A portion of the discharge appears to be received on each twig, leaf, and branch, and the whole concentrated by converging towards the trunk. The repulsion imparted to the atoms of a conductor is in some cases sufficiently great to dissipate at once in vapor, fine metallic wires, and this so instantaneously that the silk covering by which they are surrounded for telegraphic purposes is not burned.

The repulsive energy is not alone exerted laterally, but, perhaps, in a greater degree in the line of direction of the conductor, tending to separate it as it were, by transverse sections. Hence, when electricity passes through a wall into the interior of a house, a pyramidal mass of plaster is thrown out; a similar effect is frequently produced when the discharge takes place between the cloud and the level earth; a large conical or pyramidal hole is formed, from which the earth is thrown out as if by the explosion of a quantity of powder beneath the surface. Such excavations are supposed by some to indicate a discharge of electricity from the earth to the cloud, but no conclusion of this kind can, with certainty, be drawn from the phenomena. It simply indicates an intense repulsive energy exerted between the atoms of matter in the line of the discharge. It sometimes happens, when an old tree, which, perhaps, has been moistened by the rain, is struck by lightning, instead of being rent laterally, it is broken off transversely, the upper part being projected vertically upward. This effect, however, is not usually produced, since the force exerted by the tree to resist transverse breaking is generally much greater than that to prevent lateral tearing apart.

In the passage of electricity from a charged conductor, or from a cloud to the earth, it always follows the line of least resistance, and by an antecedent induction, determines the course it is to pursue. This is strikingly exhibited by an experiment devised by Sir W. S. Harris. A number of separate pieces of gold leaf are attached to a sheet of paper. If a discharge sufficiently strong to dissipate the gold and blacken the paper be passed through them, its course will be shown by the blackened parts; and it is especially worthy of remark, that not only are the pieces out of the line of least resistance untouched, but even portions of other pieces are left unchanged from the same cause. Now, these separate pieces of gold leaf may be taken to represent detached conductors fortuitously placed in the construction of a building.

The apparently fitful course of a discharge in its passage through a building frequently excites surprise, leaping, as the electricity does, from one conductor to another, and sometimes descending to the earth in several streams; but that the discharge should leap from one conductor to another, through a considerable intervening space of air, is not surprising, since its original intensity was sufficient to enable it to break through a stratum of the atmosphere of perhaps a mile in thickness before it reached the house.

Whenever electricity passes through an interrupted conductor so as to exhibit the appearance of light, a great increase of intensity is always manifested at the point of disruption, as if the charge halted here for a moment until a sufficient quantity of the fluid could accumulate to force its passage through the obstacle. An illustration of this action is presented in the fact, that at the point where the lightning leaves a conductor, and also where it is received by another conductor, signs of fusion or of more intense action are always exhibited. An effect of lightning described by Professor Olmsted, at a meeting of the American Association, in New Haven, may be explained on this principle: A row of five or six milk pans, placed in the open air on a bench, was struck by a discharge from a cloud. The electricity passed through the whole series, making two holes in each at opposite extremities of the diameter, or at the places where the electricity may be supposed to have entered and gone out.

There is another circumstance connected with the discharge of electricity having an important bearing on the construction of lightning-rods, which may be mentioned in this place. When the repulsion of the atoms of electricity in a conductor or in a cloud, and the attraction of the unsaturated matter below, become so intense as to cause a rupture in the air, the electricity of the cloud is precipitated upon the conductor, and not only restores the natural quantity, but also gives it for a moment a redundancy of electricity, a fact which must be evident from the theory, when we consider the distance at which the induction is communicated. As this charge of free electricity, for example, passes down the rod to the earth, it assumes, as it were, the form of a wave, rendering the metal negative in advance; and thus, in the transmission of free electricity through a rod of metal, the action consists of two waves, one of redundant electricity, immediately preceded by one of deficiency. Hence, if a small ball, connected with the earth by a wire, be brought near a conductor, for example, a lightning-rod, on the upper end of which discharges of electricity are thrown from an electrical machine, sparks may be drawn from the rod, however intimately it may be connected with the earth below.

This effect was strikingly exhibited by an experiment instituted by the author of this paper, which consisted in plunging one end of a copper wire, a tenth of an inch in diameter, beneath the water of a well, and throwing sparks of electricity from a globe of a foot in diameter on the upper end, which was terminated by a small ball. Although in this case the conductor was as perfect as possible, yet sparks sufficiently intense to explode the oxy-hydrogen pistol were obtained throughout the whole length of the wire.

This effect was not due, as some have supposed, to the tendency of the electricity to seek another passage to the earth, as may be shown by catching the spark in a Leyden jar; but it was solely the effect of a transient charge of electricity passing along the surface of a conductor from one extremity to the other.

The phenomena may be expressed generally by the statement that, when electricity is thrown, as it were, explosively, by a disruptive discharge through the air, on the end of an insulated conductor, it does not pass silently to the earth, but tends, in part, to be given off in sparks to all surrounding bodies. It is on this account that we object to the otherwise admirable arrangement of Sir W. Snow Harris for the protection of ships from lightning. Though the main portion of the discharge of electricity is transmitted innoxiously to the ocean by means of the slips of copper which are carried down along the mast, and through the bottom of the vessel to the sheathing beneath, as proposed by him, yet we consider it safer to conduct it across the deck, and over the sides of the vessel to the copper sheathing.

It is true, the quantity which tends to fly off laterally from the rod, is small, yet we have shown, by direct experiment, that it is sufficient, even when produced by the electricity of a small machine, to set fire to combustible materials; and, therefore, it cannot be entirely free from danger in a ship, for example, loaded with cotton.

The atoms of electricity, in their transfer from one body to another, still retain their repulsive energy; and, if the discharge be not very large in proportion to the size of the conductor, it will principally be transmitted at the surface.

If the charge be very large, and the conductor small, it will probably pervade the whole capacity, and, as we have seen, in some cases, will convert into an impalpable powder or vapor the solid particles. Because electricity in a state of rest is found disturbed at the surface of a body, it was immediately assumed, without examination, that electricity in motion passed along the surface; but this conclusion was supposed to be disproved by the fact that the conducting power of a wire for galvanic electricity is in proportion to the area of the cross section, from which it follows that this kind of electricity pervades the whole mass of the conductor. But galvanic electricity differs from common electricity, apparently in the exertion of a much less energetic repulsion, and in a greater quantity developed in a given time. The deduction, therefore, from the experiments with galvanism can scarcely be considered as conclusive in regard to frictional electricity.

To settle this point, the author of this paper instituted a series of experiments, which conclusively proved the tendency of electricity of high tension, that is of great repulsive energy, to pass along the surface. It will be sufficient to give as an illustration of this fact, the result obtained by the arrangement represented in Fig. 11, in which A B is

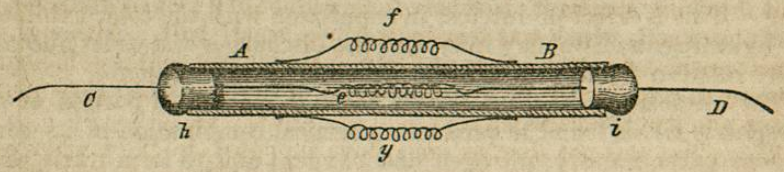

Fig. 11.

a copper wire, one of the best conductors of electricity, of the size usually employed for ringing door-bells, passing through the axis of an iron tube, or a piece of gas-pipe, about three feet long. The middle of this wire was surrounded with silk, and coiled into a magnetizing spiral, into which a large sewing needle was inserted. The wire was supported in the middle of the tube by passing it through a cork at each end, covered with tin-foil, so as to form a good metallic connection between the copper and the iron. *f* and *g* are two other magnetizing spirals of iron wire, on opposite sides of the tube, the ends soldered to the iron. When these two spirals were also furnished with needles, and a discharge from a Leyden jar sent through the apparatus, as if to pass along the wire, the needle inside of the iron tube was found to exhibit no signs of magnetism, while those on the outside presented strong polarity. This result conclusively shows that, notwithstanding the interior copper wire of this compound conductor was composed of a material which offered less resistance to the passage of the charge than the iron of which the outer portion was formed, yet when it arrived at the tin-foil covering of the cork, it diverged to the surface of the tube, and still further diverged into the iron wire forming the outer spirals. We must not conclude, however, from this experiment that the electricity actually passes on the outside of the tube. On the contrary, we must infer from the following fact, that it passes just within the surface. If the iron be coated with a thin covering of sealing-wax, the latter will not be disturbed when a moderate discharge 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,