may be produced of great length by much smaller electric force than is necessary to produce the same length of discharge in the case of ordinary thunder-storms; for my apparatus will produce sparks of thirty or forty feet in length at a low pressure of the air, while the same character of spark only six or seven feet in length is produced in air at ordinary atmospheric pressure. When such discharges are excited in glass vessels from which the air is still more exhausted, the zigzag, dazzling spark merges into the pink glow which is characteristic of the northern lights, and we may form some conception of the nature of these lights, and of the tenuity of the air in which they arise. They may be conceived as an evidence of electrical storms at great heights.

The study, therefore, of powerful electrical discharges will undoubtedly increase our knowledge of the character of lightning discharges, and add to our knowledge of meteorology. I confess that my respect for their manifest energy constantly increases. It is fortunate that we rarely, if ever, are visited by their full power.

THE PROTECTION OF ELECTRICAL APPARATUS AGAINST LIGHTNING.

BY ALEXANDER JAY WURTS,
Of the Westinghouse Electrical Company.

OUR subject deals largely with the static spark. In the lightning-stroke we see it in its grandest and most powerful form. A step or two across a thick carpet on a dry winter's day, and the spark which may be produced is so small as to be almost invisible. Benjamin Franklin with a key drew static sparks from his kite-string. The lightning and the spark are the same in character, the difference being simply one of degree; moreover, the little snap of the tiny spark differs only in degree from the splitting crash of the lightning-flash.

The static spark, or disruptive discharge, as it is often called, has many interesting characteristics quite different from the ordinary electric current found in our lighting and trolley wires. The latter is a constant and comparatively gentle force which is easily controlled, like the force of wind or of flowing water. The disruptive discharge is sudden and violent, more like the flight of a bullet or the blow of a hammer. It is not easily controlled, and it obeys laws which are but imperfectly understood. The static spark is not, as is commonly supposed, a simple passage from one point to another; it is oscillatory; it surges back and forth with inconceivable rapidity. In lightning-flashes about twelve oscillations may be observed, the time interval being reckoned at about the one hundred thousandth part of a second. The oscillatory character of the discharge gives rise to remarkable phenomena, which are the immediate cause of many idiosyncrasies or lightning freaks.

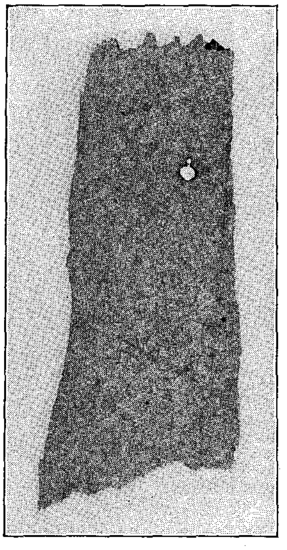
Those characteristics which more particularly concern us are:

(1) That of surging, already mentioned; (2) that of self-induction, which is a result of surging; (3) that of "side-flash," or selection, this being a result of self-induction; and (finally) that of penetration.

Self-induction is a property which gives rise to a counter-force or choking effect. It is dependent on the oscillatory character of the discharge, and exists to a considerable degree in straight wires, but is vastly more pronounced in coils. Coils of wire, therefore, when used in connection with static discharges, are called choke coils.

Side-flash, the result of self-induction, is commonly called a freak. A disruptive discharge will often leave what would ordinarily be called an excellent conductor and side-flash through the high resistance of the atmosphere to other objects. For example, a disruptive discharge, rather than pass through a coil of bare copper wire, will take a short cut, and jump from one convolution to the other, although, as electrical resistance is ordinarily understood, the path through the copper wire offers an incomparably lower resistance than any single one of the air-spaces between the convolutions. And then, a lightning-flash will not infrequently strike some good conductor, such as a lightning-rod, follow it for a short distance, and then side-flash, selecting its own path through a wall of brick or stone to a neighboring gas-pipe or bell-wire. Ordinarily we should say that the lightning conductor would not offer a fraction of the resistance offered by a stone wall. It is self-induction which, giving rise to a counter-force or choking effect, causes the discharge to side-flash.

The penetrating power of the discharge is the bugaboo of electricians. The lightning-flash literally bores a hole through the atmosphere, just as a bullet would bore its way through a mass of jelly. Smaller discharges will pass through shorter distances of air. Solid insulating materials are also more or less easily punctured. The discharge brought about by stepping over a thick carpet, as already described, would pierce a sheet of thin paper, whereas sparks from an engine-belt might easily bore a hole through this magazine. If Franklin had held a piece of glass between his key and the kite-string, it is probable that the sparks would have readily pierced the glass with small round holes.



PIECE OF PAPER PERFORATED BY STATIC DISCHARGES FROM THE TROLLEY WIRES OF THE DENVER TRAMWAY CO., COL.

During thunder-storms the atmosphere, and all conducting objects in the immediate neighborhood, become charged with electricity at a constantly increasing potential or intensity as we recede from the earth. At the top of the Washington Monument a potential of three thousand volts has been measured, and at the top of the Eiffel Tower ten thousand volts. Even objects directly on the earth, such as railroad tracks, wire fences, etc., become charged, and in the high altitudes of our western country wet rocks will frequently show signs of electrostatic charge. All such charged objects will spark, and the phenomena above described will in every case be more or less plainly visible.

Now, overhead wires, like the objects already mentioned, become charged during thunder-storms, but the wires themselves are rarely struck by lightning. If they were placed in a vertical position, reaching from the earth toward the clouds, then the lightning would in many cases strike the wires and follow them into the earth. But there is no electrical reason why lightning should pay any especial attention to a horizontal wire, nor does the fact that a wire may be carrying ordinary electric current render it any more liable to atmospheric electric disturbance. Overhead wires then become charged with static electricity, and will spark. These sparks are very penetrating, and will bore through insulating materials of high resistance. A wire thus charged is also liable to side-flash; that is, sparking is liable to occur at one place or another without apparent reason. A reason, of course, exists; but, unfortunately, the explanation of it serves only to show the impossibility of predetermining the point or points at which the discharge will take place. When a lightning-flash occurs, all electrified bodies in the neighborhood undergo a tremendous shaking up, as it were. A new condition of electric equilibrium is at once established, and during this readjustment electric waves are set up in overhead wires, which travel with inconceivable rapidity from end to end, and which, being reflected, interfere with one another very much as water waves do. For example, if a trough of water were raised at one end, and then quickly lowered, the water in the trough would quietly surge back and forth; but if the end of the trough be raised a second time, a new system of surging may be started in such a manner that the two will interfere with each other, and cause splashing at certain points where crests of the two systems combine to form other crests. Calm or smooth surfaces will be noticed at points where a crest of one system has been neutralized by a trough of the other system. In electric wires we have somewhat analogous conditions during thunder-storms; we have what a sailor would call a "choppy sea." It will thus be seen how impossible it would be to predetermine the points at which electric splashing or side-flash would be likely to occur.

With a word or two now about the construction of electrical apparatus, we shall be in a position to understand the particular danger which threatens electric systems during thunder-storms; also the means employed for avoiding this danger.

In general, and as far as our present purpose is concerned, electrical apparatus may be said to consist of coils of insulated copper wire and iron cores placed within the coils. There are, then, three materials present—iron, insulation, and copper. The iron is usually grounded—that is, connected with the earth. The copper is in contact with the overhead wire; it is electrically a part of it, and the insulating material, which may be of shellacked muslin, fiber, hard rubber, mica, or any similar material, serves to separate the copper from the iron. It serves to confine the current to the copper, forcing it to pass through the convolutions of the coil rather than allow it to take a short cut through the iron, which it would certainly do if the insulating material were not present. Now, during thunder-storms the static or disruptive discharge, in side-flashing from one point or another of the copper wire, frequently perforates the insulating material, establishing thereby electrical communication between the copper and the iron, and through which opening the dynamo current will follow the spark, causing in an instant a destructive and intensely hot electric arc, which will quickly reduce both copper and iron to a blackened mass.

In telephone and telegraph circuits the current is not ordinarily powerful enough to follow the disruptive discharge through the insulation; nevertheless, the discharge itself is quite sufficient to damage the instrument seriously, and interrupt the service.

Having thus far described some of the important phenomena which are associated with electric systems during thunder-storms, and having also shown how electric apparatus may be damaged thereby, we will now consider the means which have been devised for protecting such apparatus.

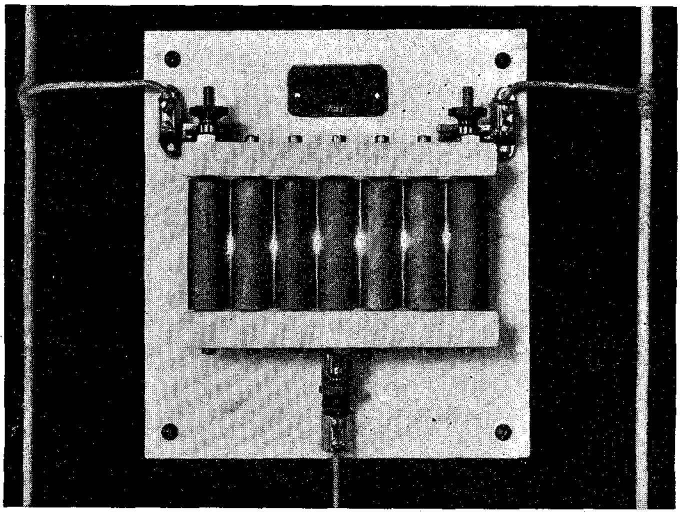
The instruments used for this purpose are called "lightning-arresters" and "choke-coils." A choke-coil is simply a coil of insulated wire. It may, however, have special forms. A lightning-arrester, in its simplest form, consists of two pieces of metal placed about one thirty-second of an inch apart, the space between them being called a "spark-gap." When in service, one of these pieces of metal is connected with the overhead wire to be protected, the other with the earth. During thunder-storms the static charges are expected to jump over the spark-gap of a lightning-arrester,—that is, side-flash at that point,—and so pass to earth, rather than perforate the insulation of the system. If Franklin had held a sheet of paper between his key and the kite-string, and if a second person had placed a second key in closer proximity to the string than Franklin's key, nearly all the sparks would have passed or have been diverted to the second key. The paper would perhaps not have been perforated at all; the second key would have protected the paper, and could properly have been called a protector or diverter. To-day a similar device is called a "lightning-arrester," which name is obviously a misnomer.

If we strip an electric installation of all its mechanical features save those which immediately concern our subject, we shall find Franklin's kite-string corresponding to the copper, the sheet of paper to the insulating material, and the key to the iron.

A lightning-arrester as above described in its simplest form, while it allows the spark to pass, will also allow the dynamo current to follow the spark, and thereby establish a short circuit, which means an enormous flow of current, a dangerous arc, and possible danger from fire; and, further, by reason of the selective character of discharges,—that is, the tendency to side-flash at one point or another, according to the conditions of our electric "choppy sea,"—the discharge does not always pass over the spark-gap of the arrester; very often it will quite ignore this spark-gap, and pass on to do its destructive work in the electrical apparatus. The latter difficulty is avoided to a very great extent by placing a considerable number of lightning-arresters along the wire, thereby multiplying the opportunities for discharge. The danger to the apparatus is also very much lessened by connecting choke-coils in the wire between the apparatus and the arresters. The coils, then, by virtue of their inductive resistance, tend to choke the discharge back, and force it over one or more of the lightning-arrester spark-gaps. However, should the insulation of the apparatus be weak or defective, the discharge will surely find it out, in spite of all the lightning-arresters and choke-coils that might be employed. In this respect the manufacturers of light and power apparatus are far in advance of the manufacturers of telephone and telegraph apparatus. The former have apparently made a more thorough and searching study of the problem in all its requirements, whereas the latter seem to have confined their efforts more particularly to the construction of a lightning-arrester having a sensitive spark-gap. It is not likely that material advances will be made in the art of protecting telephone and telegraph apparatus until a better grade of insulation is adopted.

After all, it is the formation of the electric arc at the spark-gap of a lightning-arrester which has probably caused more trouble, more study, and has been the cause of more novel inventions, than all the other details of this problem put together.

A lightning-arrester, to be serviceable, must be capable of discharging the line indefinitely; but the simple form of lightning-arrester which we have described will, when connected to light or power circuits, burn up at the first discharge, unless means are taken to prevent it. In the early days this difficulty was avoided by placing fuses or strips of lead in the lightning-arrester circuit, so that when the electric arc was formed, owing to the passage of the dynamo current, the lead fuse would melt and thereby interrupt the current. But during a thunder-storm it was often a dangerous matter to replace these fuses, so other devices were invented, which had for their object the automatic interruption of the arc, without interfering with the service of the lightning-arrester. These automatic lightning-arresters, however, were generally constructed with moving parts, which were liable to get out of order, and at best they constituted a remedy rather than a preventive. Some of these gave excellent satisfaction for a time; but with the larger currents and higher working pressures of modern light and power plants, it soon became evident that arcs and moving parts were very undesirable features.



A MODERN LIGHTNING-ARRESTER.

The apparatus is shown in operation and protecting two wires. There are no moving parts, and the dynamo arc is suppressed by the use of a certain alloy which has the remarkable property of instantly extinguishing electric arcs.

And so once more the inventors went to work, with the final result that lightning-arresters, as now constructed, have no moving parts, and operate without destructive arcs. In fact, nearly all the difficulties have at last been overcome, and before long it may be that atmospheric electricity, instead of being an enemy, will become a boon to mankind. Is not atmospheric electricity one of the great natural forces? Who can say that it may not some day obey man and do his service?

NEEDLESS ALARM DURING THUNDER-STORMS.

BY ALEXANDER McADIE.

THE year 1753 is memorable in the history of electrical development. The experiments of the colonial philosopher with lightning had awakened a general enthusiasm in the scientific circles of Europe. In at least three capitals philosophers were pressing hard after Franklin, and great activity was shown, when suddenly there occurred in St. Petersburg a mishap which checked the ardor of all investigators, and exerted an influence which has lasted until to-day. During a thunder-storm, while stooping the better to follow the indications of an electrical "gnomon" (in modern phrase, electrometer), Richman met instant death. Coins in his pockets were fused, and many of the tearing and throwing effects associated with high potential, oscillatory discharges were apparent. Richman's companion, standing three feet away, was uninjured, although much damage was done to the doors and woodwork of the room. This escape has been frequently commented upon, but a systematic study of the conditions determining immunity has never been made. The trend of investigation has been in the other direction, and the fatality of lightning has been perhaps unduly emphasized. Voltaire crystallized this