LIGHTNING CONDUCTORS.*

By RICHARD ANDERSON, F.C.S., F.G.S.

ON the present occasion I wish to bring under the notice of the association a few cases of damage resulting to buildings which had lightning conductors attached, which have come under my own observation. The adducing of such cases furnishes the best argument, I imagine, not only for a record being kept of all accidents, but of a regular inspection of buildings which have lightning conductors attached to them.

On the 10th of October, 1878, a furniture repository situated at the back of Victoria Station, Westminster, was struck by lightning, although a conductor was attached to the building. The warehouse, which is built of brick, is 110 ft. by about 80 ft. wide, the roof is flat and covered with lead. At the southeast corner, a slate-covered tower with 4 ft. of iron cresting, rises to the height of 20 ft. above the roof. To this ornamental ironwork a solid copper band lightning conductor, $\frac{3}{4}$ in. broad by $\frac{1}{2}$ in. thick, and weighing 0.43 lb. per foot, was attached. A terminal made of $\frac{5}{8}$ in. diam. copper tube, with three discharging points 6 in. long, screwed into the rod 3 in. from the top, rose 3 ft. above the iron cresting. The rod was attached to the ironwork by means of copper wire, and the band to the slates and brickwork by gun metal clips. The copper was of very good quality, having a conductivity of 92 per cent. The electric discharge fell on the point of the lightning conductor, bending it, driving out two of the discharging points, and twisting the third. The iron cresting was shattered, and considerable damage done to the tower. Part of the discharge was no doubt carried off from the lead roof by the rain water pipes, which were in metallic communication with it. On testing the conductor shortly after the accident, I got no deflection of the galvanometer needle, and on opening out the earth terminal found the conductor carefully insulated in concrete.

On the 10th of June last, lightning struck the point of the conductor at St. Mark's Church, Skelton, slightly bending it, but did no further damage. The conductor was made of $\frac{3}{4}$ in. diam. copper rope, and had a conductivity of 52.50 per cent. On testing the conductor, while rain was falling, I found the resistance to be 600 ohms. The conductor was buried 9 in. among bricks, lime, etc., and carried 15 ft. from the building. On Saturday, the 26th of June, 1880, a heavy thunderstorm passed over South Lambeth, the lightning doing considerable damage to All Saints Church. The building in question, the style of which partakes of the characteristics of the thirteenth century, consists of a nave 92 ft. 6 in. long, 25 ft. wide, and 36 ft. high to the plate level of the roof, a chancel 31 ft. long, 20 ft. wide, and 48 ft. to the ridge, also north and south aisles 13 ft. 3 in. wide. A stone cross 4 ft. high stands on the apex of the west gable, and another of similar size stood 92 ft. 6 in. from it on the east end of the nave, a ridge of red tiles separating them. A $\frac{3}{4}$ in. diam. copper rope conductor, consisting of 49 wires, was attached to the cross on the west gable, a 5 ft. point made of copper tube rising 18 in. above it. On the afternoon of the 10th, lightning was observed to strike the point of the conductor, then dart to the stone cross of the east end of the nave, throwing it down and injuring the roof of the north aisle. On testing the conductor a few days after the building was struck, I found the lightning rod had no "earth" whatever, the rope being simply stuck 2 in. in loose rubbish. The copper was very impure, the conductivity being only 32.10 per cent., or about double that of iron.

In July last, about half-past five in the morning, lightning struck one of the chimneys of Normanhurst Court, near Battle, Sussex, notwithstanding a lightning conductor was attached to it. Normanhurst stands on high land, and commands a magnificent view of the whole channel from the South Foreland to Beachy Head. The buildings are constructed of hard blue stone, roofed with Broseley tiles; and are in the style of the age of Francis I. There were two lightning conductors on the buildings; one on an octagonal tower, which rises from the S. W. angle, having a balcony and a lofty stone spire, about 120 ft. high, the other on the S. E. chimney, which was struck, about 126 ft. distant from the tower. The lightning conductors consisted of 12 copper wires, 15 B. W. G., woven into the form of a band 1 in. broad, and weighing 0.36 lb. per foot. The air terminal, which rose 3 ft. above the chimney coping, consisted of an iron point 12 in. long, covered with a composition which on scraping appeared to be lead; this was attached by means of a coupling joint to a copper tube 6 ft. long, and weighing 0.28 lb. per foot. The copper band was connected to the rod by another coupling joint. The chimney coping consisted of eight ornamental stone pinnacles 3 ft. high and 2 ft. square at the base. The terminal rod was placed on the center of the chimney, and insulated from it. The lightning discharge struck the chimney, destroying three of the pinnacles, which, falling through the roof below, did considerable damage. The air terminal was bent, and the composition on the point melted 3 in. The wires near the terminal point were likewise partly fused, and, on taking out one wire 25 ft. below the terminal rod, I found it so irregular in thickness that it had to be redrawn before the conductivity could be determined. On testing the earth terminal, I could get no deflection of the galvanometer needle, the conductor being buried in dry earth within a stone wall 8 ft. above the fosse, or asphalted area. The conductor on the tower had "good earth." The conductivity of the copper was 80.5.

In my recently published work on "The History and Application of Lightning Conductors," the following cases among others are given:

On the 6th of August, 1878, lightning struck the powder magazine at the Victoria Colliery, Burntcliff, Yorkshire. At the time of the explosion the magazine contained about 2,000 lb. of gunpowder. The magazine was an oblong building of brick, 9 ft. long, 5 ft. wide, and 6 ft. high (internal dimensions), and it had a uniform thickness of three bricks. At the end was a heavy iron door, and at the other a lightning conductor, consisting of a copper wire rope seven-sixteenths of an inch in diameter. The point of the terminal rod was about 13 ft. above the top of the building, and a similar length was carried into the ground, and terminated in clayey soil at a depth of 3 ft. The conductor was fixed to a pole distant about 2 in. from the end of the building opposite to that in which the iron door was fixed. It was not connected with the iron door in any way. On testing the conductivity of the copper rope it was found to be only 30.2 instead of 93 or 94 per cent. The conductor should not have been insulated, but brought down the pole, carried along the roof down the iron door post, and so into the ground.

In August, 1879, lightning struck one of the pinnacles of the tower of Cromer Church, Norfolk, although on another pinnacle only 27 ft. 6 in. distant, a good copper conductor, having a diameter of $\frac{5}{8}$ of an inch was placed. On testing the conductor by means of a galvanometer, I found it and the earth connection in thorough order. In this case, a point should have been placed on each of the pinnacles, and joined to the main conductor.

In May, 1879, the steeple of the church at Laughton-en-le-Morthen was struck by lightning and damaged. The spire, 175 ft. in height, had attached to it a thin tube made of corrugated copper, about $\frac{7}{8}$ of an inch in external diameter, and $\frac{1}{2}$ internal; the copper being 1.32 of an inch in thickness. It was made in short lengths joined together by screws and coupling pieces, but there was no metallic contact whatever between the pieces, which were much corroded. The conductor was not in contact with the building, but was kept at a distance of $2\frac{1}{2}$ in. by twenty-one insulators. The earth contact was obtained by bending the tube and burying it in the ground at a depth of from 6 to 18 in., the soil being dry loose rubbish, the earth terminal being only 3 ft. It was placed in a corner formed by a double-stem buttress, which came between the conductor and a lead-covered roof attached to the spire; the distance between the conductor and the lead roofing being about 6 ft. 6 in. The lightning appears to have come down the conductor a certain distance, and finding the road to earth bad, it passed through the buttress, dislodging about two cartloads of stone, and then down the cast iron pipes leading from the lead covered roof, and so to earth.

From the instances quoted, it is evident that it is not sufficient merely that rods of copper should be attached to a building, but it is necessary that once put up, they should be regularly inspected to see if they are in good order, so as to be really efficacious. That this is rarely done is one of the main reasons why accidents by lightning occur in places nominally protected by conductors. It is, perhaps, not too much to assert that at present not one in a thousand of our public buildings in England are regularly tested.

There can be no manner of doubt that in the matter of lightning conductors they manage things better on the other side of the Channel than with us. The French Government are in the constant habit of consulting the most eminent scientific men on the subject of protecting public buildings against the destructive influence of lightning. There is scarcely an instance in which a British Government ever did such a thing. It is true the Houses of Parliament had lightning conductors erected upon them at a very great cost and under scientific advice. But all who understand the subject practically agree in saying that it is very doubtful whether the magnificent pile of buildings in which our legislators assemble is really, that is efficiently, protected. At all events, I understand the earths have never been tested since the conductors were erected in 1852. That the Victoria Tower should have been struck in June, 1868, and slightly damaged, tends to show that the conductors at that time were not in an efficient state.

From the examination I have made I am pretty correct in stating that one-half of our cathedrals and three-fourths of our churches have not even nominal protection. For all that science has done, the Queen may any day be killed in her apartments in Windsor Castle, the Prince of Wales in Marlborough House, and the Prince Minister in Downing Street. To see the difference between England and France in this respect, one has but to cross the Channel between Dover and Calais. At Dover there are huge barracks of great length, on the top of high hills, exposed to the full fury of storms sweeping across the Channel, and the few conductors to be found upon them at long intervals are certainly not numerous enough for efficient protection against lightning, and their efficiency has never, so far as I can learn, been tested. The contrast in this respect on crossing the Channel is the most striking. At Calais the Hotel de Ville, in the Grand Place, literally bristles with lightning conductors, and so all the churches and chief buildings in the town. The same all over France, Germany, and Belgium. Without slavishly imitating our scientific neighbors, we might yet bestow some of the care they do upon the protection of our property as well as of our lives against the terrible effects of the electric force.

ON THE PROPER FORM OF LIGHTNING CONDUCTORS.*

By WILLIAM HENRY PREECE.

A LIGHTNING conductor erected for the protection of a building consists of a ribbon, rod, chain, rope, or other mass of metal attached to the highest point of the structure and descending to the earth. What shall be the form of this conductor? has been a vexed question from the days of Franklin to the present. Shall it be dependent on extent of surface or on sectional area? In other words, does the transference of electricity when the potentials are so high as to cause lightning discharges, obey the law of Ohm, or is this modified by the presence of some fresh condition? Snow Harris was a very warm advocate of the surface form. He used flat ribbons for his ships and tubes for his buildings. Henry, of Washington, believed in the efficacy of surface. According to him, frictional electricity passes at the surface, galvanic electricity through the mass. M. Melsens is found on the same side, and Guillemin, of Paris, led many French electricians to favor the same view.

On the other hand, Faraday almost angrily espoused the opposite side. "As respects electrical conduction," said he, "no advantage is gained by expanding the rod horizontally into a strap or tube. Surface does nothing; the solid section is the essential element."

The advocates of the solid and cylindrical form argue that the lightning conductor is simply a path by which electricity is transferred from a point of high potential (an electrified cloud) to a point of lower potential (the earth), and that its efficacy depends solely upon its resistance. It obeys the law of Ohm, and its efficacy is therefore for the same material dependent on its mass and sectional area.

The advocates of surface argue that, as in all cases of static charge electricity exists only on the surface, so when electricity of "high tension" is conducted away it is the surface that plays the prime part, and, therefore, the greater the surface the easier the path to the discharge. Again, they say when a cylindrical conductor conveys a charge of electricity it is raised to a "high tension," and is rendered capable of doing mischief; but with the same charge, the greater the surface the less the density on the surface, and, therefore, the greater the safety. In other words, with a given quantity of electricity, the greater the surface the less the potential. Moreover, they urge, since, according to Guillemin, currents of electricity flowing in the same

direction retard each other with the power varying with the distance separating them, and since a rod may be considered as a bundle of smaller but parallel rods, so a current of electricity may be considered as being made up of many parallel currents, each retarding the other. Hence, a ribbon will conduct better than a rod, because the currents are spread further apart, and retard each other less. These arguments have led to the employment of unsightly ribbons and expensive tubes, which have considerably interfered with the establishment of this very necessary element of safety to buildings.

The arguments in favor of the surface form are, in the opinion of the author, deductions of exploded theories, from imperfect experiments, or from erroneous interpretations of well-ascertained facts. No direct experiments have ever been made to solve the question, as far as the author knows. Quantities of electricity, that is, static discharges from condensers, are in incessant use for telegraphic purposes, and are found to follow exactly Ohm's law, even with the most delicate apparatus. The knowledge of the flow of electricity through conductors, of retarding influence of electro-static capacity upon this flow, and of the distribution of charge, has become so much greater of late years through the great extension of submarine telegraphy and the labors of Sir William Thomson, Clerk-Maxwell, and others, that I question if any English electrician would now be found to argue in favor of the surface form. Nevertheless, ribbons and tubes still continue to be used, and it appeared very desirable to settle the question experimentally. I determined to try and do so.

FIRST EXPERIMENTS, JUNE 28, 1880.

Dr. Warren de la Rue, who is always ready to place his splendidly-equipped laboratory at the service of science, not only allowed me to use his enormous battery and his various appliances, but aided me by his advice, and assisted me in conducting the experiments.

Copper conductors, 30 feet long, of precisely the same mass, (a) drawn into a solid cylinder, (b) made into a thin tube, and (c) rolled into a thin ribbon, were first of all obtained. The source of electricity was 3.24 chloride of silver cells. The charge was accumulated in a condenser of a capacity of 42.8 microfarads. It was discharged through platinum wire of 0.0125 diameter, of different lengths. The sudden discharge of such a large quantity of electricity as that contained by 42.8 microfarads raised to a potential of 3,317* volts is very difficult to measure. It partakes very much of the character of lightning. In fact, the difference of potential per unit length of air is probably greater than that of ordinary lightning itself. It completely deflagrates $2\frac{1}{2}$ inches of the platinum wire, but by increasing the length of the wire it could be made to reproduce all the different phases of heat which are indicated by the various shades of red until we reach white heat, fusion, and deflagration. Hence the character of the deflagration, which is faithfully recorded on a white card, to which the wire is attached, by its scattered particles, is a fairly approximate measure of the charge that has passed, while the length of wire, raised to a dull red heat, is a better one, for any variation in the strength of the current within moderate limits is faithfully recorded by the change of color.

Experiment 1.—Similar charges were passed through the ribbon, tube, and wire, and in each case $2\frac{1}{2}$ inches of wire were deflagrated. No difference whatever could be detected in the character of the deflagration.

Experiment 2.—Ten inches of wire were taken and similar charges passed through. In each case the wire was raised to very bright redness, bordering on the fusing point, and in two cases the wire broke. In each case the wire knuckled up into wrinkles, and gave evidence of powerful mechanical disturbance. The same wire was not used a second time. No difference could be detected in the effect through the different conductors.

Experiment 3.—Silver wire of the same diameter and length was used, and similar charges transmitted through it. Redness was barely visible, but the behavior of the wire was similar in each case.

The conclusion arrived at unhesitatingly was that change of form produced no difference whatever in the character of the discharge, and that it depended simply on mass.

SECOND EXPERIMENTS, JULY 19, 1880.

As it might be urged that the length of conductor tested was so short, and its resistance so small that considerable variations might occur and yet be invisible, similar lengths (30 feet) of lead—a very bad conductor, its resistance being twelve times that of copper—were obtained, drawn as a wire, made as a tube, and rolled as a ribbon, each being of similar weight.

Experiment 4.—Charges from the same condenser, 42.8 microfarads, but with 3,280 cells, were passed through, and the discharges observed on 6 inches of platinum wire 0.0125 inch diameter, which in each case was heated to bright redness. No variation whatever could be detected, whether the wire, the tube, or the ribbon was used.

Experiment 5.—In order to form some idea as to how closely we could estimate any variation in the character of the discharge, we used a long piece of platinum wire, and adjusted the lengths until we obtained just visible redness; then a diminution of ten per cent. (3 feet) produced a marked change to dull redness, and further excisions raised the temperature to brighter and still brighter red.

The conclusion arrived at was that any change in resistance of five per cent. would have been clearly and easily discernible.

It therefore appears proved that the discharges of electricity of high potentials obey the law of Ohm, and are not affected by change of form. Hence, extent of surface does not favor lightning discharges. No more efficient lightning conductor than a cylindrical rod or a wire rope can, therefore, be devised.

AN ELECTRO-DYNAMIC PARADOX.

By M. GERARD-LESCUYER.

DYNAMO-ELECTRIC machines, of which the Gramme machine is the most common type, are reversible—that is to say, if they are traversed by a current they produce motion, and may serve for the transmission of force. Under similar conditions magneto-electric machines with constant currents possess the same properties. But if the current produced by a dynamo-electric machine is passed into a magneto-electric machine, a novel phenomenon is produced. As soon as the circuit is closed the electro-magnetic machine sets itself in motion, and takes a regular speed in proportion

* Read before Section A of the British Association at Swansea, Aug. 27, 1880.

* Read before the British Association, 1880.

* The electromotive force of the chloride of the silver cell is 1.03 volt.