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No. 434. Read the following Circular memorandum from the Officiating Assistant Secretary to the Government of India, Public Works Department, (Civil Works—Miscellaneous,) to the Governments of Madras, Bombay, Bengal, North-Western Provinces and the Punjab, in the Public Works Department; the Chief Commissioners of Oudh, Central Provinces, British Burmah, Mysore and Coorg, and Assam; the Resident at Hyderabad; the Agents to the Governor-General for Central India and Rajpootana; the Superintendent of Port Blair and Chief Commissioner, Andaman and Nicobar Islands; the Inspector-General of Military Works; the Principal, Thomason College, Roorkee, dated Simla, 30th October 1876, No. 73 :—

IN continuation of Circular No. 32 P W, dated the 1st June last, forwarding a memorandum of the points of information which the Committee of the British Association for the advancement of Science consider important in cases of accident from lightning, the undersigned is directed to circulate, for general information and guidance, a paper by Dr. Mann on the protection of buildings from lightning, which was read before the Society of Arts on the 23rd April 1875.

(Signed) G. F. L. MARSHALL, Captain, R.E.,
Offg. Asst. Secy. to the Govt. of India.

THE PROTECTION OF BUILDINGS FROM LIGHTNING.

By R. J. MAN, M.D.,

President of the Meteorological Society, &c.

IN bringing the subject alluded to in this communication under the notice of the Society of Arts, the author intends to mark the present state of exact science in regard to the matter, and to describe as compactly as may be done, consistent with intelligent and sufficient explanation, the way in which buildings may be most conveniently and certainly secured against damage from lightning.

As, however, it is the purpose of this paper to deal intelligently, rather than dogmatically and prescriptively, with the theme, attention must in the first instance be drawn to certain established principles of electrical science which underlie the explanation that has to be given. This is essentially necessary in this case, because the most absurdly inefficient, and often dangerous, attempts to protect buildings from lightning are continually encountered, and because these constructional blunders can almost always be directly traced to ignorance or misapprehension of simple and well-ascertained electrical laws.

It is a familiar and at the same time an all-important fact, that the electric force is transmitted readily through certain kinds of bodies, such as metals and moist substances, which are therefore termed conductors; and that it is transmitted with comparative difficulty through other substances, such as glass, gutta-percha, and resins, which are called "insulators."

It should be, however, understood that the rigidly scientific interpretation of this difference is, that dissimilar bodies, of whatever kind, vary in the resistance which they offer to the passage of the electrical energy, and that that passage is effected easily and readily when the resistance is small, but slowly and with difficulty when the resistance is great. In strict accuracy there is probably no such thing as an absolute electrical insulator. If a rod of glass and a rod of metal be presented to an excited electric, the electrical charge will escape through both, but very nearly the whole will go through the metal and almost none will go through the glass. The precise proportion that will traverse each will be determined by the relative powers of resistance inherent in the glass and in the metal. The matter is spoken of, in loose terms, as if all the discharge went through the metal and none through the glass; and this answers very well for

purposes of familiar explanation, because the quantity that escapes through the glass is so very trifling, that it is incapable of producing any perceptible mechanical effects.

All forms of electrical machines which are constructed for producing artificial manifestations of electrical force are produced by so arranging insulators and conductors as that the force may be generated on the surface of the insulators, and then collected and conveyed by the conductors in an accumulated form, the conductors that effect the accumulation being in their turn insulated, so that the gathered force may not escape as immediately as it is engendered, and therefore before its mechanical or other obvious effects can be manifested and examined.

But the action of artificial electrical machines is also in a very large degree dependent upon another fundamental law of electrical action which is less easy to explain, but which is of such universal importance that it must be thoroughly understood and indeed be kept constantly in mind, as the great ruling power in most of the phenomena that have next to be considered. The influential law which is here alluded to is the one which is involved in all that is recognised as "electrical induction." Whenever an insulated conducting body is brought near to another electrically excited body, but in such a way as that it is not in actual contact with it, the insulated conductor immediately shows signs of being as it were sympathetically affected by the mere presence of the excited body. When the excited body is withdrawn, the sympathetically-aroused excitement in the insulated conductor subsides; when it is brought back into close neighbourhood, the excitement immediately returns. This is what is called "induced electrical action," or "induced electricity."

The effect is very easily shown, in a suitably dry atmosphere, by placing an insulated conductor near to, and not in contact with, the excited prime conductor of an electrifying machine, and then taking the induced electricity from the separate conductor by means of a small carrier of copper foil, fixed upon the end of a glass or ebonite handle, and communicating the charge to the cap of a gold-leaf electrometer. The leaves of the electrometer immediately diverge, manifesting the presence of the electric force that is communicated to them. The experiment may be very pleasantly varied by making a living human body the seat of the inductive disturbance, if an operator stands upon a glass-legged stool with the finger of one hand touching the cap of the gold-leaf electrometer, and with the other arm stretched out so that an assistant can bring a long well-warmed glass jar that has been rubbed with silk and amalgam, and in that way electrically excited, over the extended arm and about a quarter of an inch away from it. Electrical disturbance is immediately produced inductively in the body of the operator, and made manifest by the divergence of the gold leaves of the electrometer; and the divergence is produced and subsides over and over again as the excited glass jar is brought near to the arm, or is taken away. The explanation which science offers of the very remarkable phenomenon is to the effect that the insulated conductor has intrinsically mixed up with its own molecules two distinct kinds of electrical influence, be that what it may, whether essentially a specific molecular condition, as is most probable, or some superadded and, so called, imponderable agency, and that these two kinds of electrical force are quiescent and inappreciable so long as they are equally balanced, and as it were united throughout the entire superficial mass of the conductor, but that they become operative and appreciable whenever the two kinds are torn apart and held asunder. The mere approach of the excited body effects this disturbance of the natural quiescent state, and this tearing asunder, and one of the kinds is then accumulated at one end or side of the conductor, and the other kind is collected at the opposite end or side. There is a neutral point nearly midway between, but nearer to the end that is towards the exciting body, at which no electrical influence of either kind is manifested. If the exciting body is itself positively or vitreously electrified, the end of the excited body which is nearest to it is negatively excited, and the opposite end is positively excited; the terms positive and negative being here understood simply as convenient terms invented to distinguish the two different kinds of electrical state or force.

The test of induced electricity, viewed in contradistinction to a communicated charge, is virtually that the state is called up and removed merely by the nearness and withdrawal of an

electrically-excited body. If a charge of electricity were communicated from an excited body by a momentary contact, the electrical condition would continue in the insulated conductor after the exciting body was taken away, instead of instantly disappearing as it would in the case of induced action. Also the same kind of electrical force could then be found at both ends and all over the insulated conductor.

But here there arises a very curious, and again most important, consideration. Under the circumstance of electrical excitement being called up in an insulated conductor by the near approach of an electrically excited body, the opposite ends manifest opposite electrical conditions, and on the removal of the excited body the induced action disappears. If, however, when the disturbance has been inductively produced, the insulated conductor is momentarily touched at the far end by another conducting body in contact with the earth, as the finger of an operator, the inductively separated force belonging to the insulated conductor, which is of the same kind as that of the exciting body, rushes off to the earth; and then when the exciting body is removed the insulated conductor does not return, as it would otherwise have done, to its natural and quiescent state, but manifests an electrically excited condition all over its surface of a kind opposite to that of the exciting body. It behaves, indeed, in all particulars as it would have done if an actual charge of that opposite kind of electrical force had been communicated to it by contact with a similarly excited body.

When the glass cylinder or disc of an electrical machine is positively excited by friction against the rubber, the metal points, which are in metallic communication with the insulated prime conductor, and therefore the conductor itself, become inductively electrical. The negative electricity of the inductively disturbed conductor flows off from the points to the glass to saturate its positive disturbance, and the prime conductor is consequently left overcharged with its own abandoned positive force. That is the explanation of the way in which streams of positive electricity are generated in the prime conductor of a machine by continuously rubbing its glass cylinder, or plate, against a mercurialised cushion.

It will be understood that the kind of electrical force which is manifested when a glass rod or surface is rubbed is called positive or vitreous electricity, and that the opposite kind which is produced when sealing-wax or other resinous substance is rubbed is called negative, or resinous electricity. These names were first used by the early discoverers in electrical science, and no more convenient or expressive designations for the conditions which they represent have since been found.

It has been shown, from the long-continued and most carefully conducted observations of De Saussure, Ronalds, Quetelet, and Lamont, that in dull fine weather the surface of the earth is always in a negative state of electrical excitement, and that the surrounding air is commonly in a positive state. M. Peltier attributes this positive tension of the air to the state of inter-planetary space. He considers that the vacant spaces of the universe are in a constantly positive state, and that the surface of the planetary spheres is kept in the opposite state of negative excitement by the influence of induction. In the absence of any more definite evidence on this point, it is, however, perhaps more philosophical and satisfactory to consider, as many other authorities do, that the positive state manifested by the air is effectively seated in the particles of moisture contained in the atmosphere, and that it has been carried, up with them from the earth when they rose through evaporation. M. Becquerel has shown that the surface of the sea, and the air lying immediately over it, is as constantly in a state of positive electrical excitement as the land is in a state of negative excitement. The fine weather positively electrical state of the air only appears over the land at some considerable elevation. This also, it must be added, is influenced in some material way by the varying positions of the sun. It is strongest in the season of short days, and weakest in the season of long ones; and there are also in every day two periods of comparatively strong, and two of comparatively weak, electrical excitement, which recur approximately at the same hours of the day and night. The positive electrical state of the higher regions of the atmosphere is also considerably diminished by deposits of moisture in

the air, and with very copious and rapid deposits sometimes disappears altogether, and becomes even replaced by the opposite negative state.

It may, perhaps, be well here to remark incidentally that the distinguished electrician Auguste de la Rive inclined to attribute the electrical states, which ascend to the clouds upon the aerial vapours, to chemical changes, brought about by the reactions of the inner surface of the earth's solid shell and the subjacent molten rock with probable infiltrations of the waters of the sea into that subterranean alembic. Chemical changes of the surface-material of the earth and the composition and decomposition of complex surfaces no doubt have to do with electrical manifestations and disturbances. But it must also be added that human science has not yet penetrated very far into this region of research. It is, perhaps, the one field that is most immediately open to further investigation.

We are, nevertheless, after this brief glance that has been given to preliminary considerations, now fairly in a position to understand that there are present in the cloud-sustaining air all the conditions which are essential to convert it into a mighty machine for the production and accumulation of electric force. The broad masses of insulated cloud are conductors ready to receive large charges of the developed energy; these are the prime conductors and the Leyden jars of the apparatus. The surrounding spaces of clearer and drier air are the insulators that imprison the accumulating charge. And the vapours that ascend from the earth and drift in with the winds from side regions are the carriers and feeders of the charge; they play the part of the revolving cylinder or plate. All that is necessary for the production of a thunder-storm under these arrangements is the rapid agglomeration in one spot of very dense clouds—a result which can more easily be brought about in summer than in winter, because then the air is more abundantly charged with water and because then a very slight degree of chill suffices to throw down copious deposits of the aqueous load. When a strong current of very abundant vapour ascends from a tract of moist and heated land into the higher regions of still calm air, where there is no moving wind to scatter the condensing vapours as they form, a powerful electrified mass of dense thunder-cloud is as sure to be formed as the prime conductor of an electrical machine is sure to become charged with sparks when its cylinder or plate is rubbed against the cushion. It will be here understood, however, that the real function of the cloud is simply the bringing into continuous electrical communication a wide stretch of electrically-charged air. It is the air-substance which receives the electrical force, and the condensed and closely-packed moisture of the cloud merely enables large tracts of it to come simultaneously into play as a continuous and connected charge. Sir William Thomson especially insists upon the fact that clouds are not indispensable to aerial charges and disruptive discharges of electricity. They properly act to the aerial charge exactly as the metallic coating of the Leyden jar acts to the charged glass. They facilitate the concentration of the full force of the entire connected charge upon one spot.

When a charged thunder-cloud is thus generated in the upper regions of the air and hemmed round by its circumscribing insulation, all the complicated phenomena of induction immediately appear. Other neighbouring masses of insulated and conducting cloud have their quiescent state sympathetically or inductively disturbed, and the primary mass of the storm-cloud being positively charged, their nearer parts manifest negative energy, and their further parts the opposite positive state. If an intervening layer of other cloud floats between the storm-cloud and the earth, its bottom becomes positive towards the negative earth, and its top negative towards the storm-cloud. The inductive influence of a highly-charged thunder-cloud is extended in this way to almost incredible distances, amounting even to several leagues. Very commonly the inductive power of clouds quite on the far horizon is indicated by delicate instruments, like the atmospheric electrometer of Peltier, or Gourjon, in which two or three thousand turns of a wire brought from a metal globe, or a tuft of fine platinum wires, raised high in the air and continued to the ground are wound on the way round a sensitive and delicately-poised magnetic needle. The air-space surrounding a positively charged storm-cloud is always in a state of negative excitement from the influence of induction. When a storm-cloud drifts over a

fixed station a delicate electrometer first indicates the presence of negative electricity as this approaches; it then shows positive electricity while actually engaged with the cloud, and then again manifests negative excitement as the cloud passes away. When a storm-cloud hangs low over the earth, the negative reaction of that part of the ground is very largely intensified by induction, and the positive charge of the lowest portion of the cloud is in its turn also strengthened by the same agency. Storm-clouds are for the most part positive in their actual communicated and accumulated charge. But it sometimes happens that negative vapours are poured out suddenly from the moist heated ground for some unascertained reason, and then negatively active storm-clouds appear. It has been found that hail-storms are generally connected with these abnormal negative cloud-charges.

When a charged thunder-cloud hangs low over the earth, all projecting bodies rising from the ground are most powerfully influenced by the inductive action, and conducting bodies, such as rods, tubes, and sheets of metal, more powerfully than bodies that have less conducting capacity. All such prominent bodies become highly charged with electrical force of an opposite character to that which is concentrated in the cloud, and which strains to escape to the cloud at the same time that the electricity of the cloud in its turn tends to escape to them. If no passage of the electrical force takes place between the prominent objects and the cloud, it is simply because for the time being the intervening layer of insulating air affords a sufficient resistance to prevent such occurrence. The cloud is then drawn nearer to the earth by the influence of mutually tending forces, and, perhaps, is at the same time driven into closer propinquity by the wind, until at length the narrowed resistance of the air is overcome by the simultaneous heightened tension of the accumulated electricities. The lightning stroke then flashes between and the tension is lessened. In this lightning stroke some positive electricity passes from the cloud to the earth, and some negative electricity from the earth to the cloud. The positive escape releases the negative induction of the objects placed on the ground and the negative escape saturates and satisfies the positive charge of the cloud. In some circumstances the lightning stroke may take place through very large distances—according to Delisle and Petit as large as even nine and ten miles—especially if a kind of interrupted trail of partial conducting material is laid along its course. But for ordinary circumstances the striking distance varies between 650 and 6,500 feet.

When the lightning stroke finally takes place, it of necessity occurs through the line of smallest resistance that is open to it. It invariably falls upon the most prominent conducting substances that are offered, and this constitutes the provision upon which all proceedings for protection against lightning are primarily based; and it should here be understood that there is no doubt or uncertainty of any kind involved in this part of the consideration. An electrician will present a metal rod and a glass rod to the charged conductor of an electrical machine in the positive certainty that the spark will dart out upon the metal, and not upon the glass; and he will perform the experiment a thousand times without any variation in the result. That the lightning will strike upon a good conducting surface in preference to a bad one, provided the entire course of the discharge through the good conductor is an open and an easy one, is as certain as that a ball of metal will be struck by the spark of the electrical machine in preference to a lump of resin or glass.

But there is a second consideration of scarcely less consequence in the arrangements for defence against injury from lightning, namely, the well-proved fact that even the most powerful electrical discharge passes through substances affording an easy way and offering small resistance without disturbing the molecular condition of those substances in the slightest degree. It is only when it has to force its way through badly conducting bodies, which afford considerable resistance to the passage, that it effects destructive mischief, which it then brings about by severing their component molecules, so as to split up and disintegrate the mass. When good conductors are of very small dimensions, they, in their turn, also afford considerable resistance to the transmission of the electric force. But in their case the resistance tells, not in shattering the resisting mass, but in heating it. A very fine wire is rendered red hot by the passage of a

powerful electrical discharge, and it may, if the discharge is energetic enough, be melted, and so disintegrated by the passage. But it is never explosively shattered, as bad conductors are, under any circumstances.

The lightning which is seen in a dark sky flashing between a storm-cloud and the earth, or between two storm-clouds, is a trail of intense sharply-defined light, often appearing to move along a zig-zag course, and occasionally dividing into two, or possibly into three, branches. The duration of the light does not exceed the thousandth part of a second. This has been very ingeniously demonstrated by Professor Wheatstone, by causing a wheel with a number of spokes to rotate so rapidly that the spokes disappear, unless when the wheel is lit up by a flash of lightning, when the spokes of the rotating wheel are seen distinctly, and the wheel itself looks as if standing still, because the illumination is for so brief a time that it has ceased before the advancing spokes have materially changed their position. Professor Tyndall shows this result very prettily in his lectures at the Royal Institution, by lightning up the rotating disc by the successive discharges of a small Leyden jar, so placed that the spark occupies the focal point of a concave mirror looking towards the disc. The disc is rotated rapidly by a multiplying wheel, and the electrical machine is worked continuously, so that the Leyden jar keeps on discharging itself by overflow at repeated intervals. With each discharge the radiant spokes of the disc present themselves to the eye as if they constituted for that instant a stationary object. The exact rate of the rotation of a wheel being known, it is easy to calculate the duration of a light which lasts only long enough not to allow the onward movement of a spoke to be discovered.

The lightning flash is most probably often formed of numerous successive discharges following each other in the most rapid succession, and when this is the case the duration of the light may be somewhat prolonged. The author of this communication has distinctly seen the lightning in the subtropical districts of Southern Africa quivering for quite notable instants from this cause, and seemingly widened into straps or bands having an appreciable breadth. The broad sheets of lightning-illumination, which are commonly observed during the prevalence of a storm, are, however, quite distinct from these lines of luminous discharge. They appear to be due to the leaping of electric discharges of much lower intensity, from cloudlet to cloudlet, as the re-distribution and re-adjustment of the electric force takes place within the constituent masses of the cloud, exactly as happens in the "spangled pane" of the electrician when the electric discharge is made through the diamond-shaped mass of tallow distributed upon glass. The sheet lightning of the horizon is merely the reflection of the light propagated from discharges that are taking place beyond the visible part of the earth's curvature.

There is yet another form of lightning which is of exceeding interest to the electrician and which is characterised by prolonged endurance and slow movement. This form has the aspect of a ball of fire, often as large as a child's head, which travels slowly and perceptibly along the ground, and finally explodes like a bomb-shell, with a loud detonation, scattering zig-zag rays in all directions. These ball lightnings have been watched in their slow march through the air, even as long as eight and ten seconds, and they constitute the kind of lightning that has been most commonly noticed in the interior of houses. They are essentially the lightnings that "disappear up the chimney!" Their true character is, perhaps, yet but imperfectly understood. They certainly differ in essential particulars from the ordinary lightning stroke. They are not electrical discharges pure and simple. Auguste de la Rive inclined to consider them of the nature of compact balloons of explosive gas generated by electrical agency, and shining by inherent luminosity before being finally exploded. Mr. Varley suggested the very ingenious probability that the ball is really a luminous brush discharge from a negatively charged cloud, leading gradually up to the final burst, and moving slowly forward with the charged mass, of which it is the escaping terminal.

The luminous line marking the course of a lightning discharge is really a "crack" produced in the resisting substance of the air when the pent-up and accumulated force finally breaks a way through the resistance. Sir William Thomson speaks of it as being as much a crack as the fissure made by the escape of an overintense charge through a weak point in the glass, the only

difference in the two cases being that the crack remains in the glass, but is immediately effaced in the substance of the air. "The path is prepared beforehand by induction." Mr. W. H. Preece has very graphically and admirably expressed the actual state of the case in an excellent paper read in 1872 to the Society of Telegraph Engineers in which he says: "The particles of air or other matter in the path are raised to such a high state of polarisation, that they are in a state of 'tottering equilibrium,' and the slightest acquisition of force or diminution of resistance, either by the approach of the conductor or increase of quantity, destroys this condition, and we have a discharge with all the effects of light, heat, and mechanical energy. A ship sailing calmly over the ocean, a moving railway-train, a horseman galloping home for shelter from the approaching storm, may prove the last straw to break this camel's back."

The light which is seen along the course of a discharge of lightning is unquestionably incandescent matter distributed along the track. This is now definitely proved by the employment of the spectroscope. M. Fusinieri, who gave much attention to this bearing of the subject, had, however, arrived at this conclusion long before the spectroscope was known. He satisfied himself that lightning always contains material substances, and super-eminent iron, sulphur, and carbon in a state of great fusion, and also of ignition and combustion. M. Fusinieri conceived that the lightning derived this substantial patulum of its fires from the molecules of these substances that are always floating about as impalpable impregnations in the air. But it is most probable that particles are taken up by the electric discharge from the conducting bodies that form part of its course, and carried along with it. Numerous very curious instances of this absorbing and transporting action are on record. The remarkable case spoken of by M. de la Rive, in which a gold bracelet was taken up from the arm of a lady closing a window during the flash of lightning, without doing any material harm, is well known. There are instances in which particles of gold seemed to have been transported through the actual substance of thick plates of silver. The removing of the gilding from the frames of pictures by lightning is of frequent occurrence. The author of this paper remembers one case in which the particles of gold had been stripped away from the picture-frames in a room that was damaged by lightning, and attached to the walls in spangles at different places. One very curious instance of the influence of the electrical discharge upon metallic masses was brought under the author's notice by his friend Mr. Shepstone, the Secretary for Native Affairs in the Colony of Natal. A settler's homestead, known as the "German House," on the road leading from the seaport to the capital, was struck by lightning, and burnt down. In the situation of a box which had contained money there were found afterwards lumps of metals formed by the fusion of gold and silver coins. But near to these were a sixpence and a half-sovereign lying face to face, which had been both drilled with a large hole, and at the same time firmly soldered together round the circumference of the hole. The stamp mark in the sixpence was entirely effaced. It is only, however, when metallic substance is in comparatively small mass, or when it forms the termination of a conducting track, upon which a concentrated charge is received, that this disintegration and absorption of metallic bodies occurs. The electric discharge passes through a sufficiently large metallic mass without producing any molecular disturbance, or manifesting any mechanical effect at all.

We are now in a position to return advantageously to the consideration that when a lightning discharge falls from a charged cloud to the earth, it of necessity takes the line of least resistance that is open to it, whatever that may be, and if that line lies along sufficiently large and absolutely continuous metallic substance, the effective resistance to its passage is so small, that no mechanical violence or heating effect of any consequence ensues. This, therefore, at once indicates what the first expedient in providing artificial protection from mechanical injury must be. A continuous rod of good conducting metal must be carried from the top of the building to the ground. Then when the stroke of lightning chances to fall upon the building, it goes by the easy way, and flows harmlessly and silently through the metallic rod to the earth, and the less perfect conducting materials of the house, such as bricks, mortar, cement, and wood, are not touched. In order, however, that this desirable result may be brought about, it is essential that

the metallic rod shall be large enough to carry quietly and harmlessly the largest discharge that may have, under any circumstance, to pass through it. As a rain-water pipe must be made large enough to carry safely away the largest rainfall that can occur if flooding is to be avoided, so the lightning conductor must be made large enough to carry the heaviest lightning that can strike. And it is even more important that this should be secured in the case of lightning than in the case of rain, because an overflow of fire is a more serious matter than an overflow of water. Some electricians consider that an insufficient lightning conductor is better than none at all, because there have been instances again and again where buildings have been saved from mischief on the discharge of lightning, although the lightning conductor that has effected their protection has been burnt up and destroyed. As in such cases, however, a new lightning rod has to be immediately supplied, it would have been obviously better that the conductor of double capacity should have been erected in the first instance. The author of this paper must also add that he has some reason to look upon the conclusion itself with doubt. There is always danger from fire if a lightning conductor of insufficient dimensions happens to be carried along near combustible materials. The lightning stroke is certainly more likely to fall where a lightning conductor, of whatever kind, is placed, than it would be if there were no such appliance. The lightning conductor, in such circumstances, may be "the slight acquisition of power which destroys the tottering equilibrium; the last straw which breaks the camel's back," alluded to by Mr. Preece. There certainly is as much danger in the interpolation of a lightning rod in such tottering equilibrium as there would be in a "a horseman galloping along over the ground." What the damage is that a conductor of insufficient size may effect is well illustrated in the practice of firing charges of gunpowder in mines by the platinum fuse. A fine wire of platinum is made part of a current of electrical communication in the midst of a charge of gunpowder. When a current of electricity is passed through the wire it becomes red hot, on account of not having sufficient size to convey the electricity without derangement of its molecules, and the red hot wire fires the gunpowder. If the platinum wire had had the thickness of a pencil, instead of a hair, the same charge of electricity would have passed without the explosion of the gunpowder. Another very telling illustration is supplied by the not uncommon occurrence, where a small soft metal gas-pipe is attacked by a powerful discharge of lightning, and the gas-pipe is fused, and the gas set light to. What the dimensions in a lightning conductor are that would fulfil this essential condition of giving sufficient capacity for the safe transmission of the largest possible discharge is yet an unsettled question. In his excellent monograph already alluded to, Mr. Preece argues that a No. 4 telegraph wire of galvanised iron, which is a quarter of an inch in diameter, is sufficient for the protection of most dwelling-houses, because No. 8 wires, of only half this capacity, are found practically to protect telegraph posts from damage by lightning. It is, however, most probable that in the case of telegraph wires a lightning discharge is distributed among several of these protectors, as several are brought into the system by the conducting telegraph wires above. Mr. Preece alludes to two No. 8 wires having been fused and destroyed by lightning in one season. M. Arago gives the case of a chain 128 feet long, formed of successive rods of iron one quarter of an inch in diameter, which was fused through its whole length by a lightning discharge. On the other hand, rods of iron three-quarters of an inch in diameter have been known to convey very powerful lightning strokes to the ground harmlessly and safely. In the instructions of the "Academie des Sciences," drawn up by Gay-Lussac and Pouillet, 1823 and 1824, a square iron bar three-quarters of an inch in diameter was adopted as ensuring ample capacity for all practical purposes. An iron pipe, having the same sectional mass of metal, is better than a solid rod, because the electrical force is transmitted by the surface of the conductor, and a pipe obviously has more surface than a solid rod of the same relative mass. Galvanised iron is better than uncoated iron in the first place, because its surface is protected against rusting; and in the second place because the zinc conducts with three times greater facility than iron. A rope of galvanised iron consisting of 42 strands of sixteenth of an inch wire is a very convenient form of conductor, on account of its ready flexibility, for purposes of conveyance and adaptation to angles and irregularities of a building, and on account of the

long stretch that can be made in continuous lengths. If a conductor is made of several pieces, it is indispensable that those pieces should be joined together by absolutely perfect metallic union, or there will be greatly increased resistance to the passage of the electric force in consequence of the gaps. In strands of galvanised iron the galvanic surface affords a very easy path for the electricity, and the iron core is a stubborn metal in reference to heat, and not readily destroyed. A 42-strand wire rope of the character that has been described affords as much surface, and is in all respects as good a conductor as a strip of stout galvanised iron four inches broad. Copper is a five times better conductor than naked iron. A rope of copper wire one-sixteenth of an inch thick and with 28 strands would be as efficient as a galvanised iron wire rope of 42 strands. Dimensions of this value are recommended, because they are unquestionably equal to any demand that can be made upon them, and because there is yet some measure of uncertainty in regard to the possible intensity of the electrical discharge in exceptional cases. It may perhaps be necessary to point out, in regard to this particular bearing of the subject, that the sole reason why telegraph engineers incline towards conductors of smaller capacity is that reduction in cost virtually increases the number of lightning conductors that are used. This is a very important practical consideration. But in the face of it, and after patient and long-continued weighing of the whole subject, the author of this communication, in his experience as a lightning engineer in South Africa, notoriously a favorite haunt of the thunder-storm, adopted the 42-strand rope of sixteenth of an inch galvanised iron wire, and never found any reason yet to regret his practice on this point. The provision is ample for buildings of considerable elevation. The mistake of employing too small a conductor is a very common one. Within the last few weeks the author of this paper himself, in company with his excellent friend, the Secretary of the Society of Arts, came upon a lightning conductor attached to a very handsome recently restored church in the vicinity of London, in which a single very small galvanised iron wire was used, where a lofty spire was part of the structure, and where apparently the thin wire passed down the face of this spire along a casing of wood shingles. The author submits that if this is not one of the "last straws that might break the camel's back in the circumstance of a tottering equilibrium," it ought to be. The advantage of copper, in contrast with iron, for employment as a lightning conductor, is simply that it heats less easily under an electric discharge, is very stubborn to melt, and that it is the best of all conducting substances. Its disadvantages are that it is much more costly than the galvanised iron conductor which furnishes an equal facility of passage, and that, as a metal, it undergoes a molecular change, from the frequent passage of strong currents of electrical force, which materially affects its conducting power. It must also be remarked that copper is a very much better conductor than brass. Copper costs about one-third more than brass, but it transmits electrical currents eight times as well. Messrs. Sanderson and Proctor, of Huddersfield, and of 18, Queen Victoria Street, have recently contrived a copper tape, or strap, for lightning conductors, which costs about one shilling the foot, and which is so flexible that it possesses in a very considerable degree the advantageous properties of rope. It can be bent round the inequalities of a building with the utmost facility, can be manufactured in continuous lengths to any extent, and can even be coiled for convenience of transport. This copper tape is three-quarters of an inch wide, and an eighth of an inch thick, and therefore contains a sectional area of a little more than a tenth of a square inch of solid metal. This will most probably be found to be ample for all ordinary purposes, and it can, of course, be readily doubled in any case where lofty buildings have to be protected.

The French electricians, who are unquestionably very high authorities in matters of this class, commonly employ metallic ropes, in preference to bars, for the main stretch of the conductor, because they possess a larger sectional area than solid rods of the same diameter, are more easily placed, and adapt themselves to irregularities of structure without the trouble of forging, because they can be readily made of any continuous lengths that can be required, and, in the case of iron, can be easily galvanised, and because they are so supple and more manageable. They consider that an iron cable should have a diameter rather more than twice and a half that of a copper cable (27.3 millimetres against 1 centimetre) to have the same efficiency. M. Cailaud,

an eminent French electrical engineer, who has very recently printed an excellent book on the "Paratonnerre," records that a rope of copper, four-tenths of an inch (one centimetre) in diameter, employed as a lightning conductor at the Church of Sainte Croix at Nantes, and which was made of seven strands, having each seven threads of wire of a gauge of 0.039 of an inch (one millimetre) in diameter, had certainly transmitted several very heavy electrical discharges without suffering any injury in its own substance, and that a similar rope of one-fifth smaller diameter (eight millimetres) previously employed had been injured by lightning discharges. Copper bars a fifth of an inch (exactly five millimetres) have been known to be as much injured by a single storm as by ten years of exposure and rust. M. Viollet Leduc, on the other hand, states that copper ropes seven-tenths of an inch (eighteen millimetres) in thickness were burned at Carcassone. From a consideration of these facts and some others of a similar character, the French electricians of the present day employ ropes of copper of from four-tenths to eight-tenths of an inch (one to two centimetres) for each 82 feet of height. Mons. R. Francisque Michel, who has printed an interesting notice of the faulty state of the lightning defence of the public monuments of Paris, with some allusion to the views of M. Callaud, in *Les Mondes* of October 1874, considers that a rope of galvanised iron wire should have a diameter of eight-tenths of an inch, to afford efficient protection under ordinary circumstances. M. Callaud prefers that metallic ropes should be constructed upon hempen cores, on account of the greater pliability which this contrivance gives. It has been already observed that lightning conductors require to be of larger size in proportion to their length. The law which rules this proportion is simply that the facility of electrical transmission in any conductor is in the exact ratio of the co-efficient of the conductivity of the metal of which it is composed, multiplied by the number representing the section of the rod, and then divided by the number representing its length. The durability of any rod is, in general terms, in proportion to the square of its diameter. M. Melsens, a high French authority, prefers that there should be several conductors of small size rather than one large one; and it is at any rate generally agreed that a large building should be furnished with several conductors, and that when several conductors are combined into one stem, that stem must be of a size sufficient for the safe transmission of all the electrical force that can be furnished to it by the contributory branches.

If it so happens that metallic cables have to be joined, the individual wires of the connected ends must be untwisted, and spliced or mingled together, and then be bound tightly round with wire in such a way that the whole can be dipped into melted solder, or solder be carefully run in over a fire. Cables may be satisfactorily connected with rods by turning a spliced loop upon their ends in this way, and by then binding this loop in upon the rod by means of strong screw nuts. Mons. Michel, in speaking of the need of renewing the efficiency of the public lightning conductors of Paris, makes the excellent practical suggestion, that the ends of rods requiring to be spliced in continuous electrical communication should have plates of soft lead firmly nipped in by screw power between the ends that are to make contact, the entire joint being afterwards enclosed in a sufficient investment of solder.

The disintegrating energy of an electrical discharge is mainly expended upon the extremities of a conductor. It effects the most marked molecular disturbance on the part where it first falls, where most probably the first meeting of the two antagonistic forces occurs, and where the terms of the new alliance have to be arranged, and also on the part by which it has to issue from the conductor to the ground—the great natural reservoir of the reserve of the energy. On this account lightning conductors require to be expanded and amplified both at their summits and at their roots or base. The French Academie des Sciences directed that the top of the conductor should be a bar of iron two and a quarter inches in diameter, whether square or round, tapering up to a blunt conical copper point, shaped to an angle of thirty degrees. The pointed termination of the conductor is a matter of some practical consequence, because it establishes a slow and gentle discharge of an accumulation of electrical force at high tension, as is illustrated in the ordinary experiment where the charged conductor of an electrical machine is quietly discharged by the presentation of a sharp needle to it. De la Rive held that a metallic ball was quite

as efficient for an upper terminal as a point. But when a great number of lightning conductors are brought near together, as in protecting the buildings of an extended town, there is no doubt that if they are pointed at the top, they serve to saturate an approaching cloud, and to deprive it of its sting before it comes within striking distance. After the city of Pietermaritzburg in Natal had been largely supplied with pointed lightning conductors, under the author's fostering influence, the actual discharge of violent lightning strokes within the area of the town became almost unknown. During several years the only cases that came under the author's notice were the tops of two chimney stacks somewhat damaged, and a few lofty blue gum-trees shattered.

On account of the facility with which it could be supplied by ordinary workmen, the author adopted a terminal for the upper end of the conductor in the colony of Natal, which proved very effective and satisfactory. In this arrangement the top of a galvanised iron rope was enclosed in a tube of stout sheet zinc, finished at the summit, for the sake of ornament, by a gilded ball of turned wood, above which the strands of the wire were opened into the form of a sort of brush. Each conductor, in this way, had 42 points of its own, and the augmentation of terminal capacity was secured by the addition of the external zinc tube. The tube also supplied a ready and convenient means of attaching the conductor to chimney stacks, or to other protruding parts of the building:

The especial function and power of points is very pleasingly and completely illustrated by a series of three experiments devised by M. Gavarret, Professor of Natural Philosophy to the Faculty of Medicine at Paris. He first charges the prime conductor of an electrical machine to the highest point of tension that it can contain; he then places near to it an earth-connected rod, furnished with a point directed towards the conductor, and he shows that the tension which can be produced in the conductor diminishes constantly as the angle of the neighbouring point is made less. He next provides a Leyden jar that discharges itself by spark through a given neighbouring point, and unscrewing this point and replacing it by a crown of points he shows that thenceforth the same jar will only discharge itself silently and without a spark. He then so arranges the jar that it discharges by sparks below the plane of a neighbouring terminal point, and on fixing lateral points below that plane the spark-discharges immediately cease.

Perhaps, however, the most telling proof of the beneficial influence of points in relieving the tension of an excited electric is that which is given by a very simple and pretty experiment most easily performed. If a living man stands upon a stool with glass legs, and is placed in electrical communication with the prime conductor of an electrifying machine at work, with a gold leaf electrometer on the table three or four yards away from him, and holds in his hand a sewing needle, with one finger pressed over the point, the gold leaves of the electrometer show no manifestation of the electricity in the operator, until he unmasks the needle by withdrawing the finger from its point, when the gold leaves immediately start asunder, under the influence of the stream of electricity which is poured out upon them through the point, even at that distance. Or yet, again, if a large tassel of strips of light tissue paper is made to throw its several strips out into a divergent brush, by electrifying the tassel from a machine, the tassels of the paper collapse together immediately upon unmasking upon them a needle point held in the operator's hand at the distance of two or three feet away. There is one very important result of the employment of terminal points to lightning rods which should never be lost sight of. A lightning rod with efficient points and in satisfactory operation might be grasped by the hand of a living man, even when in action, with entire impunity, because, on account of the continued drain set up by the points, the rod can never assume any dangerously high tension. A conductor acting without a point, on the other hand, is in a state of very considerable tension when it effects its first discharge, and if it were grasped in the same way by a hand, would, in all probability, strike through that hand some very inconvenient and possibly painful proportion of the discharges. Conductors that have been acting silently with points have been seen to be struck by sinuous tracks of fire, indicating dangerous discharges of high tension, when they have been disarmed of their points.

Platinum has very generally been recommended for the construction of the terminal points of lightning rods, because it is one of the hardest known metals to melt, and because it is also not easily oxidised. The points are shaped to an angle of from 7 to 10 degrees at the top, and are made a trifle less than 2 inches (5 centimetres by the French) long. In this form they are screwed firmly into the top of a rod of copper, which is then, in its turn, connected with a cable or metallic bar below. The terminal rod is usually made of augmenting size as it descends, and is generally projected from 12 to 20 or 30 feet above the building that is to be protected. Platinum points are specially made for lightning conductors in Paris. They are supplied by Collins, of 118, Rue Montmartre; Begnet, of 96, Rue Montmartre; and Detouche, of 222, Rue St. Martin. The cost of a platinum point at these houses, grafted on brass, and from 50 to 70 centimetres (1·9 to 2·7 inches) long, is from 16 to 22 francs. For better finished work, with larger needles of platinum, grafted upon copper, the cost is from 60 to 200 francs.

M. Francisque Michel considers that the points may be quite as advantageously made of silver alloyed with copper, in the same way that it is when used for coining silver money, that is, containing 165 parts of copper to 835 parts of silver. Such points have the unquestionable recommendation that this alloy possesses a very much higher conducting power than platinum, which has 12 times less conducting power than silver and 11 times less than copper. Messrs. Sanderson and Proctor construct their points very neatly, by simply twisting the copper tape spirally at the end, after the fashion of an auger, and then filling away the termination of the flat metal into the shape of a sharp angle. The entire terminal is also gilded over the copper to the extent of eight inches. This kind of point has the very obvious recommendation that it forms a continuous portion of the actual rod, and needs no joining or attachment.

The French electricians strongly recommend, upon the ground of the experiments of Professor Gavarret, that the lightning rod should be terminated by a cluster or a crown of points, instead of by one alone, and M. Callud has given two sketches in his treatise of forms of terminal points that have been adopted in France, in one of which a circle of ten points radiates at an angle of 45 degrees round the base of the principal terminal, which rises some inches above them; whilst in the other a kind of plume of points feathers out from the base. M. Beignet of the Rue Montmartre, exhibits a model of the multiple point which the French electricians most affect. Mr. Francis, of Southampton Street, Strand, constructs a very simple and efficient multiple point of copper. The Hotel de Ville at Brussels, which is a very large building, and which has been furnished with lightning rods upon a very complete scale by Mr. Melsens, a distinguished Belgian electrician, is literally bristling with points. It has 228 points of copper and 36 points of iron in its system.

The lower termination of a lightning conductor requires the exercise of even more care than its upper end, because it is less constantly and less generally under observation, and any shortcoming or mistake in reference to it is fatal to the efficiency of the rest of the arrangements, however judiciously they may have been carried out. A faulty termination of the earth connection is, of all else, the most common and frequent blunder, in relation to lightning conductors, that is made. As that is one of the terminations of the artificially provided conducting track, it must be of enlarged dimensions, as has been already explained. It must be in very intimate communication, not merely with the ground, but with the freely conducting portion of it. If a moist contact can be secured by insertion of the rope or rod into constantly damp soil, the contact need only be large enough to diffuse what is known as the electrolytic action—that is, the chemical disintegration of corrosive metals at moist contact when electric currents are operative—over a fairly extended space. If the contact is made with dry earth, the surfaces must be very large indeed. The drier the material that is involved—unless it be an extended system of continuous metallic substance, such as the underground iron tubes of water and gas supplies in towns, which are among the most efficient ground terminals that can be adopted—the more expanded must be the surfaces of communication and contact.

It is worthwhile here to make a passing allusion to a few flagrant instances of faulty construction in the establishment of earth contacts of lightning conductors on account of the strength of the illustration that dwells in such failures. In a well known case of a lighthouse at Genoa, which was injured by lightning, and which was presumed to have been furnished with seemingly efficient protection, it was found that the bottom of the conductor had been plunged into the interior of a stone rain-water cistern, primarily constructed especially to keep out the infiltration of the sea, and therefore well adapted to prevent that moist contact with the mass of the earth which is essential to the object in view. Mr. Preece has drawn attention to a very similar case at Lydney, in North Monmouthshire, where the hollow of an iron gas tube, intended to protect the church, was inserted into the substance of a loose stone that was itself imbedded on dry pavement. One of the most sublime instances of this form, not merely of superfluous but of actually dangerous care, came under the author's own observation a few years ago, when he found in the case of a church in Norfolk, which was injured by lightning, although the tower was furnished with an apparently sufficient conductor, that the metallic rod was carried through the necks of glass bottles wherever it was attached to the masonry, and that the system of precaution was finally consummated at the base by putting the bottom of the rod into a glass bottle buried in the dry earth. But a few months since, the author undertook to see to the protection of the residence of a friend in the neighbourhood of Kensington Gardens, in which an exceptionally lofty house, even for that aspiring neighbourhood, had to be defended. A sufficient copper rope was brought down from an iron balustrade that surrounded the summit of the roof, but it so chanced that this was left lying at the lower end on the stone pavement of a sunk basement floor before the permanent earth contacts had been established, and that a thunder-storm suddenly burst over the neighbourhood while the system of protection was left in that unfinished state. The head of the household, in the absence of his scientific adviser, was, however, equal to the emergency. He had the bottom of the rope carefully coiled away into the interior of a wooden pail, determined, most probably, that if the lightning did come down the rope, it should at any rate be kept in the pail until it could be carried away by some competent hand. In one very instructive instance, a house in Natal, which had been furnished with one of the author's galvanised wire ropes for a conductor, but not under his personal superintendence, was injured by lightning. The house was a low-hipped structure, of one storey. The rope had been brought from the top roof ridge which was of metal, along one of the hip angles, then down a corner post, and buried in the ground. The lightning, however, had perversely preferred to go down an opposite hip, where there was, so far, a metal road and had then leaped through the wall, taking some iron sash weights of a window by the way, and shattering the brick-work and doing other damage in its course. The author went down, as soon as he had heard of this accident, to investigate its cause; and the cause was simply this: the lightning conductor had been plunged into a tract of dry sand at the corner of the house. But at the other corner, by which the lightning had effected its own escape to the ground, was an old pool of water that had been filled up with earth, but was still saturated with moisture, and still connected with ramifications of infiltrated soil. In this case the lightning, when it struck the roof of the house, had divided itself between the two routes which were offered to it—the conductor and the dry sand contact of insufficient area and the wall with its stepping stones of sash weights and its abundant wet contact beneath. The proportion of the discharge which had taken these different routes was determined by the specific resistance of each way, and in the course that involved the leap through the non-conducting wall, the amount which passed was sufficient to produce the destructive disruption which occurred. All competent electrical engineers are now keenly alive to the automatic electrolytic action that is apt to take place in the earth contacts of a lightning conductor, and urge that it is not enough merely to construct an efficient lightning conductor in all its essential particulars, but that the arrangements must be examined from time to time, to make sure that no derangement has taken place. Such examination may readily be effected by making short circuits through the conductor with the wire of a galvanometer, so as to prove by the movements of the needle that the electric path is efficiently clear.

From the instant that an earth contact is established for a lightning conductor, destructive change of the surfaces of contact begins, and, sooner or later, the power of the conductor is materially impaired from this cause. This action, known as the electrolytic disintegration, requires to be constantly watched, beyond all else, and all the more because it proceeds in a region where the conductor is removed from observation by the eye, and it is most fortunate that such watching may be most efficiently and satisfactorily accomplished by so ready and convenient a means as the employment of the galvanometer. M. Wilfred de Fonvielle has indeed proposed that every lightning conductor should have an arrangement of a short circuit wire with the galvanometer attached permanently to it, in a form which he terms *Le Controleur des Paratonnerres*, and which is so designed as to be always ready for the eye of the observer. The author was once very near indeed so furnishing, at his own cost, a proof of the material need of some test and evidence of this character. He had supplied his own residence in the capital of Natal with one of his galvanised iron ropes, with the zinc tube and brush so demonstratively displayed above as to be a constant object of observation and remark to his compatriots and neighbours. The finial was placed so as to be a sort of advertisement of the enlightened practice of the owner of the house, and a standing reproof to the negligence of those who would not follow so excellent an example. The earth contact was very efficiently made, by carrying the rope along the muddy bottom of one of the streams of constantly running water that in the old Dutch settlements of South Africa are always found fringing the streets; and during many very severe thunder-storms the author sat in his easy chair, priding himself on the completeness of his arrangements. He subsequently, however, by mere accident, made the astounding discovery that for a considerable length of time the tail of his lightning rope had not been trailed in the wet mud, but was carefully packed away along a stretch of dry ground, under the shelter of a thick-set hedge, that served effectually to conceal its presence there. On some unhappy occasion, when the author was away, the water-courses had been undergoing cleansing and repair by the civic authorities, and the workmen, finding the metal rope in the mud, had taken considerable pains to pack it away in the drier and cleaner place in which it was ultimately discovered. If any accident from lightning had in the meantime occurred to the house, this case would certainly have lived in the annals of Natal, for a couple of centuries at least, as a remarkable proof of the inefficacy of lightning rods, and the great lightning doctor himself would have been held to have brought down the vengeance of the clouds upon his own ignorance and presumption.

The French electricians have contrived a very excellent expedient for making an efficient earth contact. They construct a stout harrow of galvanised iron, with recurved teeth, connect this carefully with the end of the cable or rod, and then bury it, imbedded in a mass of broken coke, in moist earth. The cable or rod is conducted to a suitable site for this terminal in channels of curved tiles, well filled with broken coke, or even sealed up in leaden tubes, if there are ammoniacal vapours to be encountered by the way. M. Callaud has a still more ingenious and admirable plan of effecting this purpose. He hangs at the bottom of the cable a galvanised iron grapnel, with four upturned and four down-curved teeth, and entangles these within a basket of netted wire, and then packs in this basket with fragments of coke; and the basket, coke, and grapnel are afterwards sunk into a pit or well, or buried deep in moist earth. M. Callaud prefers coke to charcoal, on account of its greater porosity and accessibility to moisture; and he has made some careful experiments to satisfy himself of the size which this earth terminal should have. According to the experiments of M. Pouillet and M. Ed. Becquerel, pure water conducts the electrical force 6,754 million times less freely than copper, and therefore, for free transmission, the earth contact, if effected by pure water, should have 6,754 million times the area of the main conducting cable or rod. This theoretical argument is, however, very materially effected by the fact that the water in the earth contains conducting principles of considerable power, and by other analogous considerations; and an earth contact of 1,000 square metres (1,196 square yards) has been fixed by the best French authorities as sufficient for all practical purposes for a conductor of copper, that is, one centimetre (four-tenths

of an inch) square. M. Callaud calculates that in order to accomplish this purpose his earth-basket must contain one hectolitre (two bushels and eight-tenths) of broken coke. In order that a lightning rod may perform its work perfectly, it is obvious that there must not be any greater resistance to the passage of the electrical discharge at its earth-outlet than there is in the rod or main channel of the discharge. Very commonly in badly-arranged lightning rods, it is found that there is ten thousand times more resistance at the outlet into the earth than there is in the main rod of the conductor. When this altogether excellent expedient of M. Callaud's cannot be adopted, a bore four or five inches in diameter should be sunk sixteen or twenty feet into damp soil, into which the cable should be inserted, and then the bore should be filled round the cable with broken coke, and the whole be firmly rammed down; or radiating trenches should be cut as deep as possible in the ground, and corresponding branches from the cable be then packed into these with an investment of broken coke. M. Francisque Michel gives an unqualified approval to the attachments of the lower terminal of the cable to iron service-pipes, whether of water or gas, in towns.

In Gay-Lussac's report to the French Academy of Sciences, in 1823, it was held that all large metallic masses contained in any building should be brought into metallic communication with the main system of conductors, and that there was no need whatever for the employment of insulating supports in attaching the lightning rod to the structures that it is intended to defend. These conclusions of Gay-Lussac's have been generally acted upon since his time, and no very marked case has ever occurred to stamp the practice that has been adopted in these particulars as radically wrong. In my own practice, in the colony of Natal, I have almost invariably acted upon them, and no single instance of insufficiency of protection has ever come under my notice in consequence of the arrangement. The point is, however, one upon which there is now some difference of opinion in high quarters. M. Callaud, for instance, in his recently-printed treatise on the Paratonnerre, insists upon the adoption of insulating supports for the rod, and unconditionally condemns the electrical communication of the rod with the metallic masses contained within the building; and he states in one part of that work that M. Pouillet has to some extent given in his adhesion to these revolutionary views. M. Francisque Michel, on the other hand, upon a full review of all M. Callaud's arguments, maintains the old doctrine that the conductor may safely be attached to the masonry of the building by ordinary staples or holdfasts, or any convenient way, and that insulating supports are of no use whatever, and that all masses of metal contained in a building should, as a general rule, be metallically connected with the main line of the conductor. Professor Melsens, of the Royal Academy of Belgium, one of the highest Belgian authorities, contends, upon experimental grounds, that the well-known laws of derived electrical currents apply with equal force to the transmissions of electrical force of high tension, and that scattered masses of metal in any building should be metallically connected with the conductor by closed circuits constituted by contacts with two distinct points of the rod. This divergence of view among high authorities is of notable import, because it is virtually the only material difference of practice that is encountered in the treatment of this subject by well qualified scientific men, and it may therefore be very readily admitted to be an affair that yet requires a more searching investigation and further severe question by observation and experiment. In the meantime it is of some importance that the exact bearing of the doctrine advocated by M. Callaud should be understood.

In illustration of his argument, M. Callaud takes the case of an iron balcony supported in front of the window of a house at some elevation from the ground, and considers the possible result to living men and women contained in this balcony at the time of a severe thunderstorm, accordingly as the balcony is, or is not, electrically connected with an efficient lightning rod. He argues, if the balcony is connected with a lightning rod, a living person standing upon it or leaning against its rail, is very much more likely to be struck by a discharge of lightning, than if the balcony had no such connection. In the former case the living body is likely to be made a stepping-stone for the lightning on its way to the rod. He holds that in the case

of a lightning stroke the chances are a hundred to one that a lightning rod is struck in preference to any part of a building, but that if the conductor is faulty in any particular, and scattered metallic masses are connected to it, this is tantamount to attaching the hundred chances, danger to the metallic masses and to living people placed near them. He says, in effect, a satisfactory and perfect lightning rod should be so placed that it efficiently protects every part of the structure it is attached to, and that if it does this no scattered mass of metal within the building can possibly be struck by a discharge. Therefore, connection of the rod with scattered masses of metal is superfluous and useless where the rod is efficient and perfect in itself, and objectionable and dangerous when the rod is not in an efficiently acting condition. At perhaps, the greatest force of this argument falls upon a fact which is very earnestly pressed by M. Callaud, that a lightning rod is a merely passive piece of mechanism, which does not give visible or palpable signs of its own derangement, like a clock, but which may furnish fatal proof of its imperfection too late, by killing the person who places unmerited and undue trust in its efficiency and excellence. M. Callaud remarks with some force, "Lightning cannot strike a structure that is well protected. If the lightning finds at the side of the Paratonnerre an electrical conductor that is superior to itself, the structure is then inefficiently defended. The Paratonnerre ought to dominate, to cover, to protect, a building in all its parts, and in all details, or it is better away." The gist of the whole matter, therefore, is, take care that your conductor is perfect and efficient in all its parts, and that it is in every sense adequate to the work that it is required to do, whatever may be the size of the building, and then it becomes a matter of small moment whether scattered masses or metal comprised in the building are connected with the rod or are not connected, and whether the rod is connected to the building by insulating or by non-insulating supports. M. Callaud's conclusion, however (and it is the one upon which he states that M. Pouillet has given in his adhesion), is substantially—"Connect any masses of metal with the Paratonnerre that are of necessity removed from the occasion of the close presence of living people, but on no account ever connect such masses with the Paratonnerre when they may at any time have living people in their close neighbourhood." Pending further investigation of this very interesting point, there can be no doubt that this distinction is prudent and a safe one to be adopted in practice, and that it is more prudent and more required in proportion to the insufficiency of the arrangements of the conductor. Conducting masses which are connected with the earth by less readily conducting substances occasionally give rise to a curious effect, which is technically known as the return shock, and which is altogether a result of inductive action. When a powerfully charged electric comes within a moderate distance of them, an electrical charge of an opposite character is drawn into them by induction, but this secondary charge escapes back towards the earth the instant the inducing tension is removed. The production and character of this return shock, caused by inductive action, admit of very complete illustration by electrical apparatus. An insulated conductor of long cylindrical form, but with its glass supports only half the length of the glass pillar of a prime conductor, an electrical machine, may be placed parallel with the prime conductor, but about an inch away. The secondary conductor is then to be raised to the same height as the prime conductor, by fixing its glass pillar upon the top of a pillar of wood, a fine wire being carried from the metal cylinder to the wood. A wire is then also to be carried from the secondary conductor to the earth, but is to be so arranged that a small gap may be left in some convenient part of its course. When the prime conductor is charged positively by the machine, the positive electricity of the secondary conductor is inductively driven out through the wire and the wooden pillar to the earth, and the conductor itself remains negatively charged. But when the working of the machine is stopped, and the prime conductor is deprived of its positive charge by a touch of the finger, the negative charge in the secondary conductor is also set free from its condition inductively maintained constant, and positive electricity leaps back from the earth to restore proper balance and saturation, and as it does so is seen passing as a spark through the gap in the earth-wire, because that gap affords less resistance to the passage of electricity of tension than the supporting pillar of wood. If a little gun-cotton, or some other suitable inflammable

substance is placed in the gap, it is fired by the spark at the instant of the discharge. Professor Tyndall, in his lectures at the Royal Institution, shows the production of this sympathetic inductive discharge in a very magnificent form. He has a flat coil of copper-wire imbedded in a mass of insulating resin, through which he can pass the discharge of the powerful battery of the institution, consisting of fifteen Leyden jars; and he has also a second flat coil similar to the first, which he can place parallel to it and about an eighth of an inch away, the two ends of the second coil being connected with a wire presenting a small gap of continuity. When the discharge of the battery is passed through the first coil, a powerful sympathetic discharge rushes at the same instant through the secondary coil, and makes itself manifest by a bright flash and a loud snap in the gap of the connecting wire. The discharge of an electric cloud in this way not uncommonly produces a number of sympathetic minor discharges from neighbouring bodies. The induced discharge is sometimes quite strong enough to produce mechanical mischief in resisting bodies that lie in its path. The shocks experienced by living people on the instant of a discharge of lightning without fatal results are generally of this character. It was to meet the case of these incidental induced charges, and the consequent "return shocks," that the expedient of connecting scattered masses of metal with the conductor, was originally devised. The return shock resulting from a limited inductive disturbance may be strong enough in some circumstances to cause death by the mere arrest of the vital action of the nerve structures through which it passes, without leaving behind it any trace of mechanical violence, such as is generally produced by the true lightning stroke.

The old practice of protecting buildings from lightning consisted in erecting rods of metal upon wooden frames, near to, but not in actual contact with, the walls of the house. When the author of this article first visited Natal in 1857, the houses in the two principal towns, that were defended at all had independent conductors of this class, of the rudest possible kind, erected by the side of the one-storeyed houses upon ungainly wooden frames. The conductor was composed of an iron rod, joined in three lengths, and rudely pointed above, and it was made of three different pieces—a comparatively thick one below, and a comparatively thin one at the top. This practice was primarily based upon an investigation which was conceived to demonstrate that all structures lying within a conical space, which had the conductor itself for its height and a breadth for its base equal to four times the height of the conductor, were safe. This estimate gives a fair approximation to a truth, but it is by no means absolute, and must not be empirically relied upon. It, however, furnishes a very good indication of the way in which the upper termination, or terminations, of the rod must be arranged. The terminal point should go some considerable distance above the housetops, and then if any projecting parts of the house extend beyond the surface of a line having perhaps a somewhat more acute figure than the one which has been named, other subsidiary points must be reared up from the line of the conductor above such conical slopes. Mr. Preece, in his paper, considers that the lightning conductor should only be held to afford absolute protection within a conical space in which the base is as large again as the height of the line. When, however, the general idea of the limits of this lateral protection is once clearly conceived, it becomes very easy, indeed, to render the arrangements of the upper terminals perfect for any individual case. It is only necessary that all prominent masses of metal shall be connected with the system of metallic communication, and that an additional branch of the system of defence shall be carried out whenever outlying parts of the structure get near to the conical limit of protection. This is virtually what has been done in the case of the Hotel de Ville at Brussels, with its terminal of 264 points.

When Sir William Snow Harris, now some years ago, turned his attention to the protection of ships from lightning, he devised a plan of making the lightning conductor a part of the original design and essential construction of the ship. Now all large and well-contrived vessels are always built with the lightning rod included in their structure. It is almost incredible that up to this time the same course has not been taken with houses. It is hard to understand why lightning conductors should be objects of exceptional luxury, and rain pipes objects of daily need, and the more so when rain pipes themselves can be so easily turned by a

little forethought and mechanical ingenuity into lightning conductors of the most efficient character; they only need that their joints shall be made mechanically continuous, that their earth contacts shall be perfected, that all masses of metal, with perhaps the limitation that is contended for by M. Callaud, shall be brought into metallic communication with them, and that metal terminals shall be distributed from them to the roofs above, upon the principle that has been explained. Mr. Preece has thrown out one very excellent suggestion which well deserves further thought; it is to the effect that metal ventilating pipes carried up from the sewers over the roof of the house may advantageously be made part of the arrangements for protection against lightning. The familiar case of the Monument of London is continually adduced as a proof of the readiness with which the accidental features of a building may be turned to account for this purpose. The metallic emblems of flame at the top of the column are continuously connected with the ground by means of a very thick balustrade of iron that runs as a hand-rail down the stairs; the structure is 200 feet high, and towers above all neighbouring buildings, and yet it has now stood within three years of two centuries without ever having been injuriously touched by the lightning.

It was conceived, until recently, that St. Paul's Cathedral had been efficiently protected in some similar way by the arrangement of water-pipes, and some supplementing of them by metallic rods, added by a Committee of the Royal Society some 120 years ago. Mr. Faulkner, of Manchester, however, found, in a careful examination made subsequently to 1872, that the system had become entirely inefficient for the purpose for which it was intended, by the formation of thick incrustation of rust on the contact surface of the rods, and by the interpolation of blocks of dry granite, some nine inches thick, in places, into the actual line of electrical conduction. The entire building has now been most efficiently protected, under the skilful direction of Mr. Faulkner, by carrying eight octagonal half-inch ropes of common wire from the Cross, Ball, and Golden-gallery through the metal-work of the roof of the dome, and through the metal-work and rainfalls of the lower parts of the building to the sewers, where the conducting stands terminate in copper plates pegged into the moist earth. In carrying out this work every important metallic portion of the building was separately tested by the galvanometer, to make sure that the electrical communication with the earth was virtually and substantially clear. The galvanometer was first made into a circuit with a metallic gas-pipe; and then the circuit was opened out, so that earth was made in one direction through the gas-pipe and in the other through the metallic portion of the building for the time under examination; and the test was not considered satisfactory until the deflections of the galvanometer were the same under both alternatives. In arranging methodical architectural plans of this kind, it must always be carefully borne in mind that small gas-pipes of easily fusible metal must on no account form part of the connecting lines of conducting circuit. Gas-pipes are most easily fused by a stroke of lightning, and when they are so fused the gas which escapes from the extemporised orifice is invariably set light to.

One point which was expressly urged by Mr. Preece, and by Captain Douglas Galton in the discussion of Mr. Preece's paper at the Society of Telegraph Engineers, should be most carefully kept in view in any structural plan matured for the protection of building, namely, the including of all fire-places or stoves and soot-blackened chimneys in the system of connected construction. To adopt Mr. Preece's own statement of this need—"It must not be forgotten that a chimney lined with a thick layer of soot, up which a current of heated air and volumes of smoke are ascending, and terminated by a mass of metal (the grate) is an excellent but dangerous conductor, for it ends in the room, and not in the earth."

Since the first preparation of this paper two pamphlets by Messrs. Gray and Son, of Limehouse, have come into the hands of the author, which are valuable and interesting on account of the details which they contain of a considerable series of instances of damage from lightning. Mr. W. J. Gray, of this firm, was originally concerned with Sir William Snow Harris in perfecting his plan for protecting ships, and obviously possesses a large amount of practical information in regard to accidents that have occurred. Space now only serves to say

that the Messrs. Gray endorse the practice of connecting all metallic masses in a structure with the main line of conduction, and especially urge the surrounding of all prominent objects such as the tops of tall chimneys and church towers, with continuous bands of copper brought down into direct connection with the discharging rod.

The great length to which this paper has already extended itself alone prevents some allusion being here made to the views of Professor Zenger, of Prague, who advocates the use of circular zone-like or ring-shaped conductors, embracing within their span the objects which are to be defended from injury.

There is no sufficient ground for the popular idea that accidents from lightning are of such rare occurrence that it is scarcely worthwhile to incur the trouble and cost which artificial protection involves. The figures of the statistician prove that accidents are very frequent indeed. The Escorial in Spain has been set fire to four times by lightning in less than three centuries. As many as 1,308 persons were ascertained to be killed by lightning in France between 1835 and 1852. Some time ago the mean number of deaths from lightning in each year was marked at 3 in Belgium, 9 in Sweden, 22 in England, 50 in the United States of America, and 95 in France. M. D'Abbadie records the destruction of two thousand sheep by a single discharge of lightning. Mr. Preece tells of 897 telegraph instruments injured by lightning in the first six months of 1872 in a staff of 9,475 instruments. Mr. G. J. Symons, one of the Secretaries of the Meteorological Society, has given, as the list of accidents that he had ascertained to have happened during two severe storms in June 1872, 10 deaths and 15 cases of injury to human beings; 60 houses struck and 15 burned down; and 23 horses or cattle and 99 sheep killed. It need scarcely be said that many accidents also occur every year from lightning, over and above those which get publicly spoken of or placed on record. In large towns damage to property is more frequent than destruction of human life, but in the open country destruction of life is the more frequent occurrence. In the face of figures like these, and of the fact of the slowness of man to avail himself of the ready defence which science places at his command, unfortunate humanity certainly stands very much in need of the consolation which the physiologist affords when he tells us that all danger from lightning is passed when the flash of the electrical discharge is seen, and when he further states that when men are killed by lightning they are dead before they have time to know anything about the fact, or indeed to be conscious of the fatal blow—a conclusion, by the way, which is strikingly corroborated by an unintentional experience of Professor Tyndall's, who upon one occasion passed the full charge of the powerful Leyden jar battery of the Royal Institution, by accident, through him, and was perfectly unconscious of any shock. It is something, at any rate, to have this comfortable assurance when the sense of neglected opportunity comes over the mind in an exposed situation and in an unprotected house during a severe thunderstorm. But it is humbly submitted, as an appropriate last word of this paper, that to men of well-regulated minds a good lightning conductor may, in such emergency, be found to be an even greater satisfaction and comfort.

DISCUSSION.

The Chairman said there was no time for the discussion of the subject which had been so ably brought before them, but if any one had any question to ask, he was quite sure Dr. Mann would be very happy to answer it. If there were no questions, he would propose a cordial vote of thanks to Dr. Mann.

The motion having been carried,

Dr. Mann said he was quite sure the Council of the Society would be glad to afford an opportunity for discussion on a future occasion, if it was desired. There were one or two points which might well be discussed, and if any one felt desirous of entering upon them, he should be glad if they would communicate with him before the next session, and he would then endeavour to make arrangements for the subject being again brought forward.

Proceedings of the Madras Government, Public Works Department,
19th February 1877. No. 544.

The copper tape and spiral terminal of Messrs. Sanderson and Proctor; the copper multiple points and copper earth-plates of Mr. Francis; and the octagonal copper rope used in the protection of St. Paul's, with specimens of broad and solid copper bands used in the protection of large buildings, and of the screw contacts adopted with these large flat conductors, of Mr. Faulkner, of Manchester, were exhibited to the meeting through the kindness of these gentlemen.

No. 435. ORDER THEREON, 19th February 1877, No. 544.

CIVIL WORKS, No. 33.

COMMUNICATED to all District Engineers for information.

(True Extract.)

Colonel,
Acting Joint Secretary to Government.

GOVERNMENT OF INDIA.
PUBLIC WORKS DEPARTMENT.
CIVIL WORKS.
Miscellaneous. 22 JAN 77

No. 580

To

- The Governments of Madras, Bombay, Bengal, North-Western Provinces and the Punjab, in the Public Works Department.
- The Chief Commissioners of Oudh, Central Provinces, British Burmah, Mysore and Coorg, and Assam.
- The Resident at Hyderabad.
- The Agents to the Governor General for Central India and Rajpootana.
- The Superintendent of Port Blair and Chief Commissioner, Andaman and Nicobar Islands.
- The Inspector General of Military Works.
- The Principal, Thomason College, Roorkee.

ircular No. 73 Public Works.

Dated SIMLA, October 30, 1876.

Received

No 544 27/19 Feb 77

Communicated to
all District Engineers
for information.

17.2.77

Architect
10-3-77

Circulated for general information and guidance a paper by Dr. Mann on the protection of buildings from lightning, which was read before the Society of Arts on 28th April 1875.

5080

Govt. of 1877 Madras.

PUBLIC WORKS.

To

All H. Engineers.

Dated

Issued

Recd.

Encl.

G. O. 19th Feb. 1877, No. 514

Nos. 434-35

Protection of buildings
from lightning. - Circular
of the Government of India
forwarding a paper by Dr
Mann on the —, Circulated
to all District Engineers
for information.

Chas. W. B. Esq.