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Occasional Papers

Volume I

The following papers by Sir William Snow Harris, F.R.S., inserted in a Circular Memorandum, recently issued by the War Office, contain information of such vital importance to the Artillery, in reference to the safety of Powder Magazines from the effects of Lightning, that the Committee have directed them to be reprinted in the "Occasional Papers." *A. N.*

Lightning Conductors, Principles and Instructions relative to their application to Powder Magazines and other Buildings, by Sir W. Snow Harris. F.R.S.

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1. Thunder and Lightning, result from the operation of a peculiar natural agency through an interval of the atmosphere contained between the surface of a certain area of clouds, and a corresponding area of the earth's surface directly opposed to the clouds. It is always to be remembered that the Earth's surface and the clouds are the terminating planes of the action, and that buildings are only assailed by Lightning because they are points as it were in, or form part of, the Earth's surface, in which the whole action below finally vanishes. Hence buildings under any circumstances, will be always open to strokes of Lightning, and no human power can prevent it, whether having Conductors or not, or whether having metals about them or not, as experience shows.

2. Whenever the peculiar agency, (whatever it may be), active in this operation of nature, and characterized by the general term Electricity or Electric Fluid, is confined to substances which are found to resist its progress, such for example as air, glass, resinous bodies, dry wood, stones, &c., then an explosive form of action is the result, attended by such an evolution of light and heat, and by such an enormous expansive force, that the most compact and massive bodies are rent in pieces, and inflammable matter ignited: nothing appears to stand against it, granite rocks are split open, oak and other trees of enormous size rent in shivers, and masonry of every kind frequently laid in ruins; the lower masts of Ships of the Line, 3 feet in diameter and 110 feet long, bound with hoops of iron ½ an inch thick and 5 inches wide, the whole weighing about 18 tons, have been in many instances torn asunder, and the hoops of iron burst open and scattered on the decks; it is in fact this terrible expansive power which we have to dread in cases of buildings struck by Lightning, rather than the actual heat attendant on the discharge itself.

3. When, however, the electrical agency is confined to bodies, such as the metals, which are found to oppose but small resistance to its progress, then this violent expansive or disruptive action is either greatly reduced or avoided altogether, the explosive form of action we term Lightning, vanishes, and becomes as it were transformed into a sort of continuous current action of a comparatively quiescent kind, which, if the metallic substance it traverses be of certain *known* dimensions, will not be productive of any damage to the metal; if, however, it be of small capacity, as in the case of a small wire it may become heated and fused; in this case, the electrical agency, as before, is so resisted in its course as to admit of its taking on a greater or less degree of explosive and heating effect, as in the former case. It is to be here observed, that all kinds of matter oppose some resistance to the progress of what is termed the Electrical Discharge, but the resistance through capacious

metallic bodies is comparatively so small, as to admit of being neglected under ordinary circumstances; hence it is, that such bodies have been termed Conductors of Electricity, whilst bodies such as air, glass, &c., which are found to oppose very considerable resistance to electrical action, are placed at the opposite extremity of the scale, and termed Non-Conductors or Insulators.

The resistance of a metallic copper wire to an ordinary electrical discharge from a battery, was found so small, that the shock traversed the wire at the rate of 576,000 miles in a second. The resistance however, through a metallic line of Conduction, small as it be, increases with the length, and diminishes with the area of the section of the Conductor, or as the quantity of metal increases,

4. It follows from these established facts, that if a building were metallic in all its parts, an iron magazine for example, then no damage could possibly arise to it from any stroke of Lightning which has come within the experience of mankind; *e.g.*, a man in armour is safe from damage by Lightning; in fact, from the instant the electrical discharge in breaking with disruptive and explosive violence through the resisting air, seizes upon the mass in any point of it, from that instant the explosive action *vanishes*, and the forces in operation are neutralized upon the terminating planes of action, viz., the surface of the earth, and opposed clouds.

5. All this plainly teaches us, that in order to guard a building effectually against damage by Lightning, we must endeavour to bring the general structure as nearly as may be, into that passive, or non-resisting state it would assume, supposing the whole were a mass of metal.

6. To this end. One or more conducting channels of copper depending upon the magnitude and extent of the building should be systematically applied to the walls; these conducting channels should consist either of double copper plates united in series one over the other, as in the method of fixing such Conductors to the masts of Her Majesty's Ships, the plates being not less than 3½ inches wide, and of $\frac{1}{16}$th and $\frac{1}{8}$th of an inch in thickness, or the Conductors may with advantage be constructed of stout copper pipe not less than $\frac{1}{16}$ths of an inch thick, and 1½ to 2 inches in diameter: in either case the Conductors should be securely fixed to the walls of the building, either by braces, or copper nails, or clamps; they should terminate in solid metal rods above, projecting freely into the air, at a moderate and convenient height above the point to which they are fixed, and below they should terminate in one or two branches leading outward about a foot under the surface of the earth; if possible, they should be connected with a spring of water or other moist ground.

It would be proper in certain dry situations, to lead out in several directions under the ground, old iron or other metallic chains, so as to expose a large extent of metallic contact in the surface of the earth.

7. All the metals in the roof and other parts of the building of whatever kind, should so far as possible, have metallic communication with these Main Conductors, and in case of any prominent elevated chimney, it would be desirable to lead a pointed conducting tube along it to the metals of the roof; all of which satisfies the conditions above specified.

8. *Remark* 1.—It is now proved beyond all questions, that the electrical discharge never leaves perfect conducting lines of small resistance, in order to pass out upon bad conducting circuits, in which the resistance is very great, that is an established law of nature; hence a stroke of Lightning upon such

conducting lines will be confined to the Conductors as constituting a line of discharge of less resistance than any other line of discharge through the building, which can be assigned. The apprehension of "Lateral Discharge" therefore, from the Conductor, is quite absurd, and is not countenanced by any fact whatever; if any doubt could possibly exist, it would be now most completely set at rest by the experience of the permanent Conductors, applied to the masts of Her Majesty's Ships. In very many instances furious discharges of Lightning have fallen on the masts with a crash as if the Ship's broadside had been fired, and the solid point aloft has been found melted; in all these cases electrical discharge robbed by the Conductor of its explosive violence, has traversed the line of action to the Sea, through the Ship, and through the copper bolts driven through the Ship's solid timbers, without the least damage to the surrounding masses, whether metallic, as in the case of the massive iron hoops on the lower masts, or not. Persons have been either close by or actually leaning against the Conductors at the time, without experiencing any ill consequence.

9. *Remark* 2.—It has been also been incontestably shown, that metallic bodies have not any specific attractive force or affinity for the matter of Lightning, metals are as little attractive of lightning as wood or stone; all matter is equally indifferent to Electricity so far as regards a specific attraction, hence the idea that metals attract or invite Lightning is a popular but very unlearned error contradicted by the most satisfactory evidence, and the whole course of experience; in short we find, that Lightning falls indiscriminately upon trees, rocks, and buildings, whether the buildings have metals about them or not.

In May, 1841, Lightning struck one of the high cylindrical chimneys at the Royal William Victualling Yard, Plymouth, and rent it for 60 feet down, this chimney is built of granite, is 120 feet high, and has *not a particle of metal in its* construction; but what renders the circumstance more especially applicable to the present case, is the fact, that within 100 yards of this chimney stood a Clock Tower of equal altitude, having a weather-cock and various metallic projections, a dome covered with metal, and a large Conductor along it, to the ground; yet was this clock tower unassailed by the great thunder cloud which spread its Lightnings over an area of certainly not less than 2 miles; and further, the point of the chimney at which the damage ceased was just where it passed through a massive *metallic roof* connected by large Conductors with the ground.

If no other case were on record similar to this, this case alone, according to the best inductive philosophical reasoning, would be sufficient to overturn the whole assumption of the attraction of Conductors for the matter of Lightning, and the vulgar error that such Conductors invite to the buildings the very destruction which they are set up to avoid; in this, as in numerous other recorded cases, the Lightning fell on a structure, which according to the popular error, held no "invitation" by metallic points or attraction; in preference to a structure which did hold out such invitation; a fact wholly at variance with the whole assumption.

10. *Remark* 3.—A building, as is hence clear, may be struck and damaged by Lightning without having a particle of metal in its construction; if there be metals in it, however, and they happen to be in such situations as will enable them to facilitate the progress of the electrical discharge, so far as they go, then the discharge will fall on them in preference to other bodies offering

more resistance, but not otherwise; if metallic substances be not present, or if present, they happen to occupy places in which they cannot be of any use in helping on the discharge in the course it wants to go, then the electricity seizes upon other bodies, which lie in that course, or which can help it, however small their power of doing so, and in this attempt such bodies are commonly but not always shattered in pieces. The great law of the discharge, is,—progress between the terminating planes of action viz.: the clouds and earth, and in such line or lines as upon the whole, offer the least mechanical impediment or resistance to this operation, just as water falling over the side of a hill in a rain storm, picks out or selects as it were by the force of gravity, all the little furrows or channels which lie convenient to its course, and avoids those which do not. If in the case of Lightning you provide through the instrumentality of efficient Conductors, a free and uninterrupted course for the electrical discharge, then it will follow that course without damage to the general structure; if you do not, then this irresistible agency will find a course for itself through the edifice in some line or lines of least resistance to it, and will shake all imperfect conducting matter in pieces in doing so; moreover it is to be especially remarked in this case, that the damage ensues, not where the metals are, but where they cease to be continued, the more metal in a building therefore, the better, more especially when connected by an uninterrupted circuit with any medium of communication with the earth.

Such is, in fact, the great condition to be satisfied in the application of Lightning Conductors, which is virtually nothing more than the perfecting a line or lines of small resistance in given directions, less than the resistance in any other lines in the building, which can be assigned in any other direction, and in which by a law of nature the electrical agency will move in preference to any others.

The popular objections to Lightning Conductors on the ground, that they invite Lightning to the building, that we do not know the quantity of electricity in the clouds, and that hence they may cause destruction, are now quite untenable, and have only arisen out of a want of knowledge of the nature of electrical action. What should we think of a person objecting to the use of gutters and rainpipes for a house, on the ground of their attracting or inviting a flow of water upon the building; and since we do not know the amount of rain in the clouds, it is possible that the building may be thereby inundated, yet such is virtually the argument against Lightning Conductors. *

* It has been recommended to place Lightning Conductors some feet distant from the buildings, or otherwise insulate them from the walls by glass or resin; all this is clearly opposed to the principles upon which the Conductors are applied; we should not place a rain-pipe 10 feet distant from a house if we wish to carry off rain from the roof. A lamentable result of the practice of placing Lightning Conductors distant from a building recently occurred at Compton Lodge, in Jamaica, the residence of J. Senior, Esq. A Lightning Rod, of small dimensions of iron, had been set up within 10 feet of the south-east angle of the building, as practised frequntly in cases of Gunpowder Magazines, on the assumption that the Rod would attract the Lightning, and secure the building. So far from this, the building itself was struck in a heavy thunder-storm, 28th July, 1857. The south-east angle was shattered in pieces; the escape of the family appears to have been miraculous; whilst the Lightning Rod, 10 feet distant, remained untouched. If this building had been a deposit of gunpowder, it would certainly have blown up.

To detach or insulate the Conductors is to run away from our own principle, which is, that the Conductor is the channel of communication with the ground, in which the electrical discharge will move in *preference to any other course*. To detach or insulate the Conductors, is to provide for a contingency at once subversive of our principle. Is it possible to conceive that an agency which can rend large rocks and trees; break down, perhaps, a mile of dense air, and lay the mast of a ship weighing 18 tons in ruins, is to be arrested in its course by a ring of glass or pitch, an inch thick or less, supposing its course were from any cause determined in that direction?

11. It follows from the foregoing principles, that a magazine constructed entirely of iron or other metal, would be infinitely more safe in Lightning storms than if built with masonry in the usual way; metallic roofs for magazines, with capacious metallic Conductors to the earth, would be unobjectionable, and a source of security.

Metallic gutters and ridges having continuous metallic connection with the earth are also unobjectionable.

A good method of Conductors for magazines built of masonry, would be such as already described, regard being had to the position of the building, its extent, and most prominent points, also to the nature, state, and condition of the soil, whether it be moist or dry, alluvial calcareous, or of hard rock; we must also consider the extent, disposition, and peculiar position of the metallic bodies entering into the general structure of the building, whether the roof be flat, or pointed, or angular in various parts.

The pointed projecting extremities of the Conductors, one or more as the case may be, will be commonly sufficient; but, in buildings having tall chimneys or other elevated prominent points, at a distance from the Main Conductor, it will be requisite to guard such chimneys or other parts by a pointed rod, led along them to the metals of the roof, or directly connected with the Main Conductors, by metallic connections.

12. Pointed terminations of the Conductors in the air are so far important that they tend to break the force of a discharge of Lightning when it falls on them. In fact, before the great shock actually takes place, under the form of a dense explosion, a very large amount of the discharge, which otherwise would be concentrated, runs off, as it were, through the pointed Conductor; but they have no other influence. *

With respect to these pointed terminations, no great care need be taken about them, except that they should consist of solid copper rod of about three-quarters of an inch in diameter and about a foot in length, and be united by brazing to the conducting tube, elevated at such convenient height above the walls of the building as the nature of the case may suggest.

As a support to the Conductor, when raised above the wall, we may employ a small staff or spar of wood fixed to the masonry.

It has been occasionally the practice to gild the points of Lightning Conductors, or make them of platinum, or otherwise bestow an extraordinary amount of care on perfecting the point, all of which is not only unnecessary but in some instances detrimental to the action of the Conductor; if, for example, the Conductor be constructed of copper (a metal of high conducting power) then it would be manifestly prejudicial to terminate it in a platinum point, platinum being a metal not having one-half the conducting power of copper.

* A pointed Conductor has been supposed to protect by attraction over a circular area equal to twice the radius of its elevation, which is a pure pice of hypothesis contradicted by experience; *e.g.*, Ships have been struck and damaged by Lightning on the foremast, a pointed Conductor being upon the mainmast.

Much has been said relative to the oxidation of the surface of the metal, but this is of very little moment to the line of conduction, and, in the case of copper, it is trifling. Under any circumstances the metallic oxide is better than the bad or non-conducting air, which is always in contact with the surface of the metal; beside, we observe that in many cases the wires of the Electrical Telegraph transmit currents of electricity with perfect freedom, even when enclosed in gutta percha or other non-conducting matter.

With respect then to the point—it will be sufficient if the terminating solid rod be roughly pointed; almost any termination of the conductor, even if a ball a foot in diameter, would be virtually a point when opposed to a thousand acres of charged clouds.

13. Copper linings to the doors and window shutters of magazines are not objectionable, if requisite, as a precaution against fire; but they are useless as a means of keeping out Lightning; on the other hand, it is not easy to conceive a case in which the explosion of the gunpowder is to be apprehended from the action of Lightning on the doors or windows; supposing, however, such metallic linings desirable as a precaution against common cases of fire, then the masses of metal should, according to the principles already laid down have metallic communication with the general system of conduction in the building and the Main Conductor.

Supplementary Paper.

Lightning Conductors for Magazines and other Buildings.

1. Whether a hollow or solid Conductor be the more desirable, the quantity of metal being the same?

This question has been usually considered in relation to the heating effects of an electrical discharge upon comparatively small Conductors, in which the resistance to the discharge is considerable. In this case a given quantity of electricity melts the same quantity of metal, under whatever form it be placed, whether as a solid or a hollow cylinder for example; at least such is to be inferred from the experiments hitherto contrived. See a paper by Mr. Snow Harris, *Phil. Trans.* for 1827, on Conductors of Electricity, &c, last four paragraphs. In this case it is immaterial whether the Conductor be solid or hollow, provided the mass be the same.

Another and very important view, however, is to be taken of this question, as being applicable to a case in which the mass of metal is considerable, and the heating effect so small as to admit of being neglected; in this case the resistance of the mass, as a mass, is considerable; such a case as this brings us to the consideration of certain statical laws of Electrified Conductors; since for an *evanescent portion* of time, during which a shock of Lightning traverses a Lightning Conductor, we may consider the Conductor as being more or less charged with electricity, tending to pass in a given direction, viz., the direction of the Conductor.

Now it is proved, that, in a case of this kind, the greater the extent of surface over which the Electricity can expand, the less the intensity or activity in any one point; in fact, the intensity approaches the second power or square of the surface inversely, so that a given quantity of Electricity, disposed on twice the extent of surface, has only one-fourth the activity or intensity, whilst twice the quantity on the *same* surface has four times the activity considered in any one point. Take, for example, two Conductors, A and 2 A, whose surfaces are 1 and 2, or double the surface of A; let the masses be the same if you wish.

Then if a given quantity of Electricity be disposed on, or pervade the smaller surface A, an electroscope E will evince a high intensity, and will stand out violently as it were; whereas the same quantity disposed, on 2 A will repose with so much more quietude, on the double surface, that the electroscope E will evince but little comparative action. See *Phil. Trans.* for 1834. page 220, for the laws of this action.

It is hence important to give the charge free room of expansion, by increasing the surface of the Conductor, so as to reduce the mechanical activity of the shock considered as an evanescent charge, to the least possible. This question is still open to much valuable investigation; a large number of facts might be quoted bearing on it.

Rectangular flat bars may be employed, if found convenient for attaching to the walls of a building.

2. In the case of a Rain Pipe, communicating with the Main Conductor, it would be certainly proper to connect it (the pipe) by a metallic communication with the ground, on the principles above explained; it admits of a certain quantity of the charge expanding into a general surface of conduction to the earth, as explained in preceding papers.

Remark.—All those substances, termed imperfect Conductors, such as the masonry of a building, a ship's masts, &c., are, nevertheless, Conductors to a certain extent, they will always be enabled to transmit a *given quantity* of Electricity without explosive action. In any case of a ship or building struck by Lightning, doubtless some Electricity always passes off in this way up to the limit of conducting power; *one* great end of the Conductor is to relieve the wood or masonry of the quantity it cannot discharge without explosion; by thus completing the conducting power of the general mass we *use up*, as it were, in connection with the Conductors, all the useful conduction of the wood of a ship's mast or the masonry of a building, and so convert into a source of safety what would otherwise be inefficient to the security of the building, all this is consistent with principles, before explained, relative to resistance.

3. Whether Conductors of iron may not be employed for buildings, copper being expensive and liable to be stolen, &c.?

The common Conductors of small iron rod or wire are very objectionable, they commonly rust out at the joints and have fallen to pieces, and have been often knocked in pieces by Lightning. If iron be employed, which it certainly may be, and with advantage, it should be coated with zinc, a modern practice, or what is called "*galvanized.*" Zinc is even a *better* Conductor than iron, and, being spread over the surface, would not be open to the objection of making a Conductor of two metals of unequal conducting power; in the case of the charge being constrained to pass out of the one into the other, in continuation; zinc has one-third the conducting power of copper; iron has only about one-fifth the conducting power of copper.

Where the Conductors are capacious, as respects the intensity of the shock, and are not heated sensibly, the transmission of the charge, as a question of mere conduction approaches a ratio of equality; in *heavy* shocks of Lightning the differences are important. Still there is no doubt but that a good and efficient Conductor might be formed of galvanized iron;* it should be wrought iron, and the best form would be galvanized iron pipe of two inches diameter, firmly screwed together, in joints of *extra* thickness, as in certain gas pipes; copper tubing of a given thickness, however, is always to be preferred.

4. In the case of a dry or rocky soil, it is certainly desirable to complete, so far as possible, the conducting power of the ground about the building, either by leading old iron chain out from the walls in several directions, or by leading a flow of water over it, if possible; the distance and direction of such artificial ground conduction must depend on circumstances of situation of the building. The surface of the earth being, as remarked in former paper, one of the terminating planes of the electrical action; the indication is to provide, so far as possible, for the expansion of the final shock passing through the Conductor, without which the Conductor is more or less insulated. Fortunately a thunderstorm is usually attended by heavy rain.

In the case of a building, situate on a dry or rocky soil, old iron chains may be let out from the Conductor in various directions, to the extent of about 10 or 15 yards, and from a foot to eighteen inches under the surface of the earth, and it would be further desirable, in such cases to lead a flow of rain, so far as possible, over the surface of the ground, about or near the Conductor; the termination of the Conductor in a large surface of moist earth would be even preferable to its termination in a spring of water, sunk deep, as in a well, into the ground; the action here is a superficial action of expansion in all directions. We see in the *tin* leaf coatings of the electrical jar, that the charge is in no degree influenced by the thickness of metal.

W. SNOW HARRIS.

Description of Copper Lightning Conductors, recently fixed to the new Powder Magazines, at Weedon.

The tubular Conductors on the roofs consist of wrought copper tubing, one inch diameter, and one-eight of an inch thick; and are led over the slating, and under the copings, on the inside of each gable, from the apex, towards the eave and valley gutters; and connected with the Conductor on the ridge. The Conductors running from the ridge to the valley gutters are screwed to the flat Conductors, which pass over the valley kneelers.

* Experience is not wholly in favour of the durability of the galvanized coating of iron.

The flat Conductors are fixed to the brickwork of the gables, by wrought copper holdfasts.

The flat Conductors which pass over the valley kneelers are three inches wide, and one-eighth of an inch thick, connected with and rivetted to the copper rain water-down pipes on the face of the building; thus forming a direct metallic communication with the ground; on the outer slopes of the roofs, by the copper eaves, gutters, and descending pipes in the centre of the building.

Pointed solid copper rods half an inch diameter are fixed on the point of each gable, in connection with the Conductor, on the ridge, and projecting five feet above the highest part of the building.

The Conductors or rods on the opposite gable of each roof are connected by a copper band, four inches wide and one-eighth of an inch thick, securely fixed on the ridge roll, by wrought copper nails, about two feet apart.

The copper sheathings on the doors of Magazines are connected with the lower end of the rain water pipes by flat copper bands, two inches wide, and one-eighth of an inch thick, fixed to the stone plinth by copper nails driven into wood plugs about half an inch diameter and two feet apart.

A copper band two inches wide, one-eighth of an inch thick, and about eighteen inches long, is lapped round the lower end of the rain water pipes at the surface of the ground, and fixed to the stone plinth; this band is rivetted to the upper end of the underground Conductor.

The underground Conductors, three inches wide and one-eighth of an inch thick, fixed to the band at the foot of each copper rain water pipe, run four feet from the building, to the end of which are rivetted two copper bands, each eight feet long, two inches wide, and one-eighth of an inch thick, these Conductors are about two and a half feet from the surface of the ground at the lowest end, and covered with coal ashes and earth.

Where the tubular Conductors could not be had of sufficient length in one piece, they are connected by an union joint, and strengthened by a small pipe or ferrule, about four inches long, inside the tube, and rivetted to each end in the same manner as the tubes are connected to the ridge.

In the old magazines, where the rain water pipes are lead, the tubular conductors are continued from the roof to the ground.

Letter from Mr. Heather of the Royal Military Academy, on the Method of Laying Mortars.

Woolwich, 28th July, 1858.

MY DEAR SIR,

The method of firing mortars with picket and plumb line, has often appeared to me to possess rudeness without simplicity, and to be deficient, both as regards *accuracy* and *quickness* of firing.