U.S. WEATHER BUREAU

U. S. DEPARTMENT OF AGRICULTURE,
U.S. WEATHER BUREAU.

CIRCULAR OF INFORMATION.

Circulars
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PROTECTION FROM LIGHTNING

BY

ALEXANDER McADIE,
U. S. WEATHER BUREAU.

3d Edition.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
WEATHER BUREAU.
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., May 14, 1894.

Sir: I have the honor to transmit herewith the accompanying circular of information entitled "Protection from Lightning" and to recommend its publication as a Circular of the Weather Bureau.

Very respectfully,

Mark W. Harrington,
Chief of Weather Bureau.

Hon. J. Sterling Morton,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

WASHINGTON, D. C., *April* 24, 1894.

SIR: In accordance with the direction of the Honorable the Secretary of Agriculture, in letter of April 18, 1894, the accompanying paper, entitled "Protection from Lightning," is submitted for publication as a circular of information. Upon few subjects is the community so liable to be misled as the question of the best methods of protecting life and property from lightning. The following pages give statistics of actual losses, the theory of protection in language free from technicalities, a collection of practical rules for guidance in selecting and maintaining conductors, and, finally, a notable illustration of the successful use of protectors.

The aim of the paper is to furnish information of practical value to all classes, and especially to farmers, builders, and physicians.

Very respectfully,

ALEXANDER MCADIE.

MARK W. HARRINGTON,
Chief of Weather Bureau.

LETTER OF SUBMITTAL.

WASHINGTON, D. C., *April 26, 1894.*

SIR: In accordance with the direction of the Honorable the Secretary of Agriculture, in letter of April 18, 1894, the accompanying paper, entitled "Protection from Lightning," is submitted for publication as a circular of information. Upon few subjects is the community so liable to be misled as the question of the best methods of protecting life and property from lightning. The following pages give statistics of actual losses, the theory of protection in language free from technicalities, a collection of practical rules for guidance in selecting and maintaining conductors, and, finally, examples illustrative of the successful use of protectors.

The aim of the paper is to furnish information of practical value to all classes, and especially to farmers, builders, and physicians.

Very respectfully,

ALEXANDER MCADIE.

MARK W. HARRINGTON,
Chief of Weather Bureau.

PROTECTION FROM LIGHTNING.

At the Aberdeen meeting of the British Association for the Advancement of Science Sir William Thomson made the remark, "If I urge Glasgow manufacturers to put up lightning rods they say it is cheaper to insure than to do so."

This was the answer given by practical business men, concerned only with questions of profit and loss, to the foremost physicist of our time; and their answer will serve as fairly representing views widely held, founded upon the double belief that the risk from lightning is not so very great and the protection afforded by the present methods not sufficiently certain to warrant implicit confidence and justify the necessary expense.

The recent remarkable experiments of Dr. Oliver Lodge, in his lectures before the Society of Arts, opposing and to some degree directly contradicting the empirical rules of the Lightning Rod Conference, have given support to the belief that the protection was uncertain. Indeed, realizing that his work might be misinterpreted, Lodge has stated "an idea at one time got abroad that my experiments proved existing lightning conductors to be useless or dangerous; this is an entire misrepresentation. Almost any conductor is probably better than none, but few or no conductors are absolute and complete safeguards. Certain habits of lightning rod practice may be improved and the curious freaks or vagaries of lightning strokes in protected buildings are intelligible without any blame attaching to the conductor; but this is very different from the contention that lightning rods are unnecessary and useless. They are essential to anything like security."[1]

What Lodge's brilliant experimental work does show is that the momentum of an electric current can not be overlooked in a lightning discharge. The old "drain-pipe" idea of conveying electricity gently from cloud to earth must give place to the new proposition, based upon recent discoveries, that even draining off must be done in an appropriate way to be effective. To illustrate, the rocks and trees upon a mountain side may influence and determine the course of a mountain stream, but even a good sized channel would not suffice to carry off safely an avalanche, or control the path of a landslide; so with lightning. In the past four years we have learned, through the work of Hertz and others, that when an electric current flows steadily

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[1] Page VI. "Lightning Conductors and Lightning Guards."

in one direction in a cylindrical wire its intensity is the same in all parts of the wire; but if the current be of an oscillatory character, i. e., a current which rapidly reverses its direction, the condition no longer holds, and if the alternations are very rapid the interior of the wire may be almost free from current. If lightning then be a discharge of an oscillatory character, it may happen that the current down the lightning rod would be only *skin* deep. The experiments of Tesla and Elihu Thomson with currents of great frequency of alternation and very high potentials open the door to systematic study of discharges such as the ordinary lightning flash. In daily work currents of this type are coming more and more into prominence, and the time is not far distant when the lightning flash will be studied as an electrical discharge of this character. Protection entirely adequate for such discharges will then be forthcoming. Indeed, the reasons why present methods occasionally fail are now understood, and the proper remedies apparent.

And first let us see whether it is cheaper to insure than to provide proper protection. Foreign countries, especially Germany, France, and Great Britain, have recognized the importance of obtaining reliable data concerning the loss of life and damage to property through lightning. Perhaps the work of the Royal Prussian Bureau of Statistics[1] gives the fullest and most detailed accounts of the damage done by lightning in Germany, and the relative injury. Statistics are available for the number of houses struck, the number of fires, the character of the roofing, soil, etc.

In 1891 the Weather Bureau issued to its observers instructions to report at the end of every month the names, with corroborative dates and places, of all persons killed by violent windstorms, tornadoes, and lightning. During 1890 somewhat similar statistics had been gathered, but the returns were less systematically arranged. In preparing the Weather Bureau lists, observers were directed to examine all daily papers published in their respective cities, consult all local authorities, and make inquiry if necessary. Naturally, where dependence was had upon newspaper items, there resulted much duplication, but in verifying names and dates the duplicates quickly appear and exaggerated reports are easily confined to proper limits.

From the Weather Bureau records which have been tabulated, it appears that in the United States, for the four years 1890–'93, 784 lives were lost, an average of 196 lives per year.

It is also evident that these lives were practically all lost in five months—April to September—and that in June and July the maximum death rate occurs.

The Weather Bureau records unfortunately do not give informa-

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[1] Beiträge zur Statistick der Blitzschläge in Deutschland; von Dr. Hellman, Berlin, 1886.

tion as to the extent of damage to property. To get at something like a fair commercial estimate of the destruction of property by lightning, I have made use of the "Chronicle Fire Tables" for the eight years 1885–'92. It is hardly necessary to remark that these tables are compiled from the reports of the fire departments, insurance companies, and the reports of fires in the public press, and represent a high degree of accuracy.

From information contained in these volumes, the following tables have been compiled:

Fires caused by lightning.

Year.	Number of fires.	Loss on original risk.
1885 to 1890, inclusive	2,220	$8,386,826
1891	457	1,355,525
1892	839	2,921,484

Or, in eight years, ending 1892, in the United States, and for the most part east of the Rocky Mountains, 3,516 fires, with a loss of $12,663,835.

It is very evident, therefore, that the damage done by lightning is no inconsiderable matter to be lightly passed over or turned off by replies such as the one given by the Glasgow manufacturers. It is certainly worth while to erect the proper protective apparatus.

The following table shows the number of barns, stables, granaries, churches, and dwellings set on fire by lightning during the years 1890, 1891, and 1892:

Year.	Barns, stables, and granaries.	Churches.	Dwellings.
1890	363	29	121
1891	290	11	78
1892	495	29	177

During nine years ending 1892, 2,335 barns, 104 churches, and 664 dwellings have been struck by lightning.

The question has often been raised whether there exists a periodicity in the number of lightning strokes. Statistics must cover a period of at least twenty years before an answer to this question can be given, but it is interesting to compare the number and kind of buildings struck for the last two years of which we have record.

	1891.	1892.
Barns, granaries, and stables	290	495
Churches	11	29
Country and general merchandise stores	5	6
Dwellings and tenements	78	177
Electric light stations	1	2
Grain elevators	2	4
Grain fields	1	....
Grain, hay, and straw in stack	10	12

	1891.	1892.
Ice houses	4	4
Lighthouses and life-saving stations (no other source of fire reported)	2	
Livery stables	4	4
Lumber yards	2	1
Oil refineries	2	2
Oil tanks	2	22
Railroad depots	5	7
Telegraph and telephone offices	2	3

It is of particular interest to study the geographical distribution of the dwellings and barns struck in these two years. There are some notable increases in certain States, the reasons for which are not at present discernable. Attention is directed to the figures in bold-face type.

State.	Barns.		Dwellings.	
	1891.	1892.	1891.	1892.
Connecticut	9	**23**	6	**16**
Delaware	4	5		
Illinois	17	7	7	**12**
Indiana	31	38	7	9
Iowa	19	6		
Kansas	1	2		
Kentucky	3	4		
Maine	21	23	7	**16**
Maryland	12	8		**6**
Massachusetts	12	15	8	**12**
Michigan	26	**70**		**13**
Minnesota	7	5	4	6
Mississippi	1			
Missouri	2	1	2	3
Nebraska	1			
North Carolina	2	3		2
New Hampshire	2	2		
New Jersey	14	**30**	3	**7**
New York	30	**117**	5	**23**
Ohio	26	26	6	4
Oregon	2			
Pennsylvania	29	**73**	3	**23**
Rhode Island	1	4		2
South Carolina	3			
South Dakota	3	3		
Texas	4	7		
Virginia	4			2
Wisconsin	6	**11**	2	3

According to the statistics of the German bureau, previously referred to, the frequency of lightning stroke varies somewhat with the character of the land. Thus, in their investigations it was found that in flat lands 400 to 540 buildings were struck out of 1,000,000, the rate varying in different localities.

The nature of the material used for roofing has also been considered. Classifying the various materials under the general heads "hard" and "soft," the German investigators found for ten years (1873–'83) for Schleswig-Holstein, that of all the buildings struck, 9 per cent of those having *hard* roofs and 68 per cent of those having *soft* roofs were set on fire. The nature of the building and the purpose for which it is used will, as we readily see also in our own statistics, influence the liability to stroke and fire.

One interesting point which appears to be shown by statistical studies of lightning stroke is the decreased liability to accident in *thickly settled* communities.

It may be said, in general, that the risk in the country is five times greater than in the city. For ordinary dwelling houses, not unduly exposed in city blocks, lightning rods are hardly necessary, a very considerable protection being afforded by the tin roofing, numerous cornices, gutters, etc. The geological, as well as the topographical conditions, may have some influence upon the frequency of lightning stroke. According to the authority already quoted, if 1 represents the frequency of lightning stroke in a chalk formation, 2 will represent the liability for marl, 7 for clay, 9 for sand, and 22 for loam.

With regard to trees, the oak is most frequently, and the beech least frequently, struck. The values are something like, if 1 represents the frequency for the beech tree, 15 for pines, other trees generally averaged at 40, and 54 for oaks. Trees struck are most generally those standing in the clear or on the edge of forests, and in height averaging from 16 to 20 meters (52 to 66 feet). The trunk appears to be struck about three times as often as the boughs, and generally the stroke seems to travel to the ground. Only in three out of a hundred cases did it jump to other trees.

Mr. Symons,[1] in his paper on thunderstorms, instances 16 trees struck. About one-third of these were elms, with the oak, ash, poplar, in order following, and one case each of crab-lime and willow.

It is interesting to recall at this point, the record made by Hugh Maxwell as early as 1787, that the elm, chestnut, oak, and pine were often struck, the ash rarely, and the beech, birch, and maple never. This last, however, is not true. Indeed, it is not altogether plain just why some trees escape while others suffer. Capt. Maclear,[2] discussing the action of lightning during a thunderstorm on June 6 and 7, 1889, found a great number of trees struck within a radius of 4 miles, and set to work to discover if possible the cause of the selection of these particular trees. "For contrary to general expectations," he says, "they were not the highest nor the most prominent in their immediate vicinity." A cottage, a haystack, 2 poplars, a spruce, fir, and 5 oaks, in different places, were struck within this confined area.

The storm passed in a northwest direction with southeast wind, and it is apparent that the objects struck lie nearly in a line northwest and southeast, 3 miles in length. "The spruce was very prominent on the southern brow of the hill, with two arms nearly in line with the stem; one arm was thrown to the ground and the other

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[1] Also, Appendix E. "Report of Lightning Rod Conference."

[2] "Quart. Journ. Met. Soc." 1890, p. 229.

blown down. At the juncture of the arms there was a great deal of turpentine which was thoroughly blackened." Hence, it is assumed that the prominence of the tree made it the best communication to earth, and that the collection of turpentine was raised to explosive temperature and split the tree, but a like good reason does not appear for the other objects struck. On the next day 6 oaks, a chestnut, and an ash, in various positions within one-half mile of a pond, and on the slope of ground near the pond, a young fir, and three young oaks; one-half mile south of Cranleigh 4 oaks; on Cranleigh Common an oak, and 1 mile northwest a chimney, a stable, and an oak (struck also on the day before) and a single oak occupying a fairly prominent position on the slope of high hills, 2½ miles northeast.

This last tree was struck just before the rain commenced and was split; the other trees struck during the rain were only scored. "Hence," concludes Maclear, "it is not easy to see the cause of selection, for these trees were not the most prominent, nor were they on the highest ground in the vicinity, *the only feature the groups possessed in common being that they were all either near ditches which were full of running water, or else near temporary courses taken by the deluge of water from the higher to the lower ground.*[1] The most puzzling case is that of the young fir tree and 3 young oaks in the middle of the copse near the pond. They were not higher than the other trees on the copse, but there certainly was a temporary water course close to them; other trees, however, stood equally close to water. * * * Another curious case is that of the stable struck, which was overshadowed by tall elms, where it might have been supposed that these would have taken the stroke."

Some statistics of the damage done by lightning stroke in Belgium[2] in 1889 may be appropriately inserted here. Of 324 lightning flashes, 2 struck lightning rods; 123 struck buildings, setting 36 on fire; 16 struck persons; 96, trees; 81, telegraph and telephone lines; and others, miscellaneous. In other statistics we find that of 18 deaths due to lightning; 1 occurred within a dwelling, 11 out of doors, and 6 under trees. Contrasted with the cases of death resulting from lightning stroke, let us look at 43 cases of persons struck, with results not necessarily fatal, and we find that 20 of these were in doors, 23 out of doors, including 4 under trees. No records sufficiently extended and authentic are available to ascertain what proportion of persons struck by lightning are killed outright. I know of but one record, and in that of 212 persons struck 74 were killed. This question, which is of the greatest interest, is referred to again under the last of the rules given further on for the protection of life.

One of the peculiar and most common characteristics of the action

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[1] Italics mine.

[2] Evrard and Lambotte. *Ciel et Terre*, 1891; No. 7.

of lightning is the *tearing off* or *throwing* effect. This, as we shall see further on, is just what might be expected from discharges of great frequency of alternation. Some interesting statistics are given by Parnell[1] on the mechanical tearing off and disruptive effects of lightning as distinguished even from the *heat* effects. He records 1,147 cases. Of these, 224 do not permit a determination of the character of the work done by the stroke of the remaining 923.

	Mechanical work.	Heat.
Persons and animals	52	79
Cloths, carpets, canvas, woolen, linen, and cotton goods	88	79
Masonry of all kinds	416	2
Glass, china, earthenware	82	5
Metal	206	173
Wood	254	98
Trees	63	4
Ground	60	....
Thatch, straw, etc	....	11
Gunpowder	....	15
Gas	....	19
Total	1,221	485

Col. Parnell gives, furthermore, the details in 278 cases to show the existence of an *upward* direction in the force of the stroke.

This, and the statement that "probably few persons are aware that lightning strokes are more apt to bend or break metal than to fuse it," are, in the light of the investigations of the past three years into the character of the lightning flash, easily comprehensible. A lightning flash being a break in the air (i. e., the dielectric) when the electrical strain exceeds a certain value, determined by several variables, the strongest mechanical effect may be found in any direction, upward or downward. Speaking popularly, flashes may go from cloud to earth, earth to cloud, or from cloud to cloud to earth.

II.

Beyond doubt, Franklin proved his case that lightning rods were efficacious in the protection of buildings. An illustration of the action of lightning upon a rod is shown in Fig. 4. Buildings with conductors when struck by lightning suffered little damage compared with those without protectors.

The chief defects likely to occur are blunted points and breaks in the continuity of the connection. The function of a lightning rod is twofold; first, that of conducting the charge to earth, and second, the prevention of a disruptive discharge by silent neutralization of the cloud electrification. The latter explains why a rod terminates in a point and likewise why points in good connection with the ground are always *desirable* upon buildings. Indeed, points are somewhat like small water pipes connected with a large reservoir. If you have

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[1] "Quart. Journ. Met. Soc.," Vol. VI, 1885. See also Col. Parnell's book.

enough of them and a sufficient time you may drain the largest reservoir. Furthermore, when some sudden rise or flood occurs in the reservoir, these minute drains may be of service in keeping the height of the water down.

In the case of lightning the points are the small escape pipes, the layer of air between cloud and earth the retaining wall, and the cloud electrification—or charge—the overflowing and destructive element. A large conductor, be it rod or tape, on the other hand is more like a large main or water way, which has its gate shut until the flood is imminent. Then the gate is suddenly opened and we try to compel the torrent to keep to the provided path. We trust in its ability to safely hold the flood. Generally it does. In perhaps nine cases out of ten, the lightning conductor, if it be such a one as we will describe later, does carry the flash to earth; but there are cases where the discharges have been heavy and overflows have resulted. To carry the lightning flash "the lightning conductor should offer a line of discharge more nearly perfect and more accessible than any other offered by the materials or contents of the edifice we wish to protect." To prevent the discharge "the conductor should be surrounded by points." These quotations are from the Report of the Lightning Rod Conference.

The statement that lightning always follows the path of least resistance, as commonly understood and stated, needs modification. True it is, that when the air is strained by being subjected to the electrifications of cloud and earth, the weakest spot gives away first, and this is apt to be in line with some small elevated knob or surface; but it is equally true, and is perhaps the more general case, that when a really vigorous disruptive discharge does occur, it is somewhat, as Dr. Lodge aptly puts it, like an "avalanche." As a matter of fact, we find from the study of actual cases where buildings have been struck, that lightning often disregards entirely metallic surfaces and points. What we should first know is, whether the condition is to be one of "steady strain"[1] or "impulsive rush"[1] discharge. In the case of "steady strain," the metal is apt to influence the path of discharge; in the case of an "impulsive rush" discharge, even *points* seem to lose their efficiency and become of little use.

In a letter[2] of an old British admiral there occurs a description of his being called upon to approve some specifications for a lightning conductor to be erected on a certain lighthouse. He was himself a believer in the "surface" theory of Harris; but thought that, to make sure, he would go and consult his friend Faraday. Faraday, who saw only the question of conductivity in the problem, said very positively that the solid rod was better than the tube (which gives

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[1] Terms used by Prof. Lodge.

[2] See report of Lightning Rod Conference.

greater surface with less copper), and that *solid volume was everything*, superficial area nothing. Moreover, if Harris says otherwise "then, he knows nothing whatever about it." The admiral straightway approved the solid rod conductor for the lighthouse. Within two or three days he met Harris, and bringing up the question was told by Harris "*surface* area is most important, and if Faraday says otherwise, then he knows nothing whatever about it!"

Up to a certain point Faraday was right; a copper rod an inch thick is capable of carrying almost any flash of lightning, and is undoubtedly a great protector, but if, as we have reason to believe, the core is seldom given a chance to carry the current, why have it? The views of Sir W. Snow Harris, based as they were upon close study of many thousand cases of lightning action, are finding in the experiments of to-day the confirmation so long needed.

While not going into details regarding this question of the shape of the rod, let us emphasize the fact, so recently brought out, that if an electric current flows steadily in one direction in a cylindrical wire, its intensity is the same in all portions of the wire, as shown by Hertz, but that with a current of an oscillatory character, i. e., a current which rapidly reverses its direction, this condition no longer holds, and if the direction is altered very rapidly the interior of the wire, in our case the lightning rod, may be almost free from current.

In 1882 appeared the report of the Lightning Rod Conference; in many respects the most important contribution to the literature of the subject yet made. While so many foreign governments, and in particular France, had by means of officially constituted boards taken a governmental interest in the protection of the people from the dangers of lightning, the English-speaking people of the world aside from the few directions officially issued for the protection of magazines and lighthouses, remained without any authoritative utterance upon the subject; and while this conference itself did not have strictly official sanction, it carries, from the character of its make-up, a weight certainly as great, if not greater, than an official board. It was simply a joint committee of representative members of the Institute of British Architects, the Physical Society, the Society of Telegraph Engineers and Electricians, the Meteorological Society, and two co-opted members. As might be anticipated from such auspices, the report is an excellent one, and must stand for years as the embodiment of the most widely gathered information and well-considered decisions. The report is emphatically one based upon *experience.*

The famous free-for-all discussion which occurred at the British Association Meeting in 1888, so far as our judgment goes, simply proved that the decisions of the conference could not at present be disregarded. As the president of the meeting, Sir William Thomson said, we have "very strong reason to feel that there is a very comfortable degree of security, if not of absolute safety, given to us by lightning conductors made according to the present and orthodox rules."

There are one or two further features to which attention may be called. There are some very prevalent misapprehensions with regard to lightning. For example: that it never strikes twice in the same place; that the most exposed place is always struck; that a few inches of glass or a few feet of air will serve as a competent insulator to bar the progress of a flash that has forced its way through a thousand feet of air, etc. These are alluded to in the following general directions.

III.

1. Erection of rods. Few questions have been so thoroughly discussed from practical as well as theoretical standpoints as that of the certainty of the protection afforded by properly constructed lightning rods. All barns and exposed buildings should have lightning rods. Ordinary dwelling houses in city blocks have not the need for rods that scattered houses in the country, and especially if on hill sides, have.

2. Use a good iron or copper conductor. If the latter, one weighing about 6 ounces to the foot, and preferably in the form of tape. If iron is used and it seems to be in every way as efficient as copper, have it in rod or tape form and weighing about 35 ounces to the foot. "A sheet of copper constitutes a conductive path for the discharge from a lightning stroke much less impeded by self-induction than the same quantity of copper in a more condensed form, whether tabular or solid." (Sir William Thomson.)

3. The nature of the locality (see Chapter I) will determine to a great degree the need of a rod. Places apart but a few miles will differ greatly in the relative frequency of flashes. In some localities the erection of a rod is imperative; in others, hardly necessary.

4. The very best ground you can get is, after all, for some flashes but a very poor one; therefore, do not imagine that you can overdo the matter in the making of a good ground. For a great many flashes an ordinary ground suffices, but the small resistance of $\frac{1}{10}$ ohm for an intense oscillatory flash may be dangerous. Bury the earth plates in damp earth or running water.

5. "If the conductor at any part of the course goes near water or gas mains, it is best to connect it to them. Wherever one metal ramification approaches another it is best to connect them metallically. The neighborhood of small bore fusible gas pipes and indoor gas pipes in general should be avoided." (Lodge.)

6. The top of the rod should be plated or in some way protected from corrosion and rust.

7. Independent grounds are preferable to water and gas mains.

8. Clusters of points or groups of two or three along the ridge rod are recommended.

9. Chain or linked conductors are of little use.

10. Area of protection. Very little faith is to be placed in the so-called area of protection. The committee that first gave authority to this belief considered that the area protected by any one rod was one with a radius equal to twice the height of the conductor from the ground. Many lightning rod manufacturers consider that the rod protects an area of radius equal to the height. The truth is that buildings are struck sometimes within this very area, and we now hold there is no such thing as a definite protected area.

11. Return shock. Some uncertainty exists on this point. The so-called "return stroke" is caused by the inductive action of the charged cloud on bodies within its influence, and yet some distance away from the place of the direct discharge. As explained by Lord Mahon, who first called attention thereto, the sudden return of the body charged inductively to a neutral condition, following the equalization at some distant place, is the cause of the return shock. We are beginning, however, to see more clearly into the character of the stress in the dielectric, preceding and during flashes, and it is only a question of time before the use of this term, "return shock," will be abandoned. Of far greater import are the terms "recoil kick" and "alternative path," as shown experimentally by Lodge to exist.

12. Upward motion of stroke. There is no reason to doubt that the discharge takes place sometimes from earth to cloud. That is to say, that while we now consider a lightning flash as something like the discharge of a condenser through its own dielectric, made up of excessively frequent alternations, say something like 300,000 times per second, the spark, or core of incandescent air, may seem to have had its beginning at the earth's surface. That is to say, the air gap breaks down first at a point near the earth.

13. Indifference of lightning to the path of least resistance. Nearly all treatises upon lightning up to within very recent times, assumed that lightning always followed the path of least resistance. "It is simply hopeless to pretend to be able," says Lodge, "to make the lightning conductor so much the easier path that all others are out of the question." The path will depend largely upon the character of the flash.

14. Any part of a building, if the flash be of a certain character, may be struck, whether there is a rod on the building or not. Fortunately, these are exceptional instances. The great majority of flashes in our latitudes are not so intense but that a good lightning rod, well

earthed, makes the most natural path for the flash. We have many instances, however (not to be confounded with cases of defective rods), where edifices, seemingly well protected, have been struck below the rods.

15. Parodox of parodoxes, a building may be seriously damaged by lightning *without having been struck at all.* Take the famous Hotel de Ville of Brussels. This building was so well protected that scientific men pronounced it the best protected building in the world against lightning. Yet it was damaged by fire caused by a small induced spark near escaping gas. During the thunderstorm, some one flash started "surgings" in a piece of metal not connected in any way with the protective train of metal. The building probably did not receive even a side flash. This is, therefore, a new source of danger from within, and but emphasizes the necessity of connecting metal with the rod system.

16. Lightning does sometimes strike twice in the same place. Whoever studies the effects of lightning's action, especially severe cases, is almost tempted to remark that there is often but little left for the lightning to strike again. No good reason is known why a place that has once been struck may not be struck again. There are many cases on record supporting the assertion.

17. As lightning often falls indiscriminately upon tree, rock, or building, it will make but little difference sometimes whether trees are higher than adjoining buildings.

18. It is not judicious to stand under trees during thunderstorms, in the doorway of barns, close to cattle, or near chimneys and fire places. On the other hand, there is not much sense in going to bed or trying to insulate one's self in feather beds. Small articles of steel, also, do not have the power to *attract* lightning, as it is popularly put, or determine the path of discharge.

19. Unnecessary alarm. Just in advance of thunderstorms, whether because of the varying electrical potential of the air, or of the changing conditions of temperature, humidity, and pressure, and failure of the nervous organization to respond quickly, or to whatever cause it may be due, it cannot be denied that there is much suffering from depression, etc., at these times. It is, perhaps, possible that these sufferings may be alleviated. Apart from this, many people suffer greatly from *alarm* during the prevalence of thunderstorms, somewhat unnecessarily, we think. Grant even that the lightning is going to strike close in your vicinity. There are many flashes that are of less intensity than we imagine, discharges that the human body could withstand without permanent serious effects. Voltaire's caustic witticism "that there are some great lords which it does not do to approach too closely, and lightning is one of these," needs a little revision in these days of high potential oscillatory currents. Indeed,

the other saying, "Heaven has more thunders to alarm than thunderbolts to punish," has just so much more point to it, as it is nearer the truth. *One who lives to see the lightning flash* need not concern himself much about the possibility of personal injury from that flash.

20. Finally, if you should be in the vicinity of a person who has just been struck by lightning, no matter if the person struck appears to be dead, go to work at once and try to restore consciousness. There are many cases on record proving the wisdom of this course; and there is reason for believing that lightning often brings about suspended animation rather than somatic death. Try to stimulate the respiration and circulation. Do not cease in the effort to restore animation in less than one hour's time. For an excellent illustration of a case of severe lightning shock and recovery, due, it would seem, to prompt action by the medical gentlemen present, all who are interested may consult the "Medical News," August 11, 1888. A number of cases corroborative of this view are on record in various medical journals.

IV.

A practical application of the efficiency of lightning conductors will now be considered. On June 5, 1885, the Washington Monument, at Washington, D. C., at that time the highest edifice in the world, was struck by lightning. The barograph curve (Fig. 6) shows the fluctuation in pressure about the time of the occurrence of the stroke, 3.15 p. m. The storm itself was, as usual, a secondary depression in the southeastern or southern quadrant of a "low" area, and at Washington resulted in a high forenoon temperature, with a maximum of 90° F. about noon, with fresh southerly winds, veering to southwest at noon; to northwest at 1.23 p. m.; to northeast at 1.40 p. m., and backing to northwest at 1.42 p. m.; to east at 2.20 p. m.; to northwest at 2.37 p. m., and veering to northeast at 2.40 p. m., from whence it shifted to southwest at 3.02 p. m.; to northwest at 3.10 p. m., and at 7 p. m. was blowing steadily from the north. The first thunder was heard at 1.07 p. m., and rain began at 1.23 p. m., ceasing at 2 p. m., commencing again at 2.20 p. m., and ending at 3.05 p. m. Thunder continued at frequent intervals to 3.50 p. m. The rain was at times heavy, and hail fell in the northern part of the city. Amount of rainfall at Signal Office, 0.61 inch.

Col. Casey, U. S. Army, the engineer in charge of the construction of the monument, requested Profs. Rowland, Newcomb, and Mendenhall to examine the part struck and suggest what precautions should be taken to ensure the safety of the monument. It is proper to remark that the monument had been for all practical purposes finished and had already experienced storms of seemingly greater violence.

From the letter[1] of the commissioners charged with the completion of the monument, we find that "a considerable amount of unexpected work" was performed in the erection of rods and points to protect the obelisk from lightning. "The lightning protectors as established for the monument were commenced in January, 1880, and were finished in January, 1885," practically the date of completion of the monument. The elevation of the solid aluminium pyramid (which weighs 100 ounces and is 8.9 inches high and 5.6 inches square at base, with angle at the vertex of 34° 48′) is 555 feet (169.16 meters).

The conductors consist of the four hollow wrought-iron Phœnix columns, supporting the elevator machinery. "The bottoms of these four columns rest upon and are bolted to cast-iron shoes, standing upon the floor of the large drum pit, * * * and the shoes are connected to ¾-inch soft copper rods, led to the bottom of a well in the center of the foundation. This well is 32 feet 10 inches in depth below the bottom of the drum pit and 15 feet 8 inches below the bottom of the masonry foundation, and the water stands in it permanently 2 feet 8 inches above its bottom. After the copper rods were inserted the well was filled up with clean sharp sand for a depth of 15 feet 8 inches, or up to the level of the bottom of the old rubblestone foundation of the monument. These four columns so arranged at their bases, *and always projecting above the top of the shaft*, *were continually lengthened as the building of the shaft progressed*, *and for the five summers during which the masonry was in progress acted as the lightning conductors of the edifice.*[2] No disruptive discharge of electricity was experienced during those years." When the marble pyramidion was completed, December, 1884, these four columns were within this marble covering, and from the extremity of each column a copper rod ¾ inch in diameter was run to the top stone and there united in a copper rod 1½ inches in thickness, which passed vertically through the cap stone and was screwed into the solid aluminium pyramid.

The conductors "when tested, gave an electrical resistance of .1 ohm from the tip of the terminal to the copper rods at the base, and 2.2 ohms for the ground connections, making a total resistance of 2.3 ohms for the conductor. The system was entirely completed and connected on January 20, 1885."

On April 5, 1885, during the passage of a heavy thundercloud over the monument, at least five immense sparks or bolts of electrical light were seen within a period of twenty minutes to flash between the terminals and the cloud without audible sound to the observers. A careful examination of the conductors and shaft after this phenomena failed to reveal any effects from these discharges.

On June 5, however, during the thunderstorm described above, a

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[1] Senate Ex. Doc. No. 6, 49th Congress, 1st session.

[2] Italics mine.

disruptive discharge was seen to pass between the summit of the pyramidion and the cloud. Upon examining the structure a crack was discovered in the stone on the north face of the pyramidion just under the top stone, extending through the block in a line nearly parallel to the northeast corner and about 8½ inches from it. (Fig. 5.) The fragment was pressed outward about ¾ inch at its bottom, chipping a small piece off the lower corner of the top stone into which it was locked, and was easily forced back to place and bolted to the solid stone from which it had been torn.

The recommendations of the gentlemen above named, who were asked to make a careful examination, were, in short, that the interior conductors should be connected "with a system of rods and a greater number of points, to be located upon the exterior of the pyramidion." Four ½-inch copper rods were fastened by a band to the aluminium terminal and led down the corners to the base of the pyramidion, and then through the masonry to the columns.

"As these exterior rods are each over 60 feet long, they are also connected at two intermediate points of their lengths with the iron columns by means of copper rods ½ and ¾ inch in diameter, respectively, furnishing 16 rods in all, connecting the exterior system of conductors with the interior conducting columns. Where the exterior rods upon the corners cross the 11 highest horizontal joints of the masonry of the pyramidion they are connected to each other all around by other copper rods sunk into those joints. All of these exterior rods, couplings, and fittings are gold plated, and are studded at every 5 feet of their lengths with copper points 3 inches in length, gold plated and tipped with platinum. There are 200 of these points in all."

Eight years have now passed since the alterations were made and the monument stands uninjured. Unquestionably, standing as it does, 555 feet high, in the center of flat, well-watered ground, it constitutes a most dangerous *exposure* for lightning flashes. No better illustration of the value of lightning conductors can be asked.

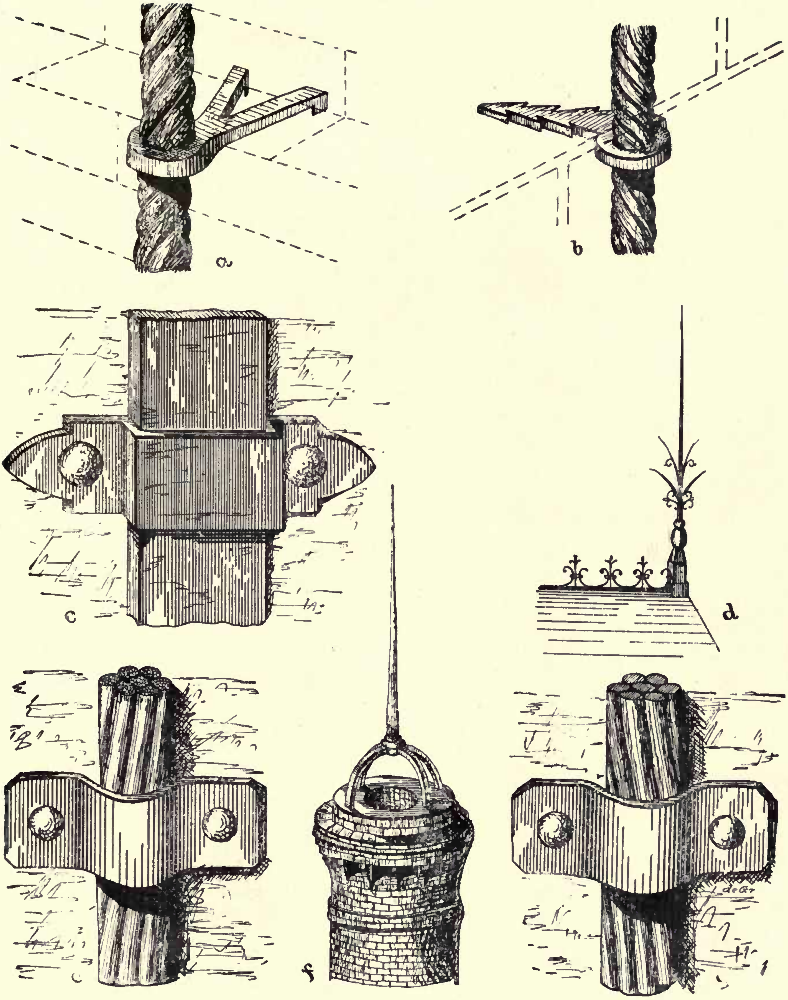


Fig. 1. Conductors and fastenings. From Anderson, and Lightning Rod Conference Report.

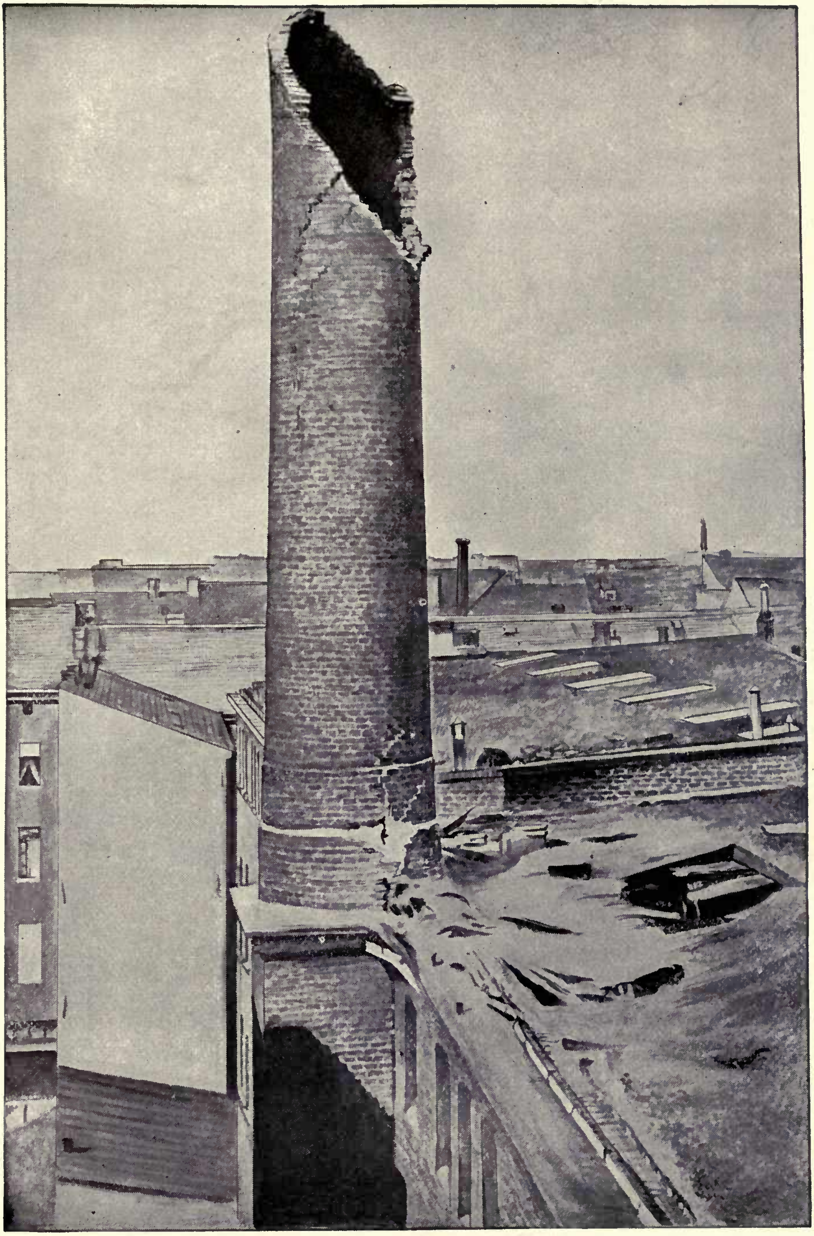


Fig. 2. Chimney, struck July 29, 1890. From *Elec. Zeits.*, Grebel.

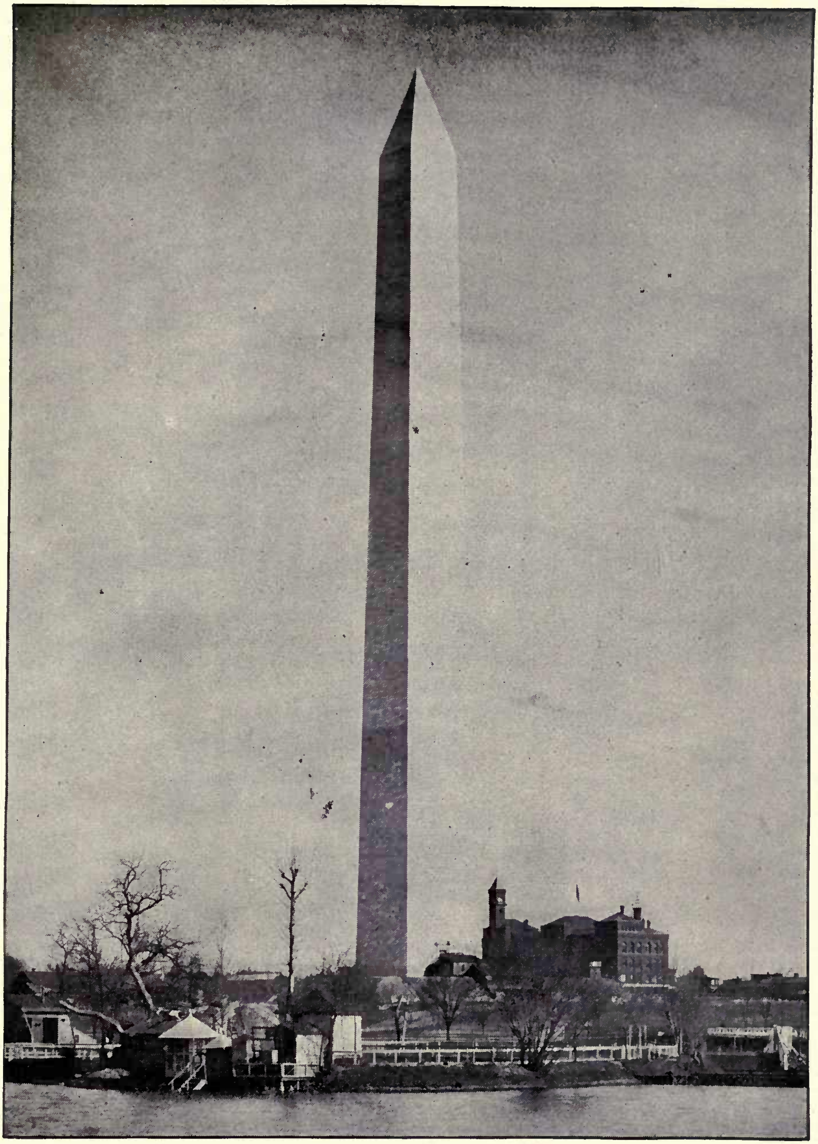
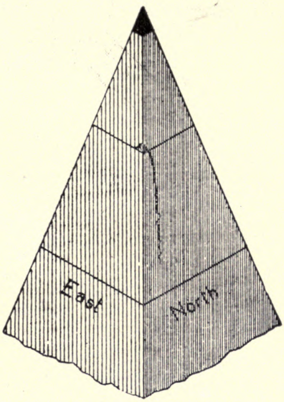


Fig. 3. Washington Monument, struck June 5, 1885.

Fig. 4. Rod melted by lightning.
From Franklin's Works.



◆ Aluminium tip weighing 100 oz.
Nearly 9" high 5½" square at base.
Height from ground 555 ft (169 metres)

Struck April 5TH 1885 without damage
" June 5TH " crack on North
face just under top stone, extending through the block in a line
nearly parallel to NE corner.

Fig. 5. Aluminium tip of Washington Monument.

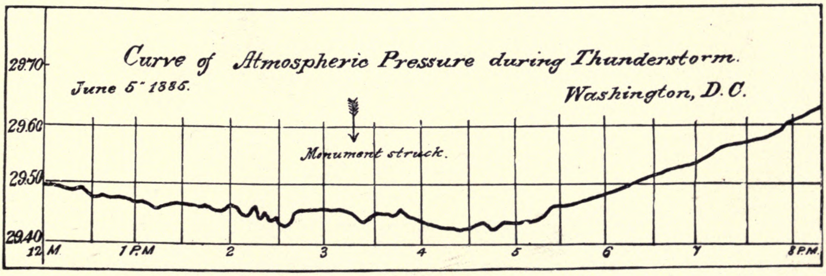


Fig. 6. Curve of barometric pressure.

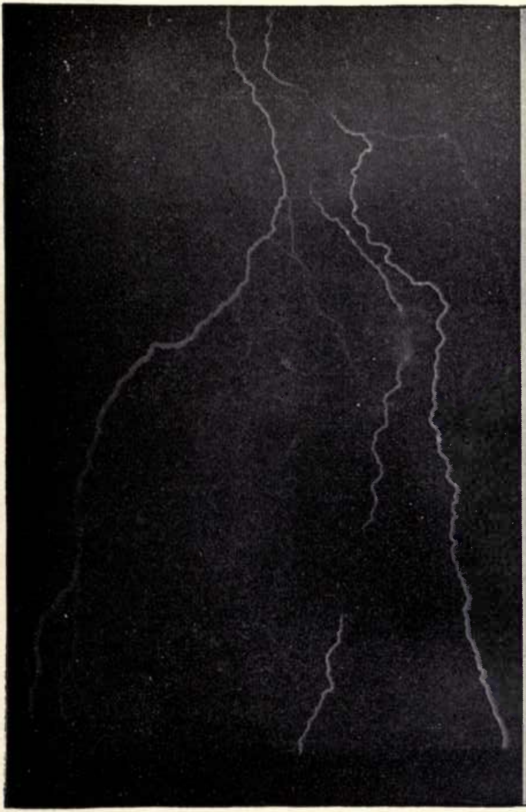


Fig. 7. Multiple flash. From "Pop. Sci. Monthly," 1893, McAdie.

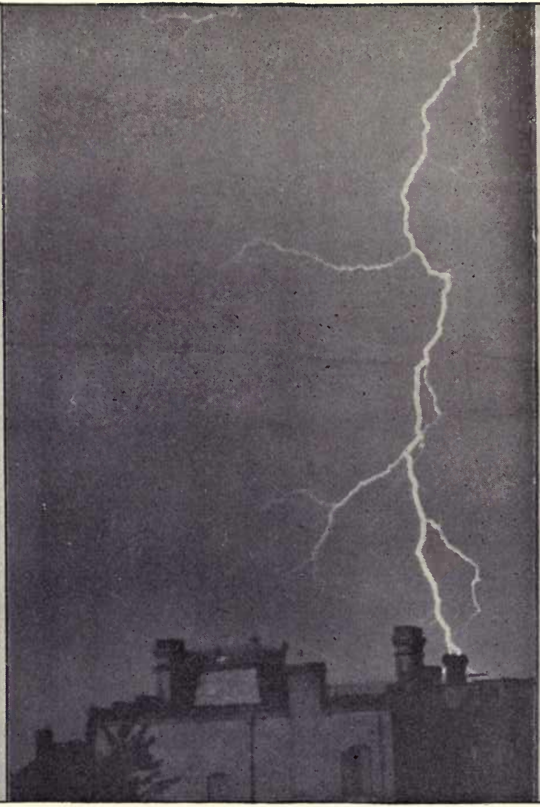


Fig. 8. Destructive flash. From photograph by McAdie.

Fig. 9. Cloud and multiple flash. From photograph by McAdie.

Fig. 10. Impulsive rush and so-called dark flashes.
From "Pop. Sci. Monthly," McAdie.

Fig. 11. Multiple flash. From "Scribner's Mag.," A. Binden.