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PROTECTION OF LIFE AND PROPERTY AGAINST LIGHTNING

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I. INTRODUCTION

1. EARLY HISTORY OF THE LIGHTNING ROD

The conception of the lightning rod dates from the summer of 1750. During that year Benjamin Franklin, in letters to his friends, Peter Collinson and Dr. Mitchel, Fellow and Member, respectively, of the Royal Society of London, reported some of the results of his researches in electricity which had led him to infer the identity between electricity and lightning. In one of those letters he suggested that damage by lightning to buildings, and other objects upon the surface of the earth, might be prevented by the erection upon their summits of sharp-pointed iron rods, the lower ends of which should be extended into the ground. In June, 1752, Franklin performed his well-known kite experiment, which was the means of fully establishing the tentative conclusions he had drawn from the results of his previous researches. In the summer of 1753 he erected on his house in Philadelphia the only lightning rod then in existence. This rod, which was of iron, extended 5 feet into the ground, and had a sharp point raised 7 or 8 feet above the roof. It was evidently intended by its inventor to serve both as a protection against lightning, and as a means of observing the effects of atmospheric electricity. Franklin's confidence in the protective properties of his lightning rod was such that he persuaded several of his friends to allow him to erect similar rods on their houses in order that he might have a better opportunity to observe their effects. After many months of patient waiting his confidence in his new device was found to be justified. During a severe thunderstorm several persons plainly saw lightning strike a rod on the house of a Mr. West. The flash was carried off without damage to the building, and the only observable evidences of its passage were a slight melting of the rod at its point and a disturbance of the earth about the place where it entered the ground, which was afterwards found to be very dry.

When Franklin felt that the usefulness of his invention had been fully established by experiment and observation, he began at once to devote a great deal of his time to advocating the use of lightning rods as a means of protecting buildings against lightning. In this he was ably assisted by many friends both in America and Europe, but the progress made was far from satisfactory. In America rods were often erected in a haphazard manner by unskilled persons, and many grievous calamities resulted. Certain individuals, whose counterparts have always been associated with the lightning-rod business, went traveling about the country selling rods and soon made themselves notorious as "lightning-rod men;" their fraudulent operations causing much prejudice against lightning rods to arise among people who would otherwise have been kindly disposed toward the new device. In England lightning rods were looked upon coldly by the Royal Society, although Peter Collison and Dr. Mitchel worked hard to secure the Society's recognition of their worth. On account of this attitude of the

Royal Society very little general notice was taken of the invention of the Philadelphia printer. This indifference was changed later into strong opposition on the part of many influential English people. In France the inventor and his invention were very cordially received in many quarters. This kindly feeling, however, was more than offset by the opposition encountered among the representatives of religious orders of all kinds, in Europe as well as in America, many of whom regarded Franklin as an infidel in the act of proposing to interfere with the operations of what they imagined to be a Divine instrument for the punishment of sinners. Because of this religious prejudice a great many years passed before lightning rods were used to any extent for the protection of church buildings, although during the same time the ringing of bells was recommended by certain of the clergy as efficacious in dispelling thunderstorms and warding off lightning strokes.

In many instances progressive persons erected lightning rods only to have them torn down later by an angry populace which imagined them responsible for crop failures, earthquakes, and other evidences of what seemed to them to be Divine displeasure. In line with this attitude of the general public toward lightning rods, it is reported that on a certain occasion an Englishman, who was residing in St. Omer, France, erected a lightning rod over his house. When this fact became generally known a great public disturbance arose and the rod was torn down and carried away. The Englishman took his case before the courts, and after protracted pleadings the French tribunals decided that, inasmuch as there was nothing in the statutes which prohibited the attachment of metal rods to buildings, such rods might be attached, provided that certain precautions were observed in so doing. The lawyer who conducted the case for the plaintiff was Robespierre, then a very young man, and at that time unknown to fame.[1]

The first recognition of the worth of lightning rods by any Government of Europe, or, indeed, of the world, was given when the Senate of Venice, on May 9, 1778, ordered the erection of lightning rods throughout the Republic.

A complete history of the lightning rod would illustrate in a striking manner the gradual vanishing, during the last century,

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[1] Richard Anderson, Lightning Conductors, p. 35.

of the superstitions formerly held by civilized people regarding the phenomena of nature.

2. PRESENT STATUS OF THE PRACTICE OF PROTECTION AGAINST LIGHTNING

After more than 160 years of use, in which the usefulness of the lightning rod has been demonstrated in a very practical manner, there is at present hardly any electrical device about which there is a greater diversity of opinions or in the application of which a greater number of diametrically opposite methods are used to accomplish the same results. As an example of this diversity of opinions, it may be stated that in some localities in the United States the impression is prevalent that the presence of a lightning rod is a menace to property, whereas in others lightning rods are generally believed to be a great protection. The belief that they are a menace has probably arisen in most cases from the notion held by many that lightning rods "attract lightning."

As examples of diametrically opposite methods in the application of lightning rods, we see the adherence to the use of glass or porcelain insulators between the rod and the building in some localities, while in others such insulators are omitted. As another example, we find that in some countries it is forcibly argued that sharp points are an absolute necessity as an adjunct to aerial terminals, whereas in others, as in Austria, a system of protection against lightning is quite generally in use in which aerial terminals are dispensed with entirely. Moreover, some advocate the use of iron for conductors, others urge copper on account of its high conductivity. The shape and size of the conductor has also caused much discussion with little agreement. A great deal more discussion without agreement has developed out of the question of whether metallic masses in and about a building should be connected to its rods, and, if they were to be connected, to what extent this interconnection should be carried. From the results of experiments some authorities have concluded that metallic masses in a powder mill should be insulated; others conclude, from the results of experiments, that they should be thoroughly earthed. Various types of earth terminals are urged by different people.

This general disagreement extends, in some respects, to manufacturers of lightning rods, at least, in the United States. Much of the disagreement among them, however, has probably arisen from competition, and in certain cases their efforts to produce something new and original have led to very fantastic results. Many curious forms of lightning conductors and points for aerial terminals have also grown out of this attempt on the part of each company to outstrip its competitors. The advantages claimed for most of these special forms of conductors and points are rather dubious, however, when considered in the light of known facts concerning lightning phenomena.

On the other hand, these manufacturers are quite agreed that the placing of aerial terminals on all vertical prominences of a building is a necessity. There are also many other points of agreement among them which will be taken up in detail later.

3. LACK OF ATTENTION BY THE PUBLIC TO PROTECTION AGAINST LIGHTNING

It has been estimated that not more than 15 or 20 per cent of the buildings in the United States which are liable to damage by lightning are protected in any manner against it. This indifference on the part of the owners of these buildings may be traced to several causes, not the least of which is the impression left by swindling lightning-rod agents of 30 or 40 years ago, who prospered greatly at the expense of a credulous public. Rods of every description were then erected at excessive cost to the purchaser and in most cases without much regard for the rules that should be followed in their erection. The object was to make a great showing with a minimum of material and labor; to accomplish this the conductors in many instances were discontinued a few inches below the surface of the ground. If the purchaser did not have the money to pay for the rods at the time they were installed he was often urged to sign a note, which was discounted at the nearest bank, sometimes after having been fraudulently raised to several times the amount the signer supposed it to call for when he affixed his signature. Hundreds of people were swindled in this manner, and found themselves in possession of what might have been a very useful device, if properly installed, but which soon came to be regarded as more or less useless by the unfortunate owners, except as scrap metal, and as a joke by those of their acquaintances who had escaped the wiles of the agent.

Authors of various works on the subject of protection against lightning are also responsible for a large part of the lack of attention to the prevention of damage by lightning. They have stated in a variety of terms that "a faulty rod is worse than no rod at all." Since lightning rods, as usually installed, readily develop faults described by these authors, many persons have considered that rods on buildings would sooner or later increase the risk to a degree which would more than offset the protection that might be obtained while the rods remained in good condition.

The statement that a faulty rod is worse than no rod at all, however, is not borne out by the evidence. On the contrary, every building that is struck by lightning shows that, to a certain degree, even a part of a rod is better than no rod at all. For instance, a writer in the Western Underwriter reports that the two ground connections of the lightning rod on a certain barn were broken at the surface of the ground and several feet of each of the two rods above that point were gone. Lightning struck the rod, killing a calf that was at the time standing near one of the loose ends of the rod, and breaking several stones out of the foundation of the barn near the other loose end. There is no report of the barn having burned, which, though it could have easily occurred under the circumstances, would have been probable had it not been for the piece of lightning rod which would be described by some persons as being "worse than no rod at all." Such instances might be multiplied almost indefinitely. In fact, any extended piece of metal in a building usually acts as a part of the path of a lightning stroke in the event of the building being struck, to the practical exclusion of damage to nonconducting paths parallel to it. This must not be taken, however, as a justification for poor construction or neglect of rods when installed. Good grounding and a continuous path to ground are important, and the maximum degree of protection can not be obtained without them.

4. THE NEED FOR INVESTIGATION AND SPREADING INFORMATION CONCERNING PROTECTION AGAINST LIGHTNING

Even a casual study of the subject of protection against lightning, as it is now practiced, shows the need for a comprehensive investigation of the electrical characteristics of lightning, such as frequency, intensity, and energy, in order that the design of lightning rods may be placed upon a scientific basis. At present no actual measurements of frequency or energy are recorded. Attempts have been made to measure the current intensity of a flash of lightning, and a more or less satisfactory estimate, based upon calculation and measurement, has been obtained, but aside from this there is almost no exact knowledge of lightning except that inferred from points of similarity between lightning and other electrical phenomena with which we are familiar. The need for spreading information on the subject of protection against lightning is also very apparent. There is a widespread popular notion that lightning rods are quite expensive, and at best not as inexpensive as fire insurance. The extent to which this idea is erroneous will be brought out hereafter in this paper. There is also a great need for emphasizing the fact that not every artisan who can scale a building is a fit person to plan and install a system of lightning rods. Although a system of lightning rods appears to be a very simple affair, the element it is intended to control is not governed by simple laws; that is, laws such as might be readily understood by an artisan not specially trained in this field. As a matter of fact, the unsuspected weaknesses which, in many cases, have developed in lightning-rod systems at the critical moment, and have lead to serious damage, could in most cases easily have been prevented if the plans of the systems had been submitted to someone qualified to pass upon them previous to their installation.

5. OBJECT OF THIS PAPER

The object of this paper is to present the information at present available on the subject of protection against lightning, with a view to bringing about a greater uniformity of practice in the installation of lightning rods, and encouraging people to make use of them as a protective device. It is also intended that this work shall prepare a foundation for future work by the Bureau of Standards in connection with this subject. To this end the literature of the subject has been carefully examined, manufacturers of lightning rods have been asked to describe the manner in which they think they should be installed, and a great deal of data has been collected from various sources from which may be estimated the desirability of protection against lightning.

No attempt is made in this paper to make every man his own lightning-rod expert, because, as shown throughout the history of the lightning rod, all such attempts have been failures.

II. DESIRABILITY OF PROTECTION AGAINST LIGHTNING

In judging of the importance of protection against lightning there are two things to be considered: (*a*) Lightning as a cause of fire and damage to property, and (*b*) lightning as a cause of personal injury and loss of life.

1. LIGHTNING AS A CAUSE OF FIRE AND DAMAGE TO PROPERTY

The data on property losses by lightning are chiefly obtainable from the reports of State fire marshals, and from compilations of data made up from the reports of fire insurance companies. These data deal almost exclusively with fires following strokes of lightning. Certain fire insurance companies make a special practice of insuring buildings and live stock against any kind of damage by lightning, but in the data which are ordinarily ascessible the records of the losses paid by these companies on account of damage by lightning without fire are too incomplete to warrant any deductions being made from them. The reports of the fire marshals from States where the office has been in existence for some time are, however, quite complete and reliable as to fires of all kinds, and the same may be said of the reports of the insurance companies in so far as insured buildings are concerned.

For the purposes of this paper the reports of fire marshals in 13 States were obtained for one or more of the years 1909 to 1913, inclusive. In nearly all cases a complete series of reports for those years was not available; several of them because of the date of establishment of the office being too recent. These reports are abstracted in Table No. 1 to show, for the different years, the percentage of the total number of fires in each State due to lightning. This percentage is seen to vary a great deal from year to year for the different States. The order in which the States having the greatest percentage of fires by lightning succeed each other in the list is as follows: Iowa, Maryland, Wisconsin, New York, Ohio, Illinois, Texas, and so on. In the long run some of these might interchange places, but they undoubtedly would remain near the head of the list.

TABLE 1

Percentages of the Total Number of Fires Caused by Lightning

States	Year	Fires caused by lightning	Total number of fires	Percentage of total fires caused by lightning
Connecticut	1910	24	2094	1.15
Do	1911	7	2090	.33
Texas	1910, 1911, 1912	899	33 000	2.73
Illinois [2]	1912	319	9092	3.51
Maryland	1912	162	2100	7.71
Oklahoma	1911	11	713	1.54
Do	1913	50	1523	3.28
New York [3]	1912	306	8165	3.75
Massachusetts [4]	1910	64	5929	1.08
Do	1911	157	6754	2.33
Do	1912	83	7430	1.11
South Dakota	1910	10	560	1.79
Do	1911	16	612	2.62
Wisconsin	1909	105	1707	6.18
Do	1910	117	2340	5.00
Iowa	1912	150	1224	12.25
Do	1913	163	2801	5.82
Nebraska	1913	17	1265	1.34
Tennessee	1911	43	1696	2.54
Do	1912	24	1996	1.20
Ohio	1910	154	4724	3.26
Do	1911	194	4930	3.94
Total	....	3075	102 745	2.99

[2] Including the city of Chicago. [3] Outside the city of New York. [4] Including the city of Boston.

The total number of fires given for some of the States include fires in large cities, such as Chicago and Boston. In large cities the proportion of fires per unit area caused by lightning is extremely low in comparison with those from other causes, the relative danger in urban and rural districts from fires due to lightning being somewhat in proportion to the relative areas in combination with other factors, such as the number of buildings per unit area. As an instance of this it is found that in Illinois, during 1912, 297 fires were caused by lightning outside of the city of Chicago, while there were 5197 fires from all causes in the same territory. During the same time there were 3895 fires from all causes in Chicago and 22 from lightning. The number of fires in the State caused by lightning was, therefore, 5.71 per cent of the number of fires from all causes, and the number of fires in Chicago caused by lightning was 0.56 per cent of the number of fires from all causes. There are also many cities of considerable size in the State aside from Chicago which were not taken account of as such in the fire marshal's report, so it is obvious that the proportion of fires by lightning in the rural districts of Illinois is much higher than that indicated by the table. This is more or less the case for the rest of the States according to the size and number of the cities located within their borders. In Massachusetts, for instance, the number of fires caused by lightning for 1910, 1911, and 1912 was 1.51 per cent of the number of fires from all causes for the entire State; outside of the city of Boston the number of fires caused by lightning was 2.19 per cent of the number of fires from all causes.

The percentage of the total number of fires for all of the States which are due to lightning is 2.99. The geographical distribution of the States is such that we may safely conclude that about 3 per cent is a fair average for the entire country. As a check on this we have Table 2, taken from Chronicle Fire Tables, which, up to 1903, was published by the Chronicle Publishing Co., of New York. This table gives an analysis by causes of 215 453 fires which occurred in insured property in every State in the United States during 1901 and 1902, and shows that 2.82 per cent of the total number of fires recorded were caused by lightning. This checks closely with the foregoing value of 2.99 per cent. This report makes the principal causes of fire fall in the following order: (1) Exposure to burning property, (2) defective flues or smokestacks, (3) sparks, all sources, (4) incendiarism, (5) careless use of matches, (6) stoves and stove pipes, (7) lamp accidents and explosions, (8) lightning.

Table No. 2 also shows that the loss by fire caused by lightning in insured property during 1901 and 1902 was 2.4 per cent of the total loss by fire from all causes, including exposure to burning property. The total loss by fire was $335 000 000, making the loss by fire due to lightning a little more than $8 000 000 for the two years.

TABLE 2 [5]

Analysis of Fires, by Causes

Causes of fires	1901		1902	
	Per cent of whole number of fires	Per cent of whole amount of loss	Per cent of whole number of fires	Per cent of whole amount of loss
Inherent (peculiar to premises):				
Defective flues, smokestacks	13.08	6.40	13.78	6.00
Stoves, stovepipes	3.64	1.31	3.77	1.11
Spontaneous combustion, lime slaking	1.59	3.70	1.33	3.86
Furnaces, defective heating apparatus	0.90	2.27	0.72	1.17
Ignition of grease, oils, paint, varnish, etc	0.49	0.34	0.48	0.49
Oil-stove accidents and explosions	2.15	0.41	2.42	0.39
Engines (stationary), boilers, steam pipes	0.21	0.76	0.22	0.48
Friction in machinery	0.31	1.20	0.42	1.26
Explosions of chemicals, gasoline, oil, dust, etc	1.18	1.64	1.11	1.47
Overheated and defective ovens and kilns	0.26	1.35	0.23	0.59
Electric wires and lights	0.94	2.86	0.97	3.33
Miscellaneous	0.08	0.42	0.05	0.38
Total	24.83	22.66	25.50	20.53
Common (not peculiar to premises):				
Sparks, all sources	6.34	5.70	6.63	5.71
Lamp accidents and explosions	3.82	1.53	3.58	1.39
Careless use of matches	4.46	1.19	3.72	0.87
Candles, gas jets	1.33	0.26	1.33	0.32
Accidents, carelessness, thawing water pipes	1.12	0.65	0.76	0.49
Ashes, hot coals, open fireplaces and grates	1.25	0.34	1.09	0.22
Cigars, cigarettes, and pipes	1.13	0.44	1.06	0.27
Explosions of gas and natural gas	0.51	0.49	0.53	0.97
Plumbers' furnaces	0.07	0.08	0.06	0.05
Total	20.03	10.68	18.76	10.29
Indirect (exterior origin):				
Exposure to burning property	28.14	28.19	26.49	29.72
Lightning	2.74	2.71	2.90	2.10
Forest and prairie fires, bonfires	0.73	0.25	1.03	0.60
Firecrackers, fireworks	0.52	0.15	0.50	0.11
Total	32.13	31.30	30.92	32.53
Crime or mischief:				
Incendiarism	5.94	6.06	5.45	5.96
Tramps, burglars, drunken men, lunatics	0.94	0.77	0.83	0.65
Mischievous children	0.29	0.97	0.50	0.12
Total	7.17	7.80	6.78	6.73
Causes unknown and not reported	15.85	27.56	18.87	31.52

[5] This table covers 111 738 fires in 1901 and 103 715 fires in 1902 and is taken from Chronicle Fire Tables for 1903.

The reports of the fire marshals in several of the States from which reports were obtained give the fire losses tabulated by causes. In Table No. 3 is given a list of these States, together with the percentage of the total fire loss in each which was caused by lightning. The average for all of the States given is 3.31 per cent. Since these States are fairly well distributed geographically, it may be concluded that an estimate of 3.31 per cent of the total fire loss for the entire country each year as being due to lightning is not far from the actual truth. During 1910 the total fire loss in the United States was approximately $250 000 000. Of this, 3.31 per cent, or about $8 500 000, may be attributed to fires caused by lightning. In order to obtain the total amount of the loss caused by lightning it would, of course, be necessary to add to this an indeterminate sum resulting from the loss of live stock by lightning and damage by lightning stroke to buildings where fire does not occur. The relative amount of the fire loss by lightning varies a great deal from year to year, however, the variation in this usually being a great deal more than the variation in the percentage of the total number of fires due to lightning. Therefore $8 500 000 is only to be taken as an approximate indication of the magnitude of the annual loss by fire due to lightning for the years immediately preceding and following 1910.

TABLE 3

Percentage of Total Fire Losses Caused by Lightning

State	Year	Loss by lightning	Total fire losses	Percentage of total fire losses caused by lightning
Oklahoma	1911	$93 215.00	$1 422 010.00	6.55
Do	1913	169 700.77	2 471 155.34	6.86
Massachusetts	1910	125 413.08	9 058 114.60	1.38
Do	1911	171 034.08	8 891 412.96	1.93
Do	1912	64 173.22	9 403 847.30	0.68
Ohio	1910	191 915.00	6 952 320.00	2.76
Do	1911	236 895.00	5 718 120.00	4.14
South Dakota	1911	28 440.00	925 252.75	3.07
Wisconsin	1909	150 435.00	4 074 435.00	3.69
Do	1910	115 000.00	3 704 323.00	3.10
Iowa	1912	229 888.00	1 882 552.00	12.20
Do	1913	396 015.00	4 942 000.00	8.01

Average for the six States, 3.31 per cent.

The foregoing figures on losses make it appear that lightning has caused an increasing proportion of the fire loss in recent years. It is sometimes inferred from this that there is a corresponding increase in the number and violence of electrical storms. On the other hand, it is seen that the percentage of the total number of fires caused by lightning has not increased perceptibly during the last decade. It is, therefore, quite probable that the increase in the percentage of loss by lightning is more largely caused by the increase in the amount and value of property exposed to fire by lightning, and by the relative decrease in the fire hazard from other causes in urban areas, where large conflagrations are less liable to occur than formerly, due to better fire protection, than by an increase in the frequency and violence of electrical storms. The present annual loss by lightning is undoubtedly many times larger than a certain unavoidable minimum, however, and the efforts put forth to prevent it should be in proportion to the economic importance of the subject.

2. LIGHTNING AS A CAUSE OF INJURY AND LOSS OF LIFE

At various times during the last 20 years estimates have been made of the annual loss of life by lightning in the United States. These estimates have, as a rule, been made by collecting clippings of newspaper reports. The chief disadvantage of this method of collecting data is that it is impossible to tell when the field has been thoroughly covered. The reports of many lightning accidents get no further that the columns of local papers, and as it is manifestly impracticable to examine all of these thoroughly, it becomes quite certain that a considerable proportion of the deaths by lightning are not included in the final summary.

During the last few years, however, the organization of vital statistics bureaus in the various States has been extended sufficiently to give quite complete reports as to the number of deaths by lightning in more than half of the States. A large proportion of the States having bureaus of vital statistics are included in the registration area of the Census Bureau, and the reports from these States are compiled annually by the Census Bureau into a report on mortality statistics for the registration area. In addition to these reports there are the reports of life insurance companies, most of which keep their death records tabulated in such a way that the records of the deaths by lightning are readily accessible, and also a large number of news clippings concerning deaths and injuries by lightning which were collected a number of years ago. From the data contained in these reports the total number of deaths by lightning annually in the United States can be estimated with fair accuracy. In the present investigation all of these sources of information were used in making up the tabular statements following.

TABLE 4

Tabular Statement of Deaths by Lightning—Data from Insurance Companies

Company	Years (inclusive)	Total number of deaths	Number of deaths by lightning	Percentage of total number of deaths due to lightning
Aetna Life Insurance Co	Not given	Accident insurance policies		1.7
Connecticut Mutual Life Insurance Co			None	0.0
Equitable Life Insurance Co	1909 to 1912	20 000	9	0.045
Fidelity Mutual Life Insurance Co	No reply			
Germania Life Insurance Co	1903 to 1912	4363	1	0.0229
Home Life Insurance Co	1903 to 1912	4206	4	0.095
John Hancock Mutual Life Insurance Co	Reported 1 death in 5 years			
Massachusetts Mutual Life Insurance Co	No data			
Mutual Benefit Life Insurance Co	No data			
Mutual Life Insurance Co	1902 to 1911	56 657	26	0.046
National Life Insurance Co	1903 to 1912	4934	2	0.040
New England Mutual Life Insurance Co	1903 to 1912	6493	3	0.046
New York Life Insurance Co	Data not submitted			
Northwestern Mutual Life Insurance Co	1902 to 1912	23 760	16	0.067
Pacific Mutual Life Insurance Co	1905 to 1912	2690	3	0.111
Penn Mutual Life Insurance Co	No data			
Phoenix Mutual Life Insurance Co	1903 to 1912	6318	1	0.016
Provident Life and Fire Insurance Co			None	0.0
Prudential Life Insurance Co.[6]	1903 to 1912	Not given	101	0.0108
State Mutual Life Insurance Co	No reply			
Travelers Life Insurance Co	No data			
Union Central Life Insurance Co	1903 to 1912	8780	10	0.114

Average, excluding Aetna life accident policies, 0.0164 per cent.

[6] The deaths in the ordinary branch of this company due to lightning were 10, or 0.04 per cent of the number of deaths from all causes. The deaths in the industrial branch were 91, or 0.01 per cent of the deaths from all causes. The total number of deaths from all causes was, therefore, 935 000. This number was used in computing the average, or 0.0164 per cent.

In order to obtain a summary of the experiences of a number of life insurance companies with regard to deaths by lightning, 22 of the largest companies in the United States were written to for information. All but 3 responded, and the data submitted are summed up in Table No. 4.

In the returns of the Aetna Life Insurance Co. it is seen that 1.7 per cent of the deaths among risks in the accident department of that company are due to lightning. Excluding this rather high value of 1.7 per cent, the average of all the rest is 0.0164 per cent. That is, out of each 1 000 000 accidental deaths in the accident department of the Aetna company, 17 000 are due to lightning, and out of each 1 000 000 deaths from all causes in the various departments of all the other companies 164 are due to lightning. The latter value is rather low in comparison with one given hereafter, which is based on data obtained from other sources. This is doubtless due to the fact that the greater portion of insured persons are city dwellers, and in cities the proportion of deaths from lightning is very small in comparison with that of deaths from lightning in rural districts.

In Table No. 5 is given a summary of the data obtained from the Census Bureau reports and the reports of the bureaus of vital statistics. The two sets of reports are made to supplement each other as far as possible. Officials in all of the States were written to in the course of the correspondence, and replies were received from all but four—Michigan, Maine, New Hampshire, and South Carolina. Florida, Georgia, and West Virginia have no registration laws at present. In South Carolina all cities of 1000 inhabitants and over, according to the census of 1900, are included in the registration area. In a number of States registration laws have but recently been passed, so very little data is available from them.

TABLE 5

Total Number of Deaths and Deaths Caused by Lightning in Each Registration State and Others from Which Data Were Obtained Through the Board of Health

State	Summary of replies from State boards of health	1909 Deaths[6a]	1909 Deaths by lightning	1910 Deaths	1910 Deaths by lightning	1911 Deaths	1911 Deaths by lightning	1912 Deaths	1912 Deaths by lightning
Alabama	No vital statistics prior to 1911					14 606	8	19 002	7
Arizona	Deaths by lightning not segregated								
Arkansas	No statistics on death by lightning								
California	Prior to 1911 not separately reported	32 000	0	32 401	0	34 012	1	36 709	3
Connecticut	No data from State board of health	17 500	3	17 498	1	17 554	1	17 314	1
Colorado	.....do	10 000	21	11 069	23	10 740	13	9979	9
Delaware	Deaths by lightning not segregated								
Florida	No vital statistics reported								
Georgia	No laws for collection of vital statistics								
Indiana	Prior to 1910 not separately reported	36 000	27	36 448	23	35 210	21	35 763	16
Idaho	Not segregated								
Illinois	Prior to 1910 not separately reported			66 634	10	64 565	26	63 897	31
Iowa	Prior to 1911 not separately reported					22 571	11	20 651	15
Kansas	No accurate vital statistics prior to 1912								17
Kentucky	Not segregated					29 867	21	29 859	12
Louisiana	Deaths by lightning not segregated								
Michigan	No reply from State board of health	38 000	16	39 888	10	37 993	17	38 756	25
Minnesota	Reply covered 3 years			22 649	14	21 988	12	20 488	20
Massachusetts	Reply covered 4 years	53 000	2	54 407	9	53 062	4	52 400	6
Montana	Deaths by lightning not segregated			3999	7	4009	8	4683	6
Mississippi	.....do								
Missouri	.....do					40 434	11	42 155	30
Maine	No reply from State board of health	12 000	1	12 726	2	12 031	1	11 672	1

[6a] Round numbers in this column are estimated from following years as described in text.

TABLE 5—Continued

State	Summary of replies from State boards of health	1909		1910		1911		1912	
		Deaths[6a]	Deaths by lightning	Deaths	Deaths by lightning	Deaths	Deaths by lightning	Deaths	Deaths by lightning
Maryland	Prior to 1910 not separately reported	20 500	3	20 805	5	20 694	7	20 477	7
New Hampshire	No reply from State board of health	7300	0	7452	1	7391	1	7134	1
New Mexico	No record of deaths by lightning or electric currents								
New York	Data for 1912 given	145 000	5	147 678	16	145 654	31	142 185	21
Nevada	Data from Jan. 1 to July 1, 1913								
Nebraska	Data on 2 years						8		3
New Jersey	Referred to census reports	39 000	4	39 504	0	38 617	5	37 779	5
North Carolina	Deaths by lightning not segregated			6752	2	6859	4	6672	0
North Dakota	Reply covered 2 years			3477	16	3130	4		
Oklahoma	Reply covered 1 year								
Oregon	Electric storms very rare in Oregon		1						
Ohio	Prior to 1909 not segregated	65 000	21	65 459	12	63 402	17	65 466	35
Pennsylvania	Referred to Census Bureau reports	119 000	17	119 815	17	111 292	40	111 842	28
Rhode Island	Reply covered 6 years	8277	0	9298	1	8657	1	8644	0
South Carolina	No reply								
South Dakota	No vital statistics prior to 1906	4511	15	4641	6	4753	14	4135	7
Texas	Reply covered 2 years						8		8
Tennessee	Registration law effective in 1914								
Utah	Reply covered 2 years			4072	3	3984	1	3885	5
Vermont	Reply covered 10 years	5871	0	6044	4	6016	1	5440	3
Virginia	Deaths by lightning not segegated								
Washington	Reply 1907–1912	11 000	0	11 052	0	10 845	2	10 187	1
West Virginia	No accurate vital statistics								
Wyoming	No accurate data								
Wisconsin	Prior to 1910 not separately reported	28 000	8	28 070	7	27 050	15	26 987	12

[6a] Round numbers in this column are estimated from following years as described in text.

TABLE 5a

State	Year	Deaths[6b]	Deaths by lightning	State	Year	Deaths[6b]	Deaths by lightning
Indiana	1913	36000	13	South Dakota	1908	4345	11
Nevada	1913	558	2	Vermont	1902	5509	1
Oklahoma	1913	....	8		1903	5949	1
Rhode Island	1906	8612	1		1904	5943	1
	1907	9010	0		1905	6339	3
	1908	8267	0		1906	6241	0
South Dakota	1906	3644	9		1907	6131	3
	1907	4129	17		1908	6034	0

[6b] Round numbers in this column are estimated from following years as described in text.

The reports from the Census Bureau did not in every case agree with the reports received from the States. This may be due to a difference in the way the year is designated, some reporting from January 1 to December 31, inclusive, and others from July 1 to June 30, inclusive.

In several of the States the deaths by lightning were obtained for a number of years and the total number of deaths was obtained only for a part of those years. In such cases advantage was taken of the fact that, as a rule, the total number of deaths in a State does not vary much from year to year. The total number of deaths for the year, or years, given was therefore assumed to hold for all of the years for which the deaths by lightning were given, and calculations were made on that basis. This method gives an approximate average for several years for each State, and is undoubtedly nearer the true mean value for a great many years than a result based on data for one or two years during which the number of deaths by lightning might be exceptional.

Table No. 6 gives the percentage of deaths due to lightning in each State from which data were obtained. The States in which the greatest proportions of deaths by lightning occur are: Nevada, North Dakota, South Dakota, Colorado, and Montana, in the order named. Utah, Minnesota, Iowa, Indiana, and Alabama are next. The State of Washington is last with 0.0077 per cent. The data from Nevada are too scant, however, to be conclusive as to whether this State should come first in the list. The reason for the States just named coming as they do in the order of proportion of deaths by lightning is quite likely found in the fact that they are situated in areas of comparatively high thunderstorm frequency, and that a much larger proportion of their inhabitants is engaged in outdoor pursuits than in other States in which the urban population predominates to a greater degree.

TABLE 6

Percentage of the Total Number of Deaths Caused by Lightning in Each State from Which Data Were Obtained

State	Per cent	State	Per cent
Alabama	0.0446	New York	0.0126
California	0.0030	Nevada	0.3500
Connecticut	0.0086	New Jersey	0.0090
Colorado	0.1580	North Carolina	0.0296
Indiana	0.0557	North Dakota	0.3030
Illinois	0.0344	Ohio	0.0328
Iowa	0.0601	Pennsylvania	0.0221
Kentucky	0.0553	Rhode Island	0.0049
Michigan	0.0439	South Dakota	0.2610
Minnesota	0.0706	Utah	0.0753
Missouri	0.0496	Vermont	0.0259
Massachusetts	0.0099	Washington	0.0077
Montana	0.1655	Wisconsin	0.0381
Maine	0.0103		
Maryland	0.0267	Average	0.03058
New Hampshire	0.0102		

Table No. 6 includes data from States situated in every zone of thunderstorm frequency in the United States; and also includes States from the highest to the lowest of population density. Hence, the average, 0.03058 per cent, may be assumed to hold for the United States as a whole. It is not admissible, however, to judge a State not given in the table by a neighboring State because the variation from State to State is too great in most cases. The death rate per thousand population for the entire country in 1910 was 15. The total population being about 92 000 000, there were about 1 380 000 deaths in 1910. Since 305.8 out of each 1 000 000 deaths are shown by the table to be due to lightning the total number of deaths by lightning in 1910 would be 422.

Table No. 7 gives the total number of deaths from all causes in the registration area, the number of deaths from lightning, the percentage of the total number of deaths from all causes due to lightning, and the States in the registration area, from 1900 to 1910, inclusive. These data were taken from the reports on mortality statistics of the Census Bureau. Tables Nos. 6 and 7 do not check because deaths in many States which are not registration States are included in Table No. 6.

TABLE 7

Table Showing the Total Number of Deaths, the Deaths by Lightning, and the States in the Registration Area

Year.	Deaths in registration area.	Deaths by lightning in registration area.	Percentage of deaths due to lightning.	Year.	Deaths in registration area.	Deaths by lightning in registration area.	Percentage of deaths due to lightning.
1900	539 939	95	0.017	1907	687 034	133	0.019
1901	518 207	127	0.024	1908	691 574	161	0.023
1902	508 640	108	0.021	1909	732 538	150	0.020
1903	524 415	92	0.017	1910	805 412	156	0.019
1904	551 354	81	0.015	1911	756 777	235	0.031
1905	545 533	80	0.015	1912	752 446	243	0.032
1906	658 105	169	0.026				

Annual averages, 1901 to 1905, 98 by lightning and 529 630 from all causes.
Annual averages, 1906 to 1910, 154 by lightning and 714 933 from all causes.
Annual averages, 1911 and 1912, 239 by lightning and 754 610 from all causes.

STATES IN REGISTRATION AREA

1900 to 1905	1906 and 1907	1908	1909	1910	1911 and 1912
Conn.	Cal.	Cal.	Cal.	Cal.	Cal.
Ind.	Colo.	Colo.	Colo.	Colo.	Colo.
Me.	Conn.	Conn.	Conn.	Conn.	Conn.
Mass.	Ind.	Ind.	Ind.	Ind.	D. C.
Mich.	Me.	Me.	Me.	Me.	Ind.
N. H.	Md.	Md.	Md.	Md.	Ky.
N. J.	Mass.	Mass.	Mass.	Mass.	Me.
N. Y.	Mich.	Mich.	Mich.	Mich.	Md.
R. I.	N. H.	N. H.	N. H.	Minn.	Mass.
Vt.	N. J.	N. J.	N. J.	Mont.	Mich.
	N. Y.	N. Y.	N. Y.	N. H.	Minn.
	Pa.	Pa.	Ohio.	N. J.	Mo.
	R. I.	R. I.	Pa.	N. Y.	Mont.
	S. Dak.	S. Dak.	R. I.	N. C.	N. H.
	Vt.	Vt.	S. Dak.	Ohio.	N. J.
		Wash.	Vt.	Pa.	N. Y.
		Wis.	Wash.	R. I.	N. C.
			Wis.	Utah.	Ohio.
				Vt.	Pa.
				Wash.	R. I.
				Wis.	Utah.
					Vt.
					Wash.
					Wis.

Examination of the Census tables shows that more than nine-tenths of the fatalities due to lightning occur in rural districts. Rural districts, for Census purposes, include all towns and villages having 2500 inhabitants or less.

The foregoing data contain nothing from which the number of persons injured by lightning may be estimated. About the only practicable method of arriving at an estimate of the number of persons injured each year by lightning is to collect news clippings over a period of years. This investigation has not been continued long enough to gather anything of this nature, so data collected in the past was resorted to. From 1883 to 1887, inclusive, H. F. Kretzer, of St. Louis, collected news clippings concerning lightning accidents in the United States and published the results in a book called Lightning Record. These results show that during the five years prior to 1887 1030 persons were killed by lightning and 2592 injured. The author expressly states that the record is incomplete, but it seems that in such a large number of cases the proportion of deaths to injuries would be such as to hold for any number of cases, in accordance with the law of probability. Assuming this to be the case the ratio of deaths to injuries is as 1 to 2.52. Applying this ratio to the number of deaths calculated for 1910 we find 1063 cases of injury as the probable number.

Although the foregoing results are not exact, they may be taken as a fairly accurate index for the years immediately preceding and following 1910 and show that during the course of a year 1500 or more persons are affected by lightning stroke, of which about one-third are killed and the rest subjected to injuries that in a great many cases are permanent. The number of persons affected by lightning stroke each year is of course insignificant in comparison with the number meeting violent deaths and injuries from other causes; however, it will be shown later that a large proportion of these persons receive their injuries in houses that are struck by lightning and that by taking proper precautions the number could be largely reduced.

III. EFFICIENCY OF LIGHTNING RODS

In the past many laboratory experiments have been made and conclusions drawn from the results as to the effectiveness or noneffectiveness of lightning rods in protecting property against damage by lightning. Much valuable information has been acquired in this way, and light has been thrown upon various phases of the practice of protection against lightning which previously remained in obscurity. In general, the conclusions arrived at in the course of these experiments have been favorable to lightning rods, but because of the difference in magnitude between lightning discharges and electrical discharges produced in the laboratory, and also because our present knowledge of the actual conditions under which lightning discharges take place is largely inferential, it is evident that these conclusions should not be accepted as final without a careful examination of such evidence as past experience of the practical kind has made available. In the course of this investigation a survey was therefore made of such reports as have been issued from time to time on fires by lightning, and the protection afforded by lightning rods, in order to obtain data showing to what extent lightning rods might be depended upon to reduce the fire hazard from lightning. An attempt was also made to learn as much as possible from persons who were directly interested in the prevention of fires of their experiences and opinions concerning lightning rods. With this end in view a large number of fire insurance companies and fire marshals were written to for information, and the results of this correspondence are summarized below:

1. RESULTS OF THE USE OF LIGHTNING RODS IN THE UNITED STATES

Correspondence with fire insurance companies did not reveal a great deal of interest in the subject of protection against lightning, excepting on the part of farmer's mutual fire insurance companies. This indifferent attitude on the part of many of the larger fire insurance companies is explained by the fact that the greater portion of their business is confined to urban areas where the danger from fires by lightning is very small in comparison with the danger from fires by other causes.

The business of the farmer's mutual fire insurance companies, however, is almost entirely confined to rural districts. It has been shown heretofore that lightning is one of the principal causes of fires in rural districts; consequently, these mutual fire insurance companies are interested in anything which will reduce the fire hazard from lightning. Some of them have collected data which tend to show that the heavy fire loss by lightning which they sustain each year would be very much reduced by the installation of lightning rods on all barns and isolated buildings. Many of these data have been published from time to time by manufacturers and jobbers of lightning rods as advertising matter, in many cases their importance being greatly exaggerated, but inasmuch as they are of real significance a brief summary is given here.

The reports of the farmer's mutual fire insurance companies of Iowa at their annual State conventions from 1905 to 1912 show that the total fire losses by lightning for the eight years, on unrodded buildings insured in the companies reporting, amounted to $341 065.52; during the same time the total losses by lightning on rodded buildings insured in these companies amounted to $4464.30, or 1.31 per cent of the losses by lightning on unrodded buildings.[7] In the cases of some of the companies 60 per cent of the buildings insured were provided with rods; in other companies the percentage of rodded buildings was less. The circular from which the data were taken states than an average of about 50 per cent of the buildings were rodded. It is also stated that an average of 55 companies reported each year, representing nearly that many counties in Iowa. The foregoing values being taken as correct the efficiency of the lightning rods in this case may therefore be estimated at nearly 99 per cent. As the reports took account of lightning-rod installations of every kind, both new and old, good and bad, these figures give strong support to the use of lightning rods, at least so far as the protection of barns and houses is concerned, since these constitute the greater portion of the risks insured in these companies.

During the last few years a great many mutual fire insurance companies have come into existence which make a business of insuring only rodded buildings; other mutual companies, which have been in existence for many years, have commenced the practice of reducing rates on rodded buildings. In both of these cases special reference is had to barns which, if unprotected, are well known to be particularly susceptible to fire by lightning. The assessments of these companies on policies covering rodded barns

[7] From a circular of the Protected Mutual Fire Insurance Association, Des Moines, Iowa. This company nsures only rodded buildings.

are, in some cases, but two-thirds of the assessments of companies insuring rodded and unrodded buildings indiscriminately; in other cases the assessments are only half of those in the companies making no distinction between rodded and unrodded risks.

As an example of the results obtained by these companies we may take the experience of the Patrons Mutual Fire Insurance Association of Northwestern Pennsylvania, which has $10 000 000 or more at risk. A number of years ago the officials of this association became alarmed by the great proportion of the losses sustained by the association which were due to lightning and sought some means of reducing them. After much observation and inquiry they became convinced that the general use of lightning rods on all barns insured in the company would accomplish the desired result. Accordingly they began, five years ago, to give a reduction of 29 per cent in the assessments on policies covering rodded barns. At first, in order to overcome prejudice against lightning rods and encourage their use, the association purchased 11 000 feet of copper-cable lightning rod and installed it on the barns of a number of its patrons at its own expense. Arrangements were made at the same time to enable other patrons to buy and put up cable thereafter at cost. This opportunity has been taken advantage of by several hundred patrons of the association and at the present time about one-eighth of the barns insured in this association are rodded. The rods put up are inspected by a representative of the association before the risk is accepted. The secretary of the association states that in five years no damage by lightning has been paid for by the association on these rodded buildings. The total loss sustained by the association annually is about $30 000, of which, judging from its reports for past years, from 30 to 50 per cent is caused by lightning setting fire to unrodded buildings.

A large number of examples such as those preceding might be set forth at length. None have come to light, however, which would change the conclusions to be drawn from those given, viz, that the damage to rodded barns by lightning is negligible in comparison with the damage to unrodded barns, assuming that in the comparison equal numbers of each are taken.

Correspondence with fire marshals and others bears out the conclusion given in the preceding paragraph. Isolated instances of failure are reported, of course, but those fire marshals who have given attention to the subject state that in their opinion lightning rods are of great value in preventing fires by lightning, especially in barns and other buildings where inflammable substances are stored. When an opinion was expressed by fire insurance companies other than the farmer's mutual fire insurance companies just mentioned, it was to the effect that if a building were properly rodded it would be practically safe from damage by lightning.

The cumulative evidence thus secured is seen to be almost entirely favorable to the lightning rod as a protective device, and gains added significance from the fact that no contrary evidence or opinions are brought forward. It is true, however, that in the greater part of the foregoing discussion barns have been almost the only form of property considered. These structures always contain more or less inflammable material, but almost no metal is used in their construction. It is therefore a comparatively easy matter to arrange a lightning-rod system in such a way as to effectively dispose of a stroke of lightning. On the other hand, in the cases of houses and other structures where the presence of chimneys and masses of metal cause complications, it would undoubtedly be found, if a large number of examples were investigated, that the foregoing value of about 99 per cent for the efficiency would be reduced. Statistics are referred to in the next section which tend to show that in the case of houses the efficiency may be between 80 and 90 per cent, taking lightning rods as they are found in the general run of installations.

2. RESULTS OF THE USE OF LIGHTNING RODS IN EUROPE

European Governments and scientific societies have given more attention to the subject of protection against lightning than has heretofore been given under such auspices in the United States. There has been a tendency among them toward uniformity in practice and a disposition to inquire into the causes of damage where protected buildings have been struck and damage reported. They have also formulated rules to be followed in the installation of lightning rods, and in many cases these rules have been made official as applying to public buildings.

The first conference of scientific societies on the subject of lightning rods was brought about by the Royal Meteorological Society of England in 1878. The report of this conference, known as the Lightning Rod Conference, was brought forward in 1881. Nothing further was done until 1901 when interest in the subject was again revived, first in Germany by the Electrotechnischen Verein of Berlin, and a little later in England where the Lightning Research Committee was organized jointly by the Royal Institution of British Architects and the Surveyor's Institution.

The principal results of the work of the Lightning Research Committee of England have been the formulation of a set of rules regarding the installation of lightning conductors and the pointing out of the causes of failure of lightning conductors to perform properly where protected buildings have been struck and damaged. A great deal of valuable information showing what these causes may be has been collected and will be referred to later. Not much has been done, however, to determine what the reduction in the hazard of fire by lightning might be by comparing the effects of lightning on large numbers of protected and unprotected buildings.

In Germany much experimental work has been done on protection against lightning. The conclusions reached have, in general, been favorable to lightning rods, although different opinions have occasionally been expressed as to the exact method which should be followed in obtaining the desired results. The results of the experimental work and observations have been summarized in the rules formulated by the Electrotechnischen Verein of Berlin in 1901, which have since been revised from time to time. Statistics have also been collected for a number of years, some of which, from Wuerttemberg, show that there is some doubt as to the efficacy of lightning rods in protecting buildings against lightning. This, however, is in accordance with an interpretation placed upon these statistics by Baurat Findeisen, of Stuttgart, and is an expression of a feeling which does not seem to be generally shared by German scientists and engineers.

Almost all of the other European countries have given more or less scientific attention to protection against lightning. A report by Dr. D. van Gulik, of Holland, made at the request of the Dutch Academy of Science, shows that the danger of fire by lightning in protected houses roofed with tile or slate is one-sixth or one-seventh of the danger of fire by lightning in unprotected houses. These statistics also show that lightning frequently diverges from conductors and causes damage, although to a far less extent than in unprotected houses.

A considerable amount of official attention is given in all European countries to the protection of public buildings against lightning. This is the case in Germany and France to a greater extent, perhaps, than in other countries. Judging from such reports as are available, the tendency in Germany is to protect all public buildings regardless of their importance. School authorities insist upon having lightning rods on all schoolhouses, and in many cities annual appropriations are made for the specific purpose of keeping the lightning rods on public buildings in repair. This is also the case in France, whereas in the United States the tendency has been to give attention only to very important structures, such as the White House and Capitol, and those in extremely exposed situations, such as the Washington Monument, lighthouses, and smokestacks on Government works.

In Europe the lightning rod was not brought into discredit during the early part of its history to the extent that it was in the United States, and, as a consequence, the European public seems to regard it in a more serious light than does the public in this country. During the century or more that it has been in use in Europe its performance has been subjected to analysis a great many times, and it seems that if it were a failure, or even an uneconomical way of insuring against damage by lightning, it would have been discarded many years ago. On the contrary, European scientists, engineers, and public officials are still deeply interested in its use, and are experimenting in various ways to improve the methods of installation in the light of modern theories of lightning.

IV. SOME POINTS OF DISAGREEMENT AMONG VARIOUS AUTHORITIES

Since the introduction of the lightning rod innumerable controversies and disputes have arisen regarding certain features of the practice of protection against lightning. The one of greatest historical interest, and which is often referred to, concerns Faraday and Sir William Snow Harris. Faraday advocated copper conductors of thickness limited only by the expense, whereas Harris advocated tubular conductors. Faraday maintained that high conductance was the chief consideration. Harris gave no particular reason for advocating tubular conductors. On a certain occasion each is reported to have said that the other knew nothing at all about the subject.

The chief points of disagreement which exist at present among persons who have given much attention to the subject of protection against lightning were touched upon briefly in the introduction, but it seems worth while to discuss some of them here at greater length, in order that certain points may be brought out in a manner which will allow them to be referred to readily in what follows.

1. NOTES ON CAUSES AND SUPPOSED CAUSES OF DAMAGE TO PROTECTED BUILDINGS

A study of some of the works of various authors on lightning rods, which are now in use, will convey the impression that unless a lightning-rod installation is maintained at an almost impossible degree of perfection its presence on a building is a menace to the safety of the property. Much stress is laid by these authors on the necessity for perfect electrical continuity and low resistance in the conductor. If a joint works loose or any other slight defect appears, it must be repaired at once or the rod torn down and put where it can do no harm. This idea—that a lightning rod changes from a complete protection to a menace with the appearance of a slight mechanical or electrical defect in it—has caused many people to do without lightning rods entirely rather than be bothered by one over which constant vigilance would have to be exercised to insure that it would be a source of protection instead of danger.

During the last few years, however, a different attitude has been taken by several men who have given a great deal of attention to protection against lightning; notably among them being Alfred Hands, of England, who has stated quite recently that even a defective lightning rod is better than no rod at all.[8] It is stated by Hands, and his statements seem to be borne out by the testi-

[8] Lightning Conductors, Electrical Review, London (v. 61; p. 337).

mony of others based on statistics, that even with lightning rods installed in the admittedly imperfect manner which was prevalent in the comparatively recent past, the number of rodded buildings struck and damaged by lightning is only 2 per cent of what it would be if they were not rodded.

Moreover, as the result of experiments on a laboratory scale with high-tension transformers, M. R. Chavannes, of France, has reached the following conclusions with regard to certain features of the practice of protection against lightning:[9] (1) "The surface of a lightning conductor is as important as its cross section. (2) The ohmic resistance of the conductor is of little importance. (3) Breaks in the continuity of the conductor are of small consequence. (4) The self-induction of the conductor should be kept as small as possible." These conclusions were drawn from the results of experiments in which sudden oscillatory discharges were impressed on the conductors. By "breaks in the continuity of the conductor" is evidently meant high-resistance joints and loose connections.

It is evidently not the intention of Hands and Chavannes to go to an extreme opposite of the position taken by the men referred to in the first paragraph of this section and advocate careless mechanical construction in the installation of lightning rods. On the contrary, the necessity for good mechanical work has never been questioned, and it is generally agreed that it is essential to anything like security. The results of the experiments and observations of Hands, Chavannes, and others, do indicate, however, that the faults in a lightning-rod system which are pointed out by many authors as being the cause of certain cases of damage are not serious faults. Furthermore, the work of the Lightning Research Committee of England, which was previously referred to, has done a great deal to show that the causes of damage in cases where protected buildings are struck are deeper seated than the superficial defects to which such damage is often ascribed. Reference to Modern Lightning Conductors, by K. Hedges, of England, which contains a large part of the report of the committee, shows that in almost every instance where damage occurred

[9] L'Electricien, Paris, Apr. 15, 1905.

to a protected building there was a mass of metal in close proximity to the lightning rod which was neither connected to the rod nor earthed. These masses of metal consisted of sheet-metal roofs, valleys, ornaments, gas and water pipes, electric-light circuits, telephone circuits, and other more or less insulated metallic bodies. When the lightning discharge occurred, these isolated masses of metal became a part of the path of the lightning stroke, probably because of high-frequency electrical oscillations or steep-wave fronts first being set up in them by the discharge. The result was generally more or less severe damage to the nonmetallic portions of the path, and in some cases fire, where inflammable material came in contact with the sparks. This damage could easily have been prevented by including the mass of metal in the lightning-rod system in the proper manner.

At the present time in the United States it is the prevailing practice among some persons who erect lightning rods to avoid entirely the interconnection of lightning rods and masses of metal present in or on the building they are intending to protect. Others interconnect, but to a limited extent only. That this practice of not making such interconnections may in some cases lead to damage which might otherwise be avoided is obvious on examination of the portion of the report of the Lightning Research Committee just mentioned. It gives 36 examples of damage to rodded buildings, nearly all caused by neglecting to connect one end of a metal roof or interior metal work to the rods and earth it properly at the other end.

From the foregoing discussion it is evident that in the past the careful efforts of some persons to obtain complete protection have resulted only in partial protection. In fact, it may be said that a large percentage of the total number of lightning-rod systems installed at the present time do not afford complete protection. This is of course due in part to ignorance on the part of those who install lightning rods concerning the conditions which must be realized in a system which will give the maximum degree of protection, but a considerable part is due to willful inattention to the rules concerning the installation of lightning rods because of the extra labor involved in following them.

2. IRON CONDUCTORS VERSUS COPPER CONDUCTORS

At various times for many years the question of the proper material for lightning conductors has been discussed from almost every possible point of view. At the present time the materials commercially available for lightning rods are copper, aluminum, and iron, or combinations of these, such as copper-clad steel. The materials most in favor, however, are copper and iron, aluminum or copper-clad steel being but little used.

It has been noted in the introduction that the first lightning rods erected were of iron, and when properly put up they seemed to give good results. Later, when copper became more easily obtainable, it supplanted iron to a large extent and has since remained more or less generally in favor. The advantages obtained in the use of copper, as set forth by the proponents of copper as against iron, beginning with Faraday, are low resistivity and great resistance to atmospheric corrosion. The advantage upon which the greatest emphasis is laid, however, is that of low resistivity. In 1892 Sir Oliver Lodge issued his book on Lightning Conductors and Lightning Guards, in which he opposed the use of copper and advocated iron for lightning conductors on account of its high resistivity. At the time Lodge's book was written scientists were just becoming familiar with the phenomena of electrical oscillations. Lightning was then (and still is by many persons) believed to be an electrical discharge of an oscillatory character, so Lodge reasoned that if lightning rods were made of material of high resistivity any oscillations which might be set up in them by a lightning flash would be damped out and the energy of the flash disposed of with less danger of side flashes and other phenomena of self-induction than in a system of lightning rods made of material of low resistivity. Nevertheless, with iron opposed on the one hand because of its high resistivity, and copper opposed on the other because of its low resistivity, neither has succeeded in forcing the other from the field. At present iron is probably sold to as great an extent as copper for lightning rods. The chief advantages claimed for iron at the present time by manufacturers of iron lightning rods are its strength and high-fusing point. The matter of atmospheric corrosion has been overcome by galvanizing so thoroughly that iron rods will last practically indefinitely, above ground at least, and connections are made by screw-joints of bronze which will last as long as the rods do. A sample of an iron rod is now in the possession of the Bureau of Standards which was in place on a house in St. Louis more than 40 years. A cross section made through a joint shows that no corrosion had taken place.

In discussing the relative merits of iron and copper, and the desirability of having a lightning conductor of material of greater or less resistivity, not much has been said by the opposing parties as to the resistance of earth connections, or the effect of their resistance on the total resistance of the system. At the Bureau of Standards an investigation was made of the resistance of a number of earth connections and the lowest resistance obtainable with a single connection without going to prohibitive expense was 15 ohms. This was obtained with a plate of sheet iron of 180 square feet in area which was laid in coke mixed with salt and earth and flooded with water. The types of earth connections generally used with lightning-rod installations would have a much higher resistance than this, doubtless reaching in some cases several hundred ohms. It is obvious, therefore, that the resistance of the metallic portion of a lightning-rod system is rather small in comparison with the total resistance to be considered, that is, the sum of the resistances of the earth connection, the rod, and the path of the lightning discharge above the rod. Consequently, in choosing between iron and copper the resistivity of the metals is not of paramount importance, even when the resistance to rapidly varying current flow is considered, as will be shown later.

3. SYSTEMS OF PROTECTION AGAINST LIGHTNING WITH POINTS VERSUS SYSTEMS WITHOUT POINTS

The prevailing practice in the greater number of European countries and in the United States in protection against lightning is to provide a lightning-rod system with aerial terminals having points to receive the discharge. In Hungary this system has been abandoned to a large extent and a system called the "contour system" has been adopted successfully in its place. It consists of iron wire, or sheet iron bands, laid along the contours of the roofs and connected to make as complete a network as possible. Aside from the lack of aerial terminals with points in the contour system the chief difference between the point system and the contour system is the increased number and decreased size of the conductors in the latter. The conductors used are of iron in most cases.

In the reports available the advantages of this system over systems provided with points are not clearly set forth, but it is evident that in part the change was made to do away with the insecure mechanical construction often met with in the erection and bracing of aerial terminals. It may also be well to note that at the time the change was made increasing attention was being given to the interconnection of metallic masses on and within the buildings, which was neglected prior to the change, and the neglect of which was doubtless the cause of the numerous failures of rods with points which were noted by Hungarian investigators. An advantage was thus apparently secured with the contour system which might as well have been obtained with the point system. Nevertheless, the contour system has proved successful and has been recommended in Holland.

4. USE OF INSULATORS BETWEEN RODS AND BUILDINGS

The question is often asked as to the advisability of using insulators of glass or porcelain in the clamps fastening lightning rods to buildings. In answer to this it may be said that a careful survey of the literature of the subject of protection against lightning does not, in works of recent date, disclose any author as advocating the use of insulators for lightning rods. Moreover, most manufacturers of lightning rods are opposed to their use, and have long since ceased to use them except in localities where local prejudice in their favor still demands that their use be continued. This prejudice doubtless arises from the idea that a lightning conductor, being a conductor of electricity, should be insulated. A confusion of ideas is here evident as to the functional difference between a conductor intended for the transmission of electrical energy and a lightning conductor. In the case of a conductor intended for the transmission of electrical energy the purpose of insulation is to keep at a minimum the proportion of the energy expended uselessly. The purpose of a lightning rod is to collect and dissipate electrical energy with as little disturbance as possible. To do this it is necessary for the lightning rod to "drain" all surrounding conductors of their store of electrical energy; hence, all of the extensive metal parts of a building must be connected to its rods and to earth. As it is manifestly impracticable to insulate these metal parts from the building, about the sole result of glass or porcelain in the clamps is to make the mechanical construction of the rods more insecure.

Furthermore, if the proper conditions exist for a lightning discharge, and the building is damp from rain or other causes, the electrical charge may spread over the entire surface of the building. When the discharge occurs, the charge on the surface of the building will tend to pass into the rod; and, if the rod is insulated, sparks over the insulators may result, whereas if the insulators were absent, leakage might be possible to a sufficient extent to prevent sparks. The latter would apply, of course, only to a building having little or no metal used in its construction; in the case of a building containing considerable metal, drainage to the metal and through the connections to the rod would probably obviate any danger from sparks over the insulators if they were present. It may also be said that the potentials of lightning strokes are so enormous that the small insulators used for lightning rods would be entirely unable to withstand them.

V. CHARACTERISTICS OF LIGHTNING FLASHES [10]

Since Franklin's discovery of the identity between electricity and lightning, many attempts have been made to estimate or determine, the current intensity, frequency, and potential of a lightning flash. The actual data which have been obtained up to the present time are, however, very scant and far from sufficient to give a good basis for calculation in designing lightning rods. The chief reason for this lack of progress in obtaining data on the electrical characteristics of lightning has been lack of means to carry out the experiments on the proper scale. The necessary experiments for obtaining more comprehensive data are

[10] Much of the material used in the preparation of this portion of the paper was abstracted from the German by Dr. G. R. Olshausen, of the Bureau of Standards.

quite generally regarded as feasible, although there are many difficulties involved in making the measurements, and it has been remarked by Tait[11] that the first Government or institution that furnishes the money will undoubtedly be the one to have the honor of making the discoveries. Nevertheless, some valuable information has been acquired by individual investigators, and in the course of this investigation an endeavor has been made to collect as much of it as appears useful in connection with protection against lightning. A summary of this work is given in what immediately follows, and such conclusions are drawn from the results as seem to be justified.

1. CURRENT INTENSITIES OF LIGHTNING FLASHES

What appears to be the only work on the current intensities of lightning flashes has been done by F. Pockels,[12] who made use in his measurements of some of the peculiar magnetic properties of basalt, and at the same time assumed that lightning discharges are unidirectional. In the course of some laboratory experiments on the magnetic properties of basalt Pockels found that for unidirectional magnetic fields the remanent magnetism of prisms of nepheline basalt depended neither on the duration nor the time variation of the field, but only on its maximum value. Basalt consists of crystals of magnetite distributed through a badly conducting mineral medium, and it is upon this formation that its peculiar magnetic property depends, there being no eddy currents set up in it by a varying magnetic field which would retard the magnetization of the specimen. A magnetic field lasting only about one-millionth of a second showed the same remanent, and probably also the same temporary magnetization, as was induced by a field kept up indefinitely at the same strength. This being the case, the remanent magnetism of the basalt might be taken as a measure of the maximum magnetic field to which it had been subjected, and consequently of the maximum value of the magnetizing current. To find the relation between the field strength and the temporary and permanent magnetic moments of a prism it was only necessary to test the specimen in known

[11] Lightning, Encyclopaedia Britannica, ninth edition.

[12] Annalen Phys. Chem., 63, p. 195; Annalen Phys. Chem., 65, pt. 2, p. 458; Phys. Zeitschrift, 2, p. 306.

magnetic fields and plot three curves, one having temporary moments as ordinates, another residual moments as ordinates, a third having the ratio of these moments as ordinates, and all having the field strength H as abscissæ.

The general appearance of the magnetization curves of basalt is the same as the appearance of the magnetization curves of soft iron. Both the temporary and remanent magnetizations increase more rapidly than the field at first, and afterwards less rapidly. The ratio of the remanent to the temporary magnetization increases at first with the field, but then becomes constant, and finally decreases. In the basalts containing the larger magnetite crystals, the remanent magnetism reaches its maximum sooner than in the others.

In order to test the method Pockels discharged known capacities which had been charged to known potentials through magnetizing circuits of known resistance and self-induction, the constants of the circuit having been chosen to give a highly damped discharge. He then calculated the maximum value of the current by means of the constants of the circuit and compared them with the values determined from the remanent magnetism. The resistance of the spark gap was neglected in making these calculations, but the results agreed very well in the two cases. The equation connecting the various quantities concerned is $i = \frac{5l}{2\tan^{-1}\frac{l}{2a}} H$; where i is the current in amperes, l the length of the basalt bar, a the distance of its middle point from the axis of the conductor, and H the value of the magnetizing field which would produce the same effect on the basalt bar as the magnetizing field of the current in question.

The following values of H, and Mr, the magnetic moment of the prism due to the remanent magnetism, were obtained on five basalt prisms:

$H = 100$	190	310
$Mr = 0.1434$	0.3616	0.5246

The results of these experiments were made use of by Pockels in making an approximate determination of the current intensity of lightning flashes, assuming, as previously stated, that the discharge in a flash of lightning is unidirectional. The first measurements were made on specimens cut from outcroppings of basalt rock which showed irregular and local magnetization which could only be due to lightning flashes. Knowing the strength of the field necessary to produce the remanent magnetism shown by the basalt, only the distance to the path of the flash was necessary to make a rough determination of the current. This distance was in some cases assumed to be the distance to the surface of the rock; in others a damaged tree was assumed to give the necessary evidence. One estimate made by assuming the distance to the flash to be the distance to the surface of the rock led to a minimum value of 2900 amperes as the current intensity; three others, on specimens obtained from the vicinity of damaged trees, gave 6400, 6600, and 10 800 amperes, respectively. These values are probably too small, because of the period of time which elapsed between the time of the flash and the time of making the measurements, and also because of the disturbance of the basalt in cutting it out.

Other observations were made on basalt prisms exposed in the vicinity of a branch of the lightning rod on the observation tower on Mount Cimone, in the Appenines. One of these prisms, which had been placed at a distance of 6.4 cm from the rod and had been subjected once to the magnetizing effects of a lightning stroke, gave $Mr = 0.52$, corresponding to $H = 303$ and $i = 10\ 200$ amperes. A second prism, which had been subjected to the magnetizing effects of four strokes, gave $Mr = 0.312$, $H = 166$, $i = 5530$. A third prism was only slightly magnetic. There were two ground connections to the lightning rod, so it is quite probable that the current divided symmetrically. The total currents in the two cases were, therefore, 20 000 and 11 000 amperes, respectively. These values are doubtless too small, because the prisms were not examined until several months after having been exposed and were subjected more or less to vibration in the meantime.

No claim whatever to accuracy is made for the foregoing results, but they show beyond a doubt that the currents in lightning flashes must be reckoned in thousands of amperes; but because the duration of the current is so short the total quantity of electricity is relatively small. To put it in other words, a small quantity of electricity discharging to earth in a few thousandths of a second makes a momentary current of very great magnitude, just as a small quantity of gunpowder exploded in a closed space very suddenly makes a very great pressure for a very short time. The magnitude of the current in a lightning discharge is also important, whatever its duration may be, because it gives an idea, which is not at present obtainable in any other way, of the magnitude of the potentials which may be set up between a lightning rod and earthed objects in its vicinity. Moreover, by means of the current and duration of a lightning flash an estimate may be made of the energy liberated in a lightning rod in the form of heat in the event of its being struck. In the next section an idea is obtained of what this duration may be.

2. FREQUENCY AND DURATION OF LIGHTNING FLASHES

The well-known flickering of lightning flashes, which is visible to the unaided eye, indicates that a flash of lightning does not always consist of a single discharge of electricity, but, on the contrary, consists usually of a number of successive discharges which follow each other with very short time intervals between them. By standing where the light from a flash does not blind the eyes an observer can detect the successive discharges for each complete flash of lightning, the number of which varies, for different flashes, from 2 or 3 to 10 or more. By means of swinging or rotating cameras photographs have been made which show separately the constituent parts of a flash in so far as they can be shown by taking impressions on a photographic plate moving at rather a slow speed. From these photographs have been calculated the total duration of the flash for a number of cases, and also the intervals of time between the successive discharges. Moreover, by visual means, using rotating disks, and other apparatus, the durations of the constituent parts of the flash have been estimated.

The first photographic evidence of the multiple character of lightning flashes was undoubtedly obtained at different times by Kayser [13] and Rümcker, each using a stationary camera, the path of the flash being shifted by the wind. The durations of the flashes were estimated from these photographs, but, owing to the fact that the velocity of the wind was not known accu-

[13] Berichte der Königl. Akad., Berlin, 1884, s. 611.

rately in either case, the results are not to be relied upon. These photographs are of importance, however, from the fact that they show the distance through which the path of a lightning flash may be shifted by the wind while the successive discharges are taking place. More will be said of this later. A few years after Kayser's and Rümcker's photographs of lightning were taken L. Weber[14] showed that it is possible to make a time analysis of any lightning flash by moving the camera while the exposure is being made, thus spreading the image of the flash over the plate and separating it into its parts. In his experiments Weber simply held his camera in his hands and gave it a rotary motion such that the optical axis of the objective approximately described the surface of a cone. As a result of this it is found that the images on the plate of corresponding points of successive discharges do not lie on a straight line, but on a circle which tends to obscure the real meaning of the picture. This method only permits a very approximate estimate to be made of the time interval between any two successive discharges.

The best work on photographic time analysis of lightning flashes has probably been done by B. Walter.[15] Walter succeeded in analyzing the sparks from an induction coil by means of a moving film and at once saw that the method would be applicable to the analysis of lightning flashes. For this purpose he mounted his camera on a fixed axis around which it was made to rotate by clockwork at a slow and uniform rate. From a photograph of a lightning flash made with this apparatus a simple calculation by means of the following formula gives a very close approximation to the interval of time between any two successive discharges: $dt=\frac{f\,dy}{\omega(f^2+y^2)}$ where dy is the distance between the images on the plate of any two successive discharges along the same path, ω the angular velocity of the camera, y the distance of the point on the plate from a line through the center of the plate and parallel to the axis of rotation of the camera, and f is the focal length of the lens.

With the apparatus described in the foregoing paragraph Walter took a number of photographs of lightning flashes and deter-

[14] Berichte der Königl. Akad., Berlin, 1889, s. 781.

[15] Annalen der Physik, 10, pt. 2, p. 393.

FIG. 1.—*Photograph of lightning flash taken with a moving camera*

(Photograph by Dr. B. Walter, of Hamburg, Germany) mined the total durations of the flashes and also the intervals of time between the successive discharges. In the case of a flash consisting of five successive discharges the total time was found to be 0.2447 second, while the intervals between the successive discharges were 0.0360, 0.0364, 0.0283, and 0.1440 second, respectively. These are fairly representative of the average duration and time intervals of the flashes of which photographs were taken. The durations and intervals are variable, however, and range for different flashes from practically zero to 0.6 second or more for the duration, depending apparently on the number of successive discharges in a flash, and from practically zero to 0.20 or 0.30 second for the intervals. A photograph taken by Larsen [16] with a rotating camera shows 40 distinct discharges in a single flash, the duration being 0.624 second and the average interval 0.0156 second. The intervals between the successive discharges varied from 0.0026 to 0.0520 second. This flash is exceptional because of the large number of successive discharges which occurred.

Fig. 1 is a reproduction of a photograph from the collection of B. Walter, which shows in a marked way the general character of a lightning flash. Beginning at the right, what may be called the predischarge is shown. This predischarge consists of a preliminary branching discharge, which is the most noticeable at the positive end of the flash, and may occur several times before the first complete initial discharge occurs. This predischarge, with each recurrence, extends itself from the positive end in steps and prepares the path for the complete initial discharge. The time of preparation of the path may be as much as one-fiftieth second. The predischarge is noticeable at the negative end, but in much less degree than at the positive end. This predischarge has been carefully studied by Walter, using moving-photographic films, and sparks from an induction coil having suitable inductances and capacities in circuit with it.[17] When the path has been fully formed by the predischarge the first complete discharge occurs. This is usually followed by several other discharges along the path ionized by the first discharge until a stage of exhaustion of the path is reached which allows a continuous discharge to occur which lasts,

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[16] Photographing Lightning with Moving Camera, Annual Report of Smithsonian Institution, 1905, p. 119.

[17] Annalen der Physik, vol. 10, pt. 2, p. 393.

comparatively speaking, for a considerable length of time, and produces striations similar to those seen in a vacuum tube. Instead of being a few millimeters in height, however, the striations in a lightning flash may be from 40 to 80 centimeters in height. When the cloud is exhausted by this continuous discharge a short cessation occurs, after which there is a final discharge, usually much weaker than the first discharges. These phenomena are all more or less clearly shown by the reproduction given in Fig. 1. Many variations from this procedure may occur but in general a flash of lightning is made up of the constituent discharges just described.

The characteristics of the constituent discharges of a flash of lightning are of the most interest in connection with the design of a lightning-rod system. Whether these discharges are unidirectional, as assumed by Pockels in his measurements of the maximum currents of lightning flashes, or whether the discharges are oscillatory has not yet been ascertained. It is doubtful whether the exact character of these discharges can be ascertained by photographic methods. K. E. F. Schmidt[18] doubts very much whether it will ever be possible by means of revolving devices to demonstrate the existence of oscillations having a period of less than 1/30 000 second. He thinks that if a flash is really periodic, methods of observation depending on electrical resonance will have more chance of success in demonstrating the oscillations. This suggestion is qualified, however, by supposing that the oscillations are not strongly damped. What this supposition will come to remains to be seen, but at present a consideration of the nature of the path of lightning discharges, and the magnetic effects of lightning which were observed by Pockels and others,[19] makes it seem more probable that the oscillations are strongly damped than otherwise.

In order to get an idea as to what the dimensions of the resonance apparatus should be Schmidt made some experiments with a rapidly revolving disk. A black disk was used, 10 cm in diameter, with a white cross on it, the arms of the cross being 2 mm in width. The disk was driven by clockwork at a rate of 50 to 60 revolutions per second, the speed depending on the tension of the

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[18] Elektrotechnische Zeitschrift, v. 26, p. 903.

[19] See P. Gamba, Magnetization of Brickwork by Lightning, Accad. Lincei, Atti, vol. 8, p. 316. Platania and Platania, Comptes Rendus, vol. 141, p. 974.

Fig. 1a.—*Same lightning flash as shown in figure 1 taken with a stationary camera*

(Photograph by Dr. B. Walter, of Hamburg, Germany)

driving spring. With this disk the following observations were made:

(*a*) Many flashes illuminated the disk so as to cause only one distinct and sharply defined image of the cross to be seen.

(*b*) More frequently, however, two, three, or more, sharply defined images of the cross were seen, either in such rapid succession as to have the appearance of being instantaneous or with distinct time intervals between them. One cross was very bright, the second, as a rule, less bright, and the third less bright than the second, and so on; with the decrease in brightness the width of the cross arms seemed also to decrease.

The relative positions of the crosses to each other, as well as the order in which they followed, varied greatly. Often the angle between two images was 45°, and then again they approached within 10° of each other.

Often the successively appearing images gave the impression that the disk turned clockwise, while in reality it turned in the opposite direction; at other times the disk seemed to oscillate.

(*c*) Several times a bright cross was observed with indistinct edges; at both sides of the four cross arms two or three fine ray-like arms appeared, making an angle of about 5° with each other.

(*d*) In the case of a very bright horizontal flash eight bright, sharp images of the cross were observed with the same angular displacement between them. One of these images was somewhat brighter than the others.

(*e*) In the case of a not well-defined lightning flash which was perpendicular to the horizon, having an altitude of about 30° to 40°, the disk appeared gray and no cross was observed.

The following conclusions are drawn from these observations:

In the first place they confirm the deductions made by Walter from his photographs, that the discharge varies greatly with different flashes of lightning.

The observations under *b* indicate a succession of partial discharges; the interval between any two discharges can only be estimated definitely, however, if they both occur within the period of one revolution of the disk. That this did not always occur is evidenced by the fact that at times the disk appeared to turn in opposition to its real direction of rotation, and at other times seemed to oscillate; hence, the intervals can not be estimated with certainty from the angles between the appearances of the images of the cross on the disk.

In the case of *a* the visible discharges must have occurred during a period of less than 1/35 000 to 1/40 000 of a second. If the period of these single discharges had been greater, a distinct broadening of the image of the cross arms would have been observed. However, no perceptible broadening of the arms of the cross were observed in any case, so the duration of the constituent parts of the flashes must, in every case but *e*, have been less than 1/35 000 second. The establishing of this time is of great importance, for the reason that in case oscillatory discharges do occur it gives an indication of the upper limit of magnitude of the period of the oscillation.

The frequency of a stroke of lightning has been calculated by Emde[20], by assuming (1) a circular conducting cloud and a circular portion of the earth's surface situated symmetrically beneath it; between these the lines of force are normal to both; (2) a concentric cylinder occupied by incandescent gas between the cloud and the earth; (3) that the current density is the same in each cross section of this cylinder, i. e., that no waves exist along the gas column. By making some additional assumptions in regard to the diameter of the cloud and flash, Emde finds a frequency of from 2000 to 8000 cycles per second, or an average of 5000 cycles. There is some doubt, however, as to the validity of Emde's assumptions, and his results should, perhaps, be taken only as in some degree confirmatory of the opinion which more or less generally is held that lightning is, in effect, an electrical discharge of medium frequency; that is, hundreds of thousands of cycles per second, as distinguished from low frequencies of a few hundreds of cycles per second, or high frequencies of a million or more cycles per second; and in most cases is of sufficiently steep wave front to excite secondary high-frequency phenomena, even though it may be so rapidly damped as to be practically a unidirectional discharge. To state definitely what ranges the frequency of lightning discharges may cover, however, requires that much more experimental work be done.

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[20] Die Schwingungszal des Blitzes, von Fritz Emde, Elektrotechnische Zeitschrift, v. 31, p. 675, 1910.

3. POTENTIALS OF LIGHTNING FLASHES

With regard to the potentials of lightning flashes but little more than estimates are available. The potential required to cause a flash of lightning a mile long has been estimated by Lodge [21] to be 5 000 000 000 volts, using as a basis the breakdown voltage of air, which is about 30 000 volts per cm. Although this seems rather improbable it can be shown by calculation, based on experimental evidence at hand as to the charges of falling rain, that such voltage conditions may be realized. Prof. Trowbridge, however, has cast doubt over the validity of these figures by means of experiments with voltages exceeding a million which seem to indicate that with long air gaps and extremely high potentials air may exhibit properties different from those shown under the voltage conditions which have hitherto been realized.[22] In designing a system of lightning rods the only potentials which need to be considered are those set up in the system itself, and in a following section an estimate is given of the magnitude which these potentials may attain.

4. SHIFTING OF THE PATH OF LIGHTNING FLASHES BY THE WIND

An examination of such reports as are available on failures to obtain satisfactory protection from lightning by means of lightning rods discloses the fact that an occasional accident occurs for which no explanation can be given, which is based on any of the causes to which failures of lightning rods are usually ascribed. In such cases if there is no evidence of neglect in connecting some mass of metal to the rod, or if there are no bad ground connections or other obvious cause to account for the phenomenon, it is usually recorded as one of the vagaries of lightning. In fact, in some of these cases it does seem as if the path of the stroke had not been chosen naturally, but had been picked out at random, the same stroke apparently striking in several places at once. An explanation for some of these phenomena may possibly be found in the evidence furnished by the photographs taken by Kayser and Rümcker, which were previously referred to. These photographs show that during the period of a multiple flash, consisting of sev-

[21] Lightning Conductors and Lightning Guards, p. 9.

[22] Some results obtained with a storage battery of 20,000 cells, Nature, v. 62, p. 32

eral consecutive discharges, the ionized path of the flash may be shifted by the wind over a considerable distance. The photograph taken by Kayser in 1884 with a stationary camera, showed a shifting of the path of the flash, in a direction at right angles to the optical axis of the objective, over a distance which, from the focal length of the lens and the supposed distance to the flash, was estimated at 4 meters (13.12 feet). The photograph taken by Rümcker under the same conditions showed a shifting of the path of the flash of 11.1 meters (36.4 feet). In taking the latter picture the camera was not inclined to the horizon, but only the board carrying the objective, thus causing the image to be sharp only in the central part. The distance from the camera to the place where the stroke fell was definitely known (530 m) so that with the known focal length of the lens (22.5 cm), and the distance between the images of the initial and final discharges on the plate (4.7 mm), it was possible to calculate with a fair degree of accuracy the distance covered by the flash at right angles to the axis of the objective. In neither of these cases was the direction of the wind known, so it is possible that the total distances over which the paths of the flashes were shifted were actually greater than those given; those given being projections of the total distances upon planes parallel to the plates. In any event, these photographs show that the path of a lightning flash can be shifted by the wind to such an extent that, although the initial discharge of a flash may take to a lightning rod and be carried off harmlessly, those following may keep to the ionized path as it is swept aside and strike a projecting corner of the building, or a tree close by.

The shifting of the path of a flash of lightning by the wind may explain what are called divided strokes. Objects near each other, as a house and a tree, are often struck apparently simultaneously, the stroke seeming to divide as it approaches the earth. Visually, of course, the stroke may appear to divide, but inasmuch as a visual image of a flash may persist for as much as one-tenth second it is likely that many strokes which appear to divide are in reality shifted by the wind. The same explanation may also apply to many so-called side flashes from rods which have been attributed to various causes. In designing a system of lightning rods this shifting of the path of a lightning stroke must, therefore, be taken into account and provision made against it as far as possible.

5. SOME CONDITIONS TO BE CONSIDERED IN DESIGNING A PROTECTIVE SYSTEM

(*A*) *Heating effects*.—The more or less meager data on the electrical characteristics of lightning which have just been given make possible certain assumptions as to the current, wave front, and duration of a flash of lightning which, to a small degree at least, are founded on facts. It is of interest to estimate from these assumptions the amount of energy in the form of heat which may possibly be liberated in a rod in the event of its being struck, and also the differences of potential which may at the same time be set up between the rod and earthed objects in its vicinity. The relative skin effects in cylindrical rods of copper and iron may also be calculated quite readily, provided, of course, that the character of the wave front is known. Let these assumptions be as follows:

(*a*) Take the maximum current in the flash as 25 000 amperes; and let it be supposed that there are 10 consecutive discharges of equal intensity.

(*b*) For the wave front let it be assumed that in one case the rate of variation of current is equivalent to 100 000 cycles per second, and in another case to 500 000 cycles per second.

(*c*) Suppose the duration of each consecutive discharge to be 1/35 000 second. The total duration of the flash, not counting the intervals between successive discharges, would, therefore, be 10/35 000 second.

(*d*) Since there are no data available as to the wave shape and damping, let an undamped, rectangular wave of current of an amplitude of 25 000 amperes be assumed as giving the severest possible conditions as to heating. The duration of the discharge being very short but little heat would be lost by radiation, and it may, therefore, be assumed that all of the heat liberated within the rod is retained by it until the discharge is completed.

(*e*) Assume a lightning rod of No. 0000 solid copper wire, with a diameter of 1.17 cm (0.46 inch) and a length of 30.5 m (about 100 feet) between two ground connections on opposite sides of a building. Place the aerial terminal in the middle. The resistance to steady currents of the rod from the aerial terminal to the two ground connections would be 0.00137 ohm at 50° C, exclusive of joints.

On account of the steep wave front of the discharge the skin effect must be taken into account in calculating the value of the resistance of the rod which is to be used in obtaining the heating effect of the current. For the equivalent frequencies assumed in (*b*) this resistance may be approximated within 2 per cent by means of the formula $R' = R\frac{\pi d}{80}\sqrt{n}$,[23] where R' denotes the high-frequency resistance, R the resistance to steady currents, d the diameter of the rod in centimeters, and n the frequency. This formula is derived on the assumption that the current impressed upon the conductor has a sine wave form. It may be that a lightning discharge has an extremely abrupt wave front, in which case the resistance given by this formula would not be correct, but inasmuch as the wave form of a lightning discharge is not known at present, the value of the resistance thus derived will have to do for illustrative purposes. Substituting in the formula it is found that when $n = 100\,000$ cycles per second, $R' = 0.00137 \frac{3.1416 \times 1.17}{80} \sqrt{100\,000} = 0.0199$ ohm. When $n = 500\,000$ cycles per second, $R' = 0.00137 \frac{3.1416 \times 1.17}{80} \sqrt{500\,000} = 0.0445$ ohm. The energy expended in heat in the rod is $I^2 R' t$, where t is the time of the discharge; in this case $\frac{10}{35\,000}$ second, as explained in (3). Substituting in the formula, $\frac{(25\,000)^2 \times 0.0199 \times 10}{35\,000} = 3553$ watt-seconds (joules). Changing this to units of heat, $\frac{3553}{4.18} = 849$ gram calories of heat liberated in the rod by the flash as assumed above, when $n = 100\,000$ cycles per second. When $n = 500\,000$ cycles per second, the heat liberated in the rod is $\frac{(25\,000)^2 \times 0.0445 \times 10}{35\,000} = 7946$ watt-seconds = 1898 gram calories.

The average specific heat of copper from 0° C to 1083° C, its melting point, is about 0.11, this value being obtained by plotting

[23] See Lord Rayleigh, Self-induction and resistance of straight conductors, Philosophical Magazine, series V, vol. 21, p. 381, May, 1886; also J A. Fleming, Principles of electric wave telegraphy, p. 90, ed. 1906.

a curve of specific heats for various temperatures and taking the average ordinate of the curve. To raise the temperature of 1 gram of copper from 30° C to its fusing point, therefore, requires about $1053 \times 0.11 = 115$ calories of heat; hence, at the equivalent frequency of 100 000 cycles, enough heat would be liberated in the rod to bring $\frac{849}{115} = 7.4$ grams of copper to the fusing point. If the equivalent frequency of the flash were 500 000 cycles, enough heat would be liberated in the rod to bring $\frac{1898}{115} = 16.5$ grams of copper to the fusing point.

It is also of interest to calculate the effect of such a stroke of lightning on an iron rod of the same dimensions. In this case the foregoing formula for R' must be modified to include the effects of the magnetic permeability of the iron. The formula thus becomes $R' = \frac{2l\ 10^{-9}}{d}\sqrt{\mu\ \rho\ n}$, where ρ is the resistivity of the iron in electromagnetic units, μ its permeability in the same units, l the length, and n and d as just given. The factor 10^{-9} is introduced to change from electromagnetic units to practical units, thus giving R' in ohms. An average value of ρ for iron is found to be 12 microhms per cm³, or 12 000 electromagnetic units of resistance. The value of μ will be comparatively small because of the extremely high-current density and consequent high magnetizing force in a conductor of 1.17 cm diameter carrying 25 000 amperes. It can be shown that μ in this case will be of the order of 2.5, so let this value be assumed for the permeability. As before, $l = 1525$ cm, $d = 1.17$ cm, and $n = 100\ 000$ and 500 000 cycles per second.

$$\therefore R' = \frac{1525 \times 10^{-9}}{1.17}\sqrt{2.5 \times 12\ 000 \times 100\ 000} = 0.0714 \text{ ohms at } 100\ 000 \text{ cycles.}$$

When $n = 500\ 000$ cycles,

$$R' = \frac{1525 \times 10^{-9}}{1.17}\sqrt{2.5 \times 12\ 000 \times 500\ 000} = 0.1596 \text{ ohms.}$$

The resistance to steady currents,

$$R = \frac{2\rho l}{\pi d^2} = \frac{0.000012 \times 1525 \times 2}{3.1416 \times (1.17)^2} = 0.00851 \text{ ohms.}$$

These values for the iron rod, in the same way as for the copper rod, are obtained on the supposition that the two parts of the rod, from the aerial terminal to the ground connections, are in parallel. The energy expended in heat in the rod if the equivalent frequency of the flash were 100 000 cycles per second, would be $\frac{(25\,000)^2 \times 0.0714 \times 10}{35\,000} = 12\,750$ watt seconds, or $\frac{12\,750}{4.18} = 3050$ gram calories. If the equivalent frequency were 500 000 cycles per second, the energy expended in heat in the rod would be $\frac{(25\,000)^2 \times 0.1596 \times 10}{35\,000} = 28\,500$ watt seconds or 6809 gram calories.

The average specific heat of iron, obtained in the same way as that of copper, is about 0.21. The number of calories required to raise the temperature of a gram of iron to its fusing point (about 1530° C) is, therefore, $1500 \times 0.21 = 315$ calories. The number of grams of iron which the heat liberated in the rod in the case of 100 000 cycles would bring to the fusing point would be $\frac{3046}{315} = 9.7$. In the case of 500 000 cycles the number of grams of iron brought to the fusing point would be $\frac{6809}{315} = 21.6$.

In all of the foregoing cases the high-frequency resistance of the rods varies inversely as the diameter, and consequently the heat liberated also varies in the same way. Thus, a rod one-half the diameter of those given under the same conditions would show twice as much metal brought to the fusing point. It thus appears that all lightning rods of ordinary size as erected at the present time are safe from being fused unless flashes occur which are of vastly greater steepness of wave front and current strength than the one just assumed for purposes of calculation, or the rods contain high-resistance joints which increase the heating effects at points. Practical experience has shown also that rods of ordinary size, meaning rods weighing from 0.5 kg per meter (5.2 ounces per foot) and upward, are seldom or never fused, except at the point and places where the flash leaves the rod for some other object. From the specific heat of iron and the quantity of metal in the rod it can be shown that the temperature of the iron rod used in the foregoing calculations would be raised about 30° C above surrounding temperatures by the quantity of heat liberated at the equivalent frequency of 500 000 cycles. The temperature of the others would be raised much less than this.

(*B*) *Potentials.*—It is evident that the heating effects of a lightning stroke as it transverses a rod are in most cases comparatively insignificant, but the same can not be said of the potentials set up between the rod and the earth or other conducting objects in its vicinity. As mentioned heretofore in this paper, the resistances of the ground connections used in lightning-rod systems are, in general, rather high, and it is not probable that many of them would be found of which the resistance of two in parallel would be less than 25 ohms. It is of interest to note what the drop in potential across such a ground connection might be, leaving out of account all superimposed effects due to high-frequency oscillations, and taking merely the drop in potential which would occur across the ground connection if the current were steady and unidirectional. Taking a value for the current as assumed above this is simply $25\,000 \times 25 = 625\,000$ volts. If, in addition to this, there are superimposed the effects of high-frequency oscillations, the necessity for care in the installation of a system of lightning rods in order to obtain the maximum degree of protection becomes quite obvious.

(*C*) *Relative skin effects.*—From a comparison of the ratio $\frac{R'}{R}$ for the different frequencies for copper and iron some information may be obtained as to the relative skin effects in rods of the same dimensions in the two metals. In the case given, for rods 1.17 centimeters in diameter, it is found that

$$\frac{R'}{R} \text{ for copper at 100 000 cycles} = \frac{0.0199}{0.00137} = 14.5$$

$$\frac{R'}{R} \text{ for copper at 500 000 cycles} = \frac{0.04451}{0.00137} = 32.5$$

$$\frac{R'}{R} \text{ for iron at 100 000 cycles} = \frac{0.0714}{0.00851} = 8.4$$

$$\frac{R'}{R} \text{ for iron at 500 000 cycles} = \frac{0.1596}{0.00851} = 18.75$$

At this high-current density and with frequencies of from 100 000 to 500 000 cycles the skin effect in iron, therefore, appears to be less than in copper. It seems, then, that at the enormously high-current intensities and steep-wave fronts of most lightning discharges there is practically no advantage inherent in either metal as far as skin effect is concerned. It is also evident from the above calculations that even though for direct currents the effective resistance of iron is about six times that of copper, and for alternating currents of low frequency is enormously greater, for electrical discharges of high frequencies or very steep-wave fronts involving very heavy currents the effective resistance of iron is much less than six times that of copper. The superiority of copper over iron for lightning conductors under these severe conditions is, therefore, much less than for direct or ordinary alternating currents. It should be pointed out in this connection that it is only in case very heavy current discharges are involved that we are much concerned with the conductance of lightning rods, and in such case the saturation of the iron would always result. Thus it is when high conductance is most important that the superiority of copper becomes relatively small.

VI. RELATIVE LIABILITY TO DAMAGE BY LIGHTNING OF DIFFERENT CLASSES OF BUILDINGS AND OTHER FORMS OF PROPERTY

It is generally recognized that certain classes of buildings and other forms of property are more liable to damage by fire from lightning than others. In recent years, however, apparently no attempt has been made systematically to obtain data from which could be shown the order in which different classes of property might fall with regard to their liability to fire from lightning as compared with their liability to fires from other causes; nor have many data been given which would show, for any particular class of property, the relation between cases of damage by fire caused by lightning and cases of damage by lightning without fire. What appear to be the most recent data of a comprehensive nature from which may be obtained a knowledge of the first of these subjects are to be found in Chronicle Fire Tables for 1903, a publication which has previously been referred to in this paper. The data contained in these tables cover a period of 19 years prior to 1903, during which time very complete records were kept by insurance companies of the number of fires from various causes and the records classified as to the property affected. Records of 150 classes of property are given, covering several million fires, and including almost every kind of insured property excepting marine property. The data on those classes of property for which 1 per cent or more of the total number of fires were caused by lightning have been abstracted and are presented in Table 8. As might have been expected oil tanks head the list, with churches and barns following in close order.

TABLE 8

Relative Liability of Different Classes of Property to Fire by Lightning [24]

Class of risks	Fires from all causes	Fires caused by lightning	Per cent of fires caused by lightning	Fires of which the causes were unknown and not reported	Fires caused by exposure to other fires	Fires, known causes aside from exposure	Per cent of fires by known causes which were caused by lightning
Oil tanks	717	158	22.00	51	288	378	42.0
Churches	6185	756	12.20	747	1152	4286	17.6
Barns, stables, graneries, etc.	146 618	14 968	10.20	40 134	37 029	69 455	21.5
Railroad depots and station buildings	4005	258	6.40	845	655	2505	10.3
Electric-light stations	603	37	6.10	108	143	352	10.5
Telegraph and telephone offices	1214	67	5.50	50	704	460	14.5
Cotton warehouses and storehouses	726	30	4.13	248	130	348	8.6
Tobacco barns	1294	49	3.80	330	223	741	6.6
Schoolhouses	4917	179	3.70	855	390	3672	4.9
Police and fire department stations	524	19	3.60	90	180	254	7.5
Cordage and twine factories	129	4	3.10	57	8	64	6.2
Railroad stables	463	14	3.00	166	41	256	5.5
Malt houses	211	6	2.84	52	27	132	4.5
Silk mills	181	5	2.80	56	60	65	7.7
Courthouses	583	16	2.75	108	87	388	4.1
Rice mills	37	1	2.70	15	3	19	5.3
Distilleries	336	9	2.68	109	22	205	4.4
Asylums	784	20	2.55	195	19	570	3.5
Oil, stills, and refineries	654	16	2.45	189	22	443	3.6
College buildings	873	21	2.40	226	92	555	3.8
Grain elevators and storehouses	2800	65	2.32	893	676	1231	5.3
Ice houses	3296	76	2.30	447	1886	963	7.9

[24] Data taken from Chronicle Fire Tables, 1903: Chronicle Publishing Co., New York.

TABLE 8—Continued

Relative Liability of Different Classes of Property to Fire by Lightning—Continued.

Class of risks	Fires from all causes	Fires caused by lightning	Per cent of fires caused by lightning	Fires of which the causes were unknown and not reported	Fires caused by exposure to other fires	Fires, known causes aside from exposure	Per cent of fires by known causes which were caused by lightning
Cotton goods factories	2109	48	2.28	387	39	1687	2.8
Warehouses and storehouses (hay)	635	13	2.05	257	85	293	4.4
Paper and pulp mills	789	15	1.90	299	29	461	3.2
Cheese and butter factories	1218	23	1.90	549	116	553	4.2
Warehouses and storehouses (wharf)	109	2	1.80	35	36	38	5.3
Flour, grist, and oatmeal mills	5613	92	1.64	2285	713	2616	3.5
Worsted and yarn mills	183	3	1.64	45	9	129	2.3
Sash, door, and blind factories	733	11	1.50	257	141	335	3.3
Halls (public)	1436	21	1.46	276	548	612	3.4
Woodenware factories	141	2	1.42	57	15	69	2.9
Clubhouses	1222	17	1.39	279	216	727	2.3
Fertilizer and phosphate works	299	4	1.34	130	13	156	2.6
Warehouses and storehouses (paint, oils, etc.)	1005	13	1.30	232	124	649	2.0
Dwellings and tenements	460 395	5921	1.29	87 721	108 070	264 604	2.2
Sugar and sirup works	255	3	1.20	118	17	120	2.5
Glassworks	511	6	1.17	183	32	296	2.0
Warehouses and storehouses (tobacco)	435	5	1.15	145	161	129	3.9
Greenhouses and floral establishments	1051	12	1.14	205	237	609	2.0
Livery, training, and hotel stables	7631	86	1.13	2617	2110	2634	3.3
Planing and molding mills	2981	33	1.10	980	372	1629	2.0
Tobacco factories	455	5	1.10	167	126	162	3.1
Woolen mills	980	10	1.02	287	63	630	1.6
Salt works	100	1	1.00	32	31	37	2.7

With regard to the relation between cases of damage by fire caused by lightning and cases of damage by lightning without fire, for given classes of property, the data given in Lightning Record by H. F. Kretzer, of St. Louis, a publication which has previously been referred to in this paper, are about all that are available. These data consist of news reports on but two classes of property, barns and houses, but enough cases are given to indicate clearly the relationship. A discussion of these data is given in a following section.

1. FIRE HAZARD TO OIL TANKS AND THEIR PROTECTION

Tanks for storing crude oil, turpentine, etc., present a very perplexing problem in their effective protection against lightning, and one which still seems very far from a definite solution. Correspondence with the Louisiana Fire Prevention Bureau, an organization representing the fire insurance companies of Louisiana, elicits the information that a great deal of experimental work has been done, but no system of protection has been developed which has been accepted generally by oil companies as giving a degree of protection at all commensurate with the expense involved. Two years ago the bureau just mentioned made an inquiry as to the matter of protection of oil tanks against lightning among a large number of oil companies. A summary of the reports, and conclusions by the chief electrical inspector of the bureau, has been submitted to the Bureau of Standards and is as follows:

Hazards.—First. It is agreed by practically all of the oil companies that lightning is the principal hazard, and the only one of any consequence, to oil tanks, and has been the cause of practically all of the fires in the oil fields. Second. We have from two sources the opinion that tanks are most frequently struck in "tank farms" where a number of tanks are comparatively close together. Third. From the Standard Oil Co. we have the opinion that wooden or combustible roofs or attachments present a greater hazard than all-steel tanks; they believe that safety lies in well-made, all-steel tanks without leaks.

Protection.—First. Protection for oil in steel tanks is generally believed to be of questionable value, certainly not commensurate with the expense involved, and it may possibly even increase the hazard. Second. The plan of protection which has been tried by the oil companies has been the erection of steel masts where tanks are grouped. Two companies have concluded that this form of protection appears to increase the lightning hazard; the Standard Oil Co. refers to an experiment near Philadelphia where steel masts were tried and removed after one season owing to the firing of several tanks. No further tanks have fired since the masts have been removed, although the tanks have been struck. Third. The plan of protection advised by the bureau has been used on comparatively few tanks in Louisiana, not over 10 in all. None of this number seems to have been fired, but two have been struck within the past five years, and in these cases the lightning rods successfully performed their functions. However, the view has been advanced that these tanks might not have been struck had they been without lightning rods. That there is some reason for this view is apparent when we consider that two tanks of this small number were struck in this period of five years, an average of four tanks per hundred per year, which seems to be high.

Conclusions.—Considering the information at hand and the opinion of those best in position to know, I must conclude: First. No form of lightning protection yet devised is known to lessen the lightning hazard to oil in steel tanks, and the results of such experiments as have been made along this line are not conclusive. Second.

From the owner's viewpoint, the considerable investment necessitated by an approved lightning-rod equipment can not be justified by any known decrease in hazard. Third. From an underwriting standpoint, the protection afforded by lightning rods being as yet only theoretical, very little, if any, credit should be allowed for them.

Notwithstanding the conclusion reached as a result of this inquiry, the lightning losses on these risks have been so heavy during the past two years that we are now again requesting that tanks be provided with lightning rods, installed according to the suggestions of the National Board of Underwriters and our special requirements. We feel, in view of the very serious hazard and the absence of any recognized safeguards, that our theoretical method of protection is better than none at all, and that we are justified in asking for its use until it is proven ineffective or something known to be better is developed. To date, all of the losses we have heard of in Louisiana have occurred to unprotected tanks.

A description of the system of protection against lightning for oil tanks, which was just mentioned, is included in Appendix I. It should, perhaps, be mentioned here that these recommendations appear to be adequate in most respects, but it seems that an important point has been overlooked in that no mention is made of the necessity for secure electrical interconnection of all of the metallic parts of the tank. If the tank were entirely of metal, with all parts securely riveted together, such a precaution might not be necessary; but in the event of a lightning stroke on a tank with a metal roof and wooden rafters held together with bolts or spikes, or with other detached pieces of metal used in its construction, the probability of sparks between the metal exterior and isolated pieces of metal in proximity to it within the tank is too great to be neglected. Because of the exceedingly inflammable character of the products of evaporation from crude oil, the smallest spark on the interior of the tank is likely to start a fire, and the only way to prevent such sparks is to bridge across every gap where they can occur with an electrical conductor.

It might also be mentioned that with oil tanks of the usual diameter (90 feet) the distances between aerial terminals would be much greater than is ordinarily allowed. The general practice is to place aerial terminals at distances of not more than 25 feet along ridges and parapets. This distance has been proved by experience to give a good degree of safety. In the case of aerial terminals installed according to the recommendations mentioned above (see Appendix I) it is readily seen that they may be as much as 70 feet apart along the rim of the tank and 45 feet apart from rim to center.

2. FIRE HAZARD FROM LIGHTNING IN BARNS AND HOUSES

An examination of Table 8 shows that the liability of barns to fires from lightning, as compared with their liability to fires from other causes, far exceeds that of houses. The difference shown in Table 8, however, is based on fires in both urban and rural districts and for this reason is doubtless greater than it would be if equal numbers of barns and houses exposed under the same conditions were taken as a basis of comparison. According to the Census reports for 1910 there are 17 805 845 dwellings and tenements in the United States, of which 7 254 242 are in urban areas, and 10 551 603 in rural districts. No data are given on the distribution of barns, but it seems reasonable to assume that at least 0.9 of them are situated in rural districts. Since the fire hazard from lightning in urban areas has heretofore been shown to be very small as compared with the fire hazards from other causes, it is evident that, if a comparison were to be made on the basis of equal numbers of barns and houses exposed under the same conditions, the difference between the percentage of house fires caused by lighting and the percentage of barn fires from the same cause would be appreciably less than shown in Table 8.

When equal numbers of barns and houses are struck by lightning it is interesting to note the proportions of each that are fired. Referring again to H. F. Kretzer's Lightning Record, it is found that in the cases of 200 barns struck by lightning the news reports show that 87.5 per cent were fired; from the same source it is found that in the cases of 325 houses struck by lightning 23 per cent were fired. In going over the reports to obtain these data only those instances were chosen wherein it could positively be told that fire did or did not occur. Cases in which this point was not set forth by direct statement, or could not readily be inferred, were rejected. It thus appears that, when struck, barns are practically four times as liable to take fire as houses. This is due, of course, to the extremely inflammable nature of their contents. In this connection it should be stated that of the 525 cases of buildings reported damaged but two or three were mentioned as having lightning rods.

There are no data available which show definitely whether or not barns are more liable to lightning stroke than houses. There seems to be a general impression existing that barns as a refuge during a thunderstorm are not as safe as houses, but it can not be shown that this impression is founded on the fact of the comparative immunity of houses to lightning strokes. On the contrary, such data as are available indicate that the opposite is the case. In Lightning Record are found 460 instances of houses being struck by lightning, whereas only 200 barns were reported as having been struck during the same time. Assuming that in the region covered there were twice as many houses as barns, there is still latitude for the inference that of equal numbers of barns and houses exposed under the same conditions as many houses as barns would receive strokes.

3. LIFE HAZARD IN UNPROTECTED HOUSES STRUCK BY LIGHTNING

The 460 houses mentioned above as being struck by lightning were occupied at the time by families of which the average number was probably close to that shown by the census for 1910, or 4.5 persons. In 254 cases out of the 460 one or more persons were either severely injured or killed. In the remaining 206 cases all of the persons in the houses escaped with no injuries at all, or with but slight shocks. As indicated above, but two or three of these houses were reported as having rods, so it might be concluded from these figures that in the case of an unrodded house being struck the chances that all of the occupants will escape harm are about 45 out of each 100. A definite statement of the chances of deaths and injuries can not be made, however, because the available data are not complete enough as to the number of persons in the houses and other factors. On the other hand, it is a fact of common observation that many houses are damaged in a minor way by lightning and no reports of such occurrences reach the newspapers. Only those cases in which the damage is severe, or deaths or injuries result, are reported. Moreover, much more metal is now used in the construction of houses in the form of heating, water and gas systems than formerly, which serves to a certain degree, at least, as a protection against lightning, so the foregoing conclusion as to the chances of death or injury in unrodded houses struck by lightning probably puts the matter far too strongly. While rodded houses are undoubtedly the safer, there is ample reason to believe that persons even in unprotected houses are much safer than out in the open, or under trees or open sheds.

VII. MATERIALS AND CONSTRUCTION OF LIGHTNING RODS

A lightning rod generally is expected to remain in a condition of usefulness for a great many years with practically no repairs or or attention. To most owners it apparently does not seem to be asking too much to require that a lightning rod shall maintain its usefulness unimpaired as long as the average building lasts, which may be 40 or 50 years; hence, the first and most important property which must be possessed by the metal of which a lightning rod is made is resistance to corrosion, both by the atmosphere and by the soil in which the lower end of the rod is usually inserted in making the earth connection. Moreover, the metal must be mechanically strong, and must admit of being made up into forms which are of good appearance, because lightning rods are usually more or less conspicuous. Three other inherent properties of the metal which must be considered, but none of which in the metals commercially available at present for lightning rods are such as to be a controlling factor in making the choice, are resistivity, specific heat, and fusing point. The metals which meet the foregoing requirements in greatest degree, or can be so manipulated as to meet them, and at the same time are not excluded from consideration because of the cost of the raw materials and manufacture, are copper, aluminum, and iron. The data contained in the following discussion of the properties of these metals were obtained from the Standard Handbook for Electrical Engineers (third edition) and publications of the Bureau of Standards.

1. PROPERTIES OF THE METALS AVAILABLE FOR LIGHTNING CONDUCTORS

(*A*) *Copper*.—Copper is the most important material available for power conductors because of its high conductivity and comparative cost. It can be cast, forged, rolled, and drawn. The chemical purity and mechanical treatment have marked effects upon its properties, and therefore both should be specified and definite. The ultimate resistance to rupture varies from 34 350 to 67 000 pounds per square inch (2420 to 4725 kg per square centimeter) and the elastic limit varies from 7000 to 40 000 pounds per square inch (493 to 2820 kg per square centimeter). In dry air copper is permanent at ordinary temperatures, but in moist air it becomes covered with a thin coating of basic copper carbonate which protects it from further corrosion. It is easily corroded by nitric acid, but not by dilute hydrochloric acid. Sulphuric acid has no effect on it at ordinary temperatures. Ammonia and oxygen dissolve it to form blue copper-oxide ammonia. It unites directly with chlorin, and, when heated, with sulphur. The specific gravity of copper is 8.89; its electrical resistivity at 20° C is 1.72×10^{-6} ohm; its temperature coefficient of expansion per degree C from 0° to 100° is 1.67×10^{-5}; melting-point, 1083° C; its specific heat at 17° C is about 0.091, at 100° C 0.095, at 200° C 0.096, at 300° C 0.098.

(*B*) *Aluminum.*—Aluminum stands next to copper in importance as a conductor of electricity. Like copper it can be cast, forged, rolled, or drawn. By forging and cold rolling it can be given rigidity. Its properties depend greatly upon its chemical composition and mechanical treatment. Mr. Blackwell found in his tests that the average ultimate resistance to rupture was 24 000 pounds per square inch (818 kg per square centimeter). The temperature coefficient of expansion of commercially pure aluminum at 40° C is 2.31×10^{-5}. Aluminum is a highly electropositive metal, hence, if aluminum is used in making a lightning rod all of the parts should be of aluminum in order to avoid galvanic action. Aluminum is not acted upon in dry air at ordinary temperatures, and the corrosion in moist air is by the formation of the oxide of aluminum—alumina, a harmless oxide, which forms an impenetrable coating on the metal and protects it from corrosion to a considerable extent. Ammonia solutions act only on the surface of aluminum, forming a coating which resists corrosion from dilute mineral acids, dilute solutions of organic acids, as well as moist and dry air. Sulphurous acid, such as is contained in locomotive flue gases, etc., will have no effect on aluminum. Aluminum is extremely sensitive, however, to the action of alkalies. Aluminum can be soldered with proper fluxes, and fluxes are also to be had by means of which aluminum can be welded, making a very neat joint, although very good workmanship is required to insure permanency. The specific gravity of aluminum is 2.70; its electrical resistivity at 20° C is 2.83×10^{-6} ohm; melting point, 658.7° C; specific heat at 20° C 0.21, at 100° C 0.22, at 200° C 0.23, at 300° C 0.24.

(*C*) *Iron.*—Iron occupies an unique position among the materials for electrical construction, being by far the best magnetic substance. In connection with high-frequency currents at low densities this magnetic property of iron is of great importance in that the relative skin effects for various frequencies are much increased over those for copper and aluminum. With extremely high current densities, however, the skin effects are more nearly the same in the three metals. The magnetic and electric properties of iron vary greatly with the chemical composition, the physical condition, the temperature, and the density of the magnetic flux. Pure iron at ordinary temperatures has a resistivity equal to about 6 times that of copper, and commercial telegraph wire has a resistivity equal to about 7.5 times that of copper. The resistivity of ordinary steel wire is from 9 to 12 times that of copper. Iron has to be galvanized to protect it from oxidation. In the case of lightning rods, as now manufactured, the galvanizing is so thoroughly done that rods exposed only to atmospheric corrosion will last practically indefinitely. If brought in contact with a gas or a chemical which acts on zinc, however, the protection obtained from the galvanizing is speedily destroyed. In earth the life of galvanized rods is apt to be rather short in comparison with the time of life ordinarily expected from a lightning rod. The specific gravity of iron is 7.7; its electrical resistivity at 20° C is 1×10^{-5}; its temperature coefficient of expansion per degree centigrade from $-18°$ to 100° C is 1.14×10^{-5}; its melting point is about 1530° C; its specific heat at 15° C is about 0.11; at 100° C, 0.11; at 200° C, 0.12; at 300° C, 0.14; at 500° C, 0.18; at 700° C, 0.32; from 720° to 1000° C, 0.22; and from 1000° to 1200° C, 0.20. The tensile strength of wrought iron varies from 47 000 to 62 000 pounds per square inch (3310 to 4370 kg per square centimeter), depending on the carbon content and other characteristics of the metal.

The foregoing data as to the physical properties of copper, aluminum, and iron are summarized in Table 9. In addition to this a statement may be made as to the relative high-frequency resistance of the three metals, assuming the magnetic permeability of the iron to be 2.5, or the same value as assumed heretofore for the purpose of calculating the heating effect in an iron rod 1.17 cm in diameter, with a maximum current in the lightning stroke of 25 000 amperes. These resistances are to each other approximately as 1.31 : 1.68 : 5 (copper, aluminum, iron respectively) for rods of the same dimensions and at the same frequency. These numbers are derived from the formula $R' = \sqrt{\frac{1}{2} pl\mu R}$ where R' is the high frequency resistance, $p = 2\pi$ times the frequency, μ the magnetic permeability of the metal, l the length, and R the resistance to steady currents. For frequencies of the order of 100 000 cycles per second this formula gives results with an accuracy of about 2 per cent; as the frequency increases the accuracy increases. Moreover, with regard to the position of these metals in the electromotive series it is found that unoxidized aluminum is the most electro-positive of the three, iron next, and copper last. There are no data on the effect of the oxide coating on aluminum in its galvanic relations with other metals. From these data may be obtained a knowledge of the relative advantages of the three metals as materials for lightning rods.

TABLE 9

Statement of Physical Properties of Metals Available for Lightning Conductors

	Copper	Aluminum	Iron
Specific gravity	8.89	2.70	7.7
Electrical resistivity at 20° C., in ohms	1.72×10^{-6}	2.83×10^{-6}	1.0×10^{-5}
Temperature coefficient of expansion, in degrees centigrade from 0 to 100°	1.67×10^{-5}	(40° C) 2.31×10^{-5}	1.14×10^{-5}
Ultimate resistance to rupture, pounds per square inch	34 000 to 67 000	24 000	47 000 to 62 000
Elastic limit, pounds per square inch	7000 to 40 000	....	18 000 to 70 000
Mean melting point	1083° C	658.7° C	1530° C
Specific heat at 17° C	0.092	0.21	0.11
Specific heat at 100° C	0.094	0.22	0.11
Specific heat at 200° C	0.096	0.23	0.12
Specific heat at 300° C	0.098	0.24	0.14
Specific heat at 500° C	....	....	0.18
Specific heat at 700° C	....	....	0.32
Specific heat at 720–1000° C	....	....	0.22
Specific heat at 1000–1200° C	....	....	0.20

It has been shown heretofore that the amount of energy actually liberated in a rod in the form of heat in the event of its being struck is not likely to be great enough in iron or copper rods of the size necessary for the proper strength and rigidity to cause fusing of the rod except in rare instances. The specific heats and melting points of the metals under consideration are, therefore, not of paramount importance, except, of course, in so far as the place where the discharge enters the rod is concerned. This applies also to aluminum, although to a much less degree than to copper and iron. The fusing point of aluminum is about half that of copper, and the amount of heat required to bring a given volume of aluminum to any given temperature is about 0.7 that for copper. The mechanical strengths of the three metals are sufficient to meet all of the requirements; rigidity in copper and aluminum can be obtained by proper mechanical treatment. In the matter of high-frequency resistance iron has a decided advantage, if it be conceded that resistance in the rod is desirable for the purpose of damping out high-frequency oscillations, although the resistance of the earth connection is in most cases so large as to make even the high-frequency resistance of an iron rod very small by comparison. In the matter of temperature coefficients of expansion the advantage is again on the side of iron, aluminum being decidedly at a disadvantage. The differences in cost are not great in the manufactured articles, the comparatively high cost of aluminum per pound being offset by its low specific gravity, and the comparatively low cost of iron per pound being offset by the cost of the galvanizing and other preparation required to protect it from atmospheric corrosion. The greatest advantage is undoubtedly on the side of the metal which is least liable to corrosion, and for all conditions copper is, perhaps, the best in this respect, although the other two may serve equally well unless exposed to corrosive agencies to which they are peculiarly susceptible. Underground, the greatest dependence is undoubtedly to be placed on copper, but even copper is corroded away in some soils at a surprisingly rapid rate.

2. MECHANICAL CONSTRUCTION OF LIGHTNING RODS

After securing a metal of the requisite strength and resistance to atmospheric and soil corrosion the next most important consideration is securing good mechanical construction, both in making up the parts of the rod itself and in placing it on the building. Rods are subject to the action of wind, snow and ice, thermal expansion and contraction; and, in the event of a stroke of lightning, to electromagnetic stresses; hence the strains tending to pull joints apart and loosen fastenings are very severe, and inasmuch as a rod is expected to withstand them without attention for many years, unusual precautions are necessary to guard against them effectually. In the following discussion some points which must be observed in the mechanical design of lightning rods are brought out, and various features of the prevailing practice as at present carried out are illustrated.

(*a*) *Contact of metals having different galvanic potentials.*—In the mechanical design and construction of lightning rods an important point to observe is that metals which occupy different positions in the electromotive series should not be placed in contact unless provisions are made to protect them from dampness, and thus prevent electrolytic corrosion. Neglect of this point may cause the security of a system of rods to be seriously impaired within a few years after its installation. The potentials which exist between some of the metals commonly used for the parts of lightning rods are as follows: Between copper and zinc, 1.099 volts; between copper and iron, 0.673 volt; between iron and zinc, 0.426 volt; between copper and lead, 0.480 volt; between iron and lead, 0.193 volt. In this series zinc is positive to copper, iron is positive to copper, zinc is positive to iron, lead is positive to copper, and iron is positive to lead. Contact between zinc and copper, or copper and iron, should therefore be avoided, because the zinc and iron will speedily be destroyed. In the case of contact between zinc and iron, the zinc will be destroyed; this is often noted in the case of galvanized iron where the galvanizing becomes impaired, the zinc rapidly being destroyed and exposing the iron to atmospheric corrosion. Galvanizing protects iron effectively, however, as long as the coating remains intact. Contact between iron and lead will cause the iron to be corroded. In the case of contact between lead and copper, electrolytic corrosion of the lead may occur, but the lead soon becomes coated with a layer of difficultly soluble lead compounds, which cause the lead to become passive, after which the two metals can remain in contact indefinitely with no further electrolytic corrosion of the lead. This fact is of great importance where it is found necessary to protect copper rods from corrosion by fumes and smoke which do not affect lead.

At the present time it is not uncommon to see copper-cable lightning rods held to wooden walls with galvanized iron nails, or with copper strap fasteners secured with these nails. Within a year or two the heads of the nails corrode away and allow the cable to come loose from the building. Other combinations of metals which produce corrosion by electrolysis when damp are often seen.

(*b*) *Joints and couplings for lightning rods.*—The first and most important requirement which must be met by joints and couplings in lightning rods is that they must remain in secure electrical contact, and not easily be pulled apart or loosened by vibration. The severest strains to which joints in lightning rods are subject are set up by electromagnetic stresses, thermal expansion and contraction, and by accumulations of snow and ice on roofs. That electromagnetic stresses may be especially severe is evidenced by the fact that rods when struck have been in many cases torn from buildings and thrown considerable distances. The same phenomenon has also been repeatedly observed under short-circuit conditions in heavy-current conductors in power plants. Aerial terminals vibrating in the wind are also a frequent cause of loose joints at the points where aerial terminals are connected to horizontal conductors, which is particularly objectionable because such joints are called upon to carry the full current of a lightning stroke. Corrosion may also produce high-resistance joints, and such joints as permit of the formation of layers of oxides between metallic surfaces, which should be in secure electrical contact, should be discarded. It is true, of course, that lightning will easily pass a high-resistance joint, even a short gap in a conductor, but it is not wise to risk the introduction of too much resistance at one place, because fusing of the rod may occur there in the event of its being struck, with an accompanying danger of fire, even though the rod prevents the stroke from penetrating the building. It is not impossible that a number of high-resistance joints in series may cause fusing of an entire rod, as has been reported in a few cases of tubular copper rods which were struck.

There are many forms of joints and couplings for lightning rods on the market which are put forward for the consideration of the prospective purchaser. The chief object in the use of these couplings is to reduce the amount of labor required in the field for the erection of rods. They may be classified roughly into three groups, viz, screw joints, clamp joints, and reduced end-and-dowel joints. These three types of joints are illustrated in Fig. 2, which shows a number of samples of joints which were submitted to the Bureau of Standards by manufacturers of lightning rods. Fig. 2 also shows a soldered joint in a cable, and a form of woven joint used in some special work.

Screw joints when well made are undoubtedly the best joints for long service in solid or tubular rods. They maintain good electrical contact and apparently are not loosened by vibration if turned up tight when erected. This evidently is due to the fact that the couplings are made of brass or bronze, which is rather soft, and when screwed together tight takes a strong grip which is not readily loosened. These joints are also free from corrosion, the brass or bronze used in their construction being similar to that used in valves which, when used in contact with iron in the presence of moisture, gives no trouble from corrosion. In putting up rods with screw joints, the lower end of the rod being securely fastened at the earth connection, the joints can not be unscrewed without twisting the rod itself. At the right in Fig. 2 are shown two typical screw joints.

Next to the screw joints shown in Fig. 2 is a clamp joint commonly used for the purpose of making connections in copper cable. In many of these clamps the cable is held by one small screw, in one end of the clamp at least, and they are open to the objections not only that the cable is easily pulled out, but also that the area of contact is small and liable to corrosion, which may increase

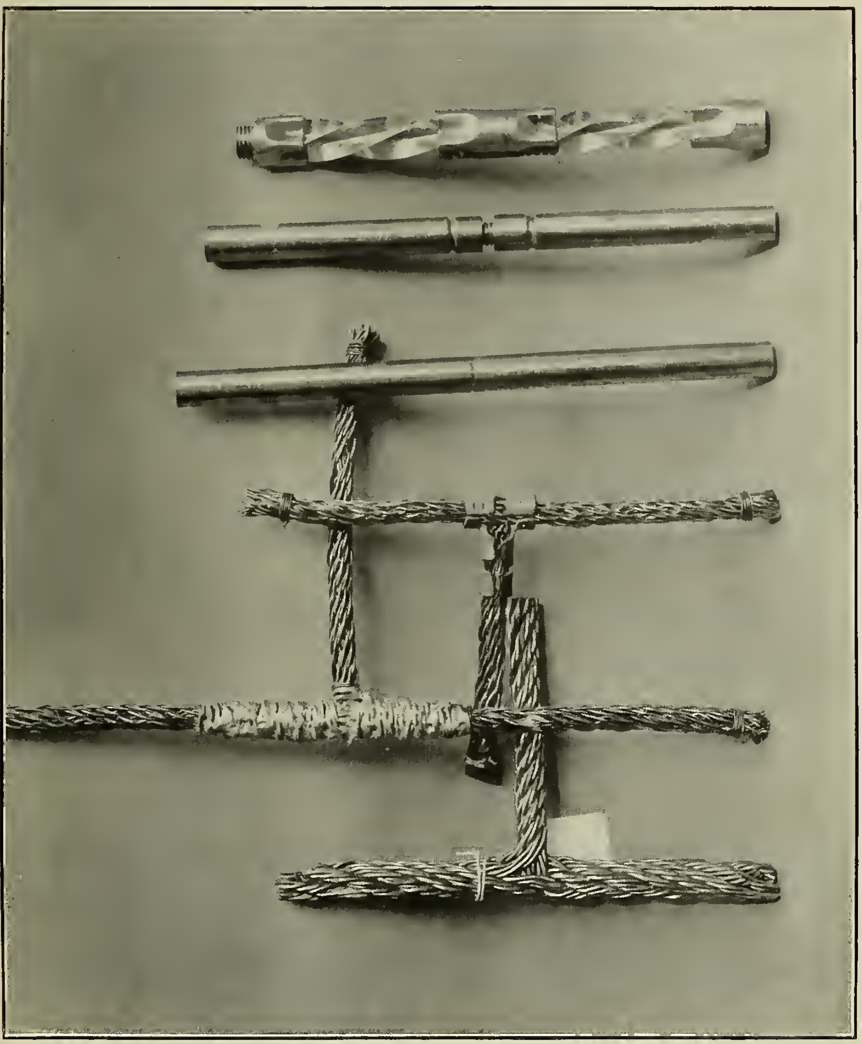

FIG. 2.—*Joints for lightning rods*

the resistance of the joint appreciably after a few years of exposure to the weather. Clamp joints made by inserting the end of the cable into a malleable copper casting and pounding or pinching the casting until it grips the cable are open to practically the same objections as clamp joints with screws. All of these clamp joints are open to the still more serious objection that they give good opportunities for careless work in the field.

Joints in copper cables are preferably made in the manner shown at the left in Fig. 2, which shows a connection of a branch cable to a main conductor, the branch conductor being unraveled about 6 inches, wrapped neatly around the main cable, and soldered. In some cases persons who erect copper-cable lightning rods and use wrapped joints omit the soldering. This may not be objectionable for temporary work if a sufficient length of unravelled cable is used, but for work which is intended to be permanent soldering is necessary to give assurance of security. In some cases, for special work, copper cable can be purchased which has the necessary branches already in place with woven joints.

Reduced end-and-dowel joints, which are used only in tubular rods, are open to the objection that there may be an occasional loose one, and also that a few years of exposure to the weather corrodes the contact surfaces seriously. In tubular joints as ordinarily erected these joints occur every 6 or 8 feet. One of these joints is shown in Fig. 2, next to the screw joints on the right.

(*c*) *Fasteners.*—The firmness with which the rod is attached to the building goes far toward determining its period of usefulness and security. There are many types of fasteners in use, varying from galvanized-iron nails to elaborate brass attachments of expensive design. Fig. 3 (see illustration facing p. 89) shows a number of types of fasteners which were submitted to the Bureau of Standards by manufacturers of lightning rods. The type which undoubtedly gives the greatest security and strength for the outlay required consists of a 2-inch screw with a hook or fork attached, as shown in Fig. 3, which can be closed over the rod to form an eye and holds it firmly in place. For brick or stone walls already erected the same device can be used in the form of an expansion screw. For brick or stone walls in process of erection hooks or forks with fan-shaped, corrugated shanks are available, which can be laid in the wall as it is put up. In using these fasteners they should be set deep enough to bring the rod quite close to the surfaces of walls and roofs in order to prevent snow and ice from accumulating and getting a sufficient purchase to tear the rod loose. Copper strap fastenings, nails, and other devices commonly sold are very insecure at best, and their use is justified only on temporary work where cheapness is the chief consideration. In this connection it should be emphasized again, as has already been pointed out above, that metals which occupy different positions in the electromotive series should not generally be placed in contact because of the possibility of electrolytic corrosion; this is particularly true in the case of fasteners, where there is a strong incentive to use a cheap iron attachment to hold a copper cable in place.

(*d*) *Protection from Corrosion by Smoke and Gases.*—In exceptional instances, as on smokestacks and in various other places, rods are subjected to corrosive agencies which may damage them in a very short time. In many of these cases, on smokestacks particularly, lead has been found to be an effective protective coating for copper rods, the copper being found quite susceptible to the corrosive action of coal smoke, while lead is but little affected by it. In Fig. 4 is shown an aerial terminal, made especially for use on smokestacks, which has been covered with lead. The points on this terminal have been platinized sufficiently to prevent corrosion by the smoke. As before stated, electrolytic action between the copper and lead would not occur to any great extent because of the formation of difficultly soluble lead compounds on the surface of the lead which would render the lead passive. This combination of metals has been found quite satisfactory for use in the protection of smokestacks.

It is recommended by some authorities, and it is doubtless a good practice, that in rodding houses the aerial terminals at chimneys be bent over to bring the point directly over the opening. In this case protection by lead would be very desirable. In the contour system of protection against lightning, where the conductor is taken directly across the opening of the chimney, protection by lead would also be very desirable.

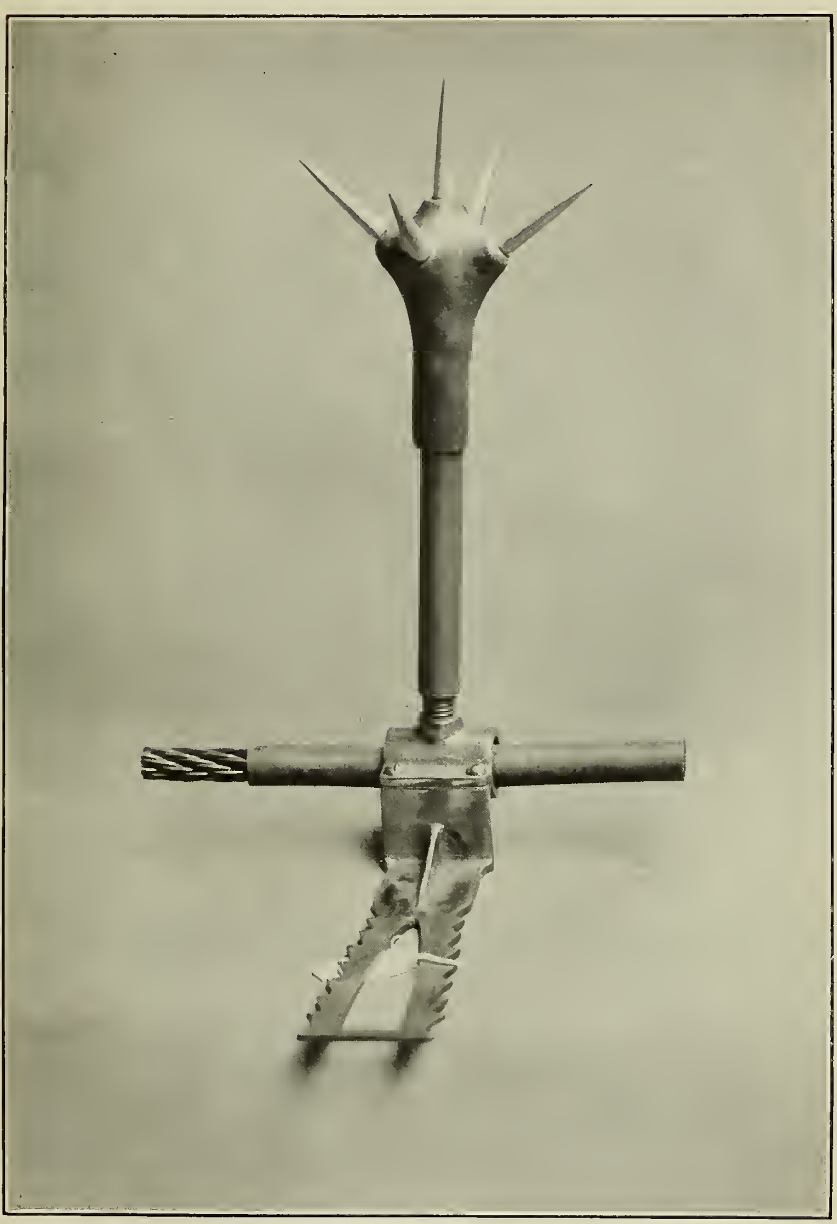

FIG. 4.—*Lead-covered aerial terminal*

(*e*) *The Shape of the Cross Section of the Rod.*—In direct line also with the mechanical design of a lightning rod is the shape of the cross section of the rod. This is considered in some quarters as being of a great deal of importance because of its relation to the skin effects characteristic of the passage of high-frequency currents through a conductor, and in the case of the passage of lightning discharges through a rod the skin effects are doubtless of considerable moment. There are two views as to the manner in which these skin effects should be provided for, one of which seems to be held quite generally by manufacturers of lightning rods, and is that the high-frequency resistance of the rods should be made as small as practicable. To do this economically the rods are made of such shape that they have a large surface area in proportion to cross-sectional area of metal. In many cases, however, this has been carried to such an extreme as seriously to impair the mechanical strength of the rod and its endurance to corrosion, and the resulting short life of the rod has done much to cause lightning rods to be regarded in many quarters as a poor investment. On the other hand, if the view of Sir Oliver Lodge and others be accepted, it is desirable to provide a conductor of as high resistance as possible for the purpose of damping out electrical oscillations without risking danger of fusing when the rod is struck. According to this view, then, a solid cylindrical conductor would be the most desirable, and stranding a conductor, or otherwise providing for skin effects, would be of negative benefit. Although, as before stated, even the high-frequency resistance of an iron rod may be small in comparison with the resistance of earth connections, any additional resistance in the rod would, of course, assist in damping out any oscillations set up in the rod, and thus be of benefit in reducing the possible rise of potential of the rod against earth.

In most of the rods sold at the present time either real or ostensible provision is made for skin effects by making the conductor in the shape of a ribbon, or of tubular cross section, in some cases even stranded conductors being woven in flat or tubular form. Stranding a conductor, of course, decreases its high-frequency resistance, but no further material decrease of high-frequency resistance is obtained by weaving the strands in the form of a tube or ribbon, the chief advantage to be obtained from making a stranded rod in one of these forms being a decrease of its self-inductance over what it would be if the metal were in the form of a solid rod or tightly twisted cable. This is an advantage of much greater moment than the decrease of high-frequency resistance, if a decrease of high-frequency resistance is to be called an advantage, but it is doubtful if the decrease of self-inductance obtained by spreading the strands out into the form of a ribbon, or expanding them into a tube, is sufficient to offset the disadvantages in other directions, such as decreased mechanical strength and increased exposure of surface of metal to corrosion. The inductance of the path of the lightning stroke through the system of rods to earth can undoubtedly be more profitably decreased, and can be made as small as necessary, by offering it a large number of parallel paths to earth at a distance from each other. This can be accomplished without material increase of cost by using a greater number of smaller conductors to earth than is usually the case.

The forms of rods sold at the present time include several types, mainly star-section iron rod, and copper cable of various shapes of cross section. In Fig. 5 are shown several samples of cable and star-section rods. The star-section rod, so called because of its cross section being of the shape of a four-pointed star, comes in lengths of 6 or 8 feet with screw joints of brass or bronze. It is sold in two principal forms, viz, twisted galvanized iron and twisted galvanized iron with a copper sheath. The copper sheath is put on before the rod is twisted; in some cases the copper is plated on. These rods are very serviceable, although there is no great advantage electrically in the use of the copper sheath, and if the sheath is not waterproof, water may enter and cause corrosion by galvanic action. The principal advantages claimed for these rods, in addition to those already enumerated for galvanized iron, are large surface area in proportion to volume of metal to provide for skin effects, and rigidity.

Copper cables are sold in forms of cross section ranging from solid-twist cables of standard sizes to a cable consisting of 28 No. 14 wires woven into a hollow, basketlike structure five-eighths of an inch in diameter. The latter conductor is the most extraordinary example that has been brought to the attention of the

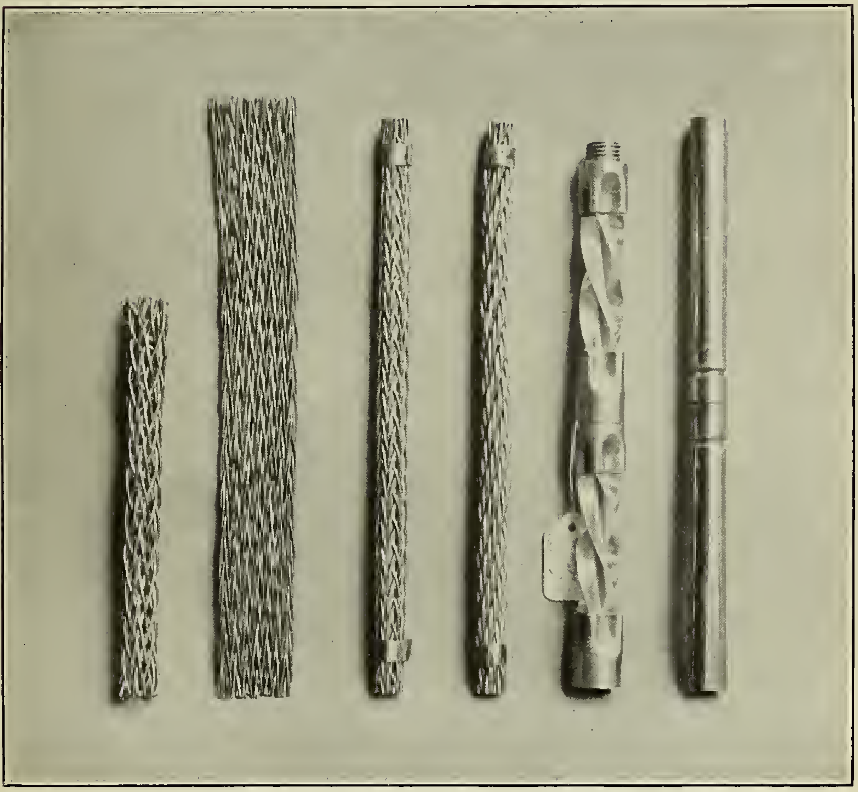

FIG. 5.—*Types of lightning conductors*

bureau. In all of these copper-cable conductors woven in tubular form the amount of metallic surface exposed to corrosion is largely increased over that of a tightly twisted cable and the tendency to sag and be pulled out of shape is enormously increased. Moreover, since lightning-rod cable is sold by the foot rather than by weight, such open or lattice work cables represent a possibility of a great saving in copper to the manufacturer in comparison with what would be required to make a tightly twisted cable of comparable dimensions.

It therefore seems that for the most advantageous system of protection against lightning the choice of rods lies between the iron rod as usually sold, or in star-section form, and tightly twisted copper cables, most of the advantages claimed for unusual forms of cable being practically nonexistent.

VIII. EARTH CONNECTIONS FOR LIGHTNING RODS

The earth connection constitutes one of the most vital parts of a lightning-rod system. The most important requirements which must be met by it are those of adequate connection to permanent moisture, and permanency. By the term "permanent moisture" is meant the general stratum of moist earth usually found at some distance below the surface of the ground which remains moist continually. At most places the upper surface of this stratum of moist earth is a few feet beneath the surface of the ground, but at some places it coincides with the surface of the ground and at others it is only found at great depths. In most localities it moves up or down according to whether the season is wet or dry. In making an earth connection for a lightning rod it is quite essential that this stratum of permanent moisture be reached; connection with it is absolutely necessary to satisfactory results, and also seems to be sufficient. In the past, earth connections have been devised which were intended to connect both with surface moisture, if it were present, and with permanent moisture, but the experience of recent years has shown that the additional elaboration at the surface is not of material advantage. It should be pointed out here that not every pool of water is connected with permanent moisture. It has sometimes been taken for granted that such is the case, and instances have been reported where pools of water on solid rock were used to establish earth connections. If the rock were granite, or some other nonporous variety, the resistance of such an earth connection might easily be many thousands of ohms.

Where bedrock is at a distance from the surface of the earth the stratum of permanent moisture is most likely to be above it, and under such conditions connection to permanent moisture is comparatively an easy matter. Experience has shown that as a rule a straight rod or pipe penetrating the earth in such places to a depth of from 6 to 10 feet, or to a point well below the foundation walls of the building to be protected, makes a very satisfactory earth connection and about the least expensive that can be had. In this type of earth terminal there are no metallic joints beneath the surface to corrode by galvanic action and give trouble; but little excavation is necessary to attain the requisite depth; and they are easily inspected and renewed. Their electrical resistance is comparable with that of plates, especially plates of the size commonly used as earth terminals for lightning rods, and on the whole they are a much more desirable form of earth connection. In view of these facts it seems that the elaborate "ground cones" and other devices intended for the purpose of making earth connections for lightning rods are unnecessarily expensive. All of the advantages claimed for them can be obtained with rods at less expense and with greater assurance of permanency.

In this connection it may also be well to add a word on the question of the so-called "ground point," which is a device consisting of a point surrounded by a tube and is intended to be attached to the lower end of the rod forming the earth connection, the idea being that it will facilitate the passage of the electrical discharge into the earth. The arguments advanced in support of its use are similar to those advanced in favor of points for aerial terminals. That these arguments do not apply to the case of the ground point is obvious, however, from the fact that the aerial point acts in a gaseous conductor (air) while the ground point is supposed to function in the earth, which is an electrolytic conductor. In air the conduction along the path of a lightning discharge is through an ionized gas, and as points in this case facilitate ionization their use seems desirable, but in an electrolyte a point serves no similar purpose. At present it is not possible to say that a ground point is of no use, but on theoretical grounds it is highly improbable that it adds anything to the efficiency of a lightning-rod system.

When bedrock is very near the surface of the earth the making of an adequate connection to earth is more difficult. In such cases the stratum of permanent moisture is likely to be beneath the stratum of rock, and hence not easy to reach. About the best that can be done under these conditions is to make an earth connection somewhat similar to the "capacity ground" used in wireless-telegraph work. This can best be done by digging a trench where each connection is to be, making it as deep as the rock layer will allow, and burying in it a strip of metal such as No. 14 gauge copper or galvanized iron an inch or so wide. The strip may well be made continuous around the building, being brought near to the surface of the ground at points where down conductors are connected to it. From the strip encircling the building radial strips may also be laid if the importance of the structure seems sufficient to make it desirable. There is no fixed area to be covered by such a network of strips, only it should be as large as practicable, the larger the better. Such earth connections have been found more or less satisfactory, although they are doubtless rather an inefficient substitute for the earth connection described in the preceeding paragraph. In connecting the rod to the strip, care has to be exercised to prevent electrolytic corrosion immediately around the connection if the rod and strip are of different metals. Soldered connections should be used and electrolytic corrosion can be prevented by embedding the joint in dense concrete to an extent sufficient to include the surface of the metal immediately surrounding it.

If there is a water-pipe system in the immediate vicinity of the rod a connection should be made to it if possible, whether rods or metal strips are used to form the earth terminal. This is a valuable addition to the system of earth terminals which should not be overlooked. Gas pipes, however, should be avoided if possible, because of the possibility of fires or explosions. On the other hand, if gas pipes are so located that it is not possible to keep at a distance of 8 or 10 feet from them, they should be electrically connected to the rod at several points, connected to earth within the building, and also well bonded around the gas meter.

The lack of permanency of earth connections as usually installed is the cause of considerable complaint. The practice followed among manufacturers of lightning rods in making earth connections of the rod type is to bore a small hole in the earth to a convenient depth and insert a length of the rod. The part of the conductor in the ground is thus no larger in diameter than that on the building, and it is doubtless due to the small size of the part of the conductor under ground that so many complaints are heard regarding the ease with which the connection with the earth is destroyed, either by breaking of the rod or by corrosion. With one or more of the ground connections of a lightning-rod system broken the effectiveness of the system becomes very much reduced; hence, it seems worth while to incur a little additional expense to insure greater permanency in this respect, and at the same time secure a decrease in resistance, which, although small, is of material advantage in most cases. The additional expense incurred is due chiefly to the increase in the size of the underground portion of the rod necessary to furnish sufficient mechanical strength and cross-sectional area of metal in proportion to surface area to provide for corrosion, and to the connection necessary between the rod on the building and the rod in the earth.

The permanency of earth connections is very quickly impaired by corrosion caused by seepage from barnyards and dumping places. If possible, it is desirable to guard against contact of earth terminals with such seepage, either by drainage or other means. In the event of corrosion from seepage or other causes it is likely to be the most severe at the surface of the ground. Much can be done to prevent such corrosion by surrounding the rod at this point with concrete. A cylinder of dense concrete 6 or 8 inches in diameter, extending a foot or so beneath the surface of the ground and 3 or 4 inches above the joint between the ground rod and the rod on the building, will serve effectually to prevent corrosion from external causes, or by galvanic action between different metals composing the joint, for a period as long as is likely to be necessary. The concrete will serve also to add very materially to the mechanical strength of the joint and assist in preventing breakage.

1. RESISTANCE OF EARTH CONNECTIONS

In making earth connections for lightning rods, efforts should in general be directed toward obtaining the lowest possible resistance consistent with economy. Inasmuch as the lowest resistance ordinarily obtainable is not less than several ohms, there is no possibility of obtaining too low a resistance. A consideration of an earth connection of zero resistance will show that the tendency toward damping of secondary electrical oscillations set up in a lightning-rod system of very small resistance by a primary discharge of steep-wave front would be very slight, and as a consequence it would be possible for high potentials to be set up between the rod and objects in its vicinity, due to resonance, but there is small chance in practice of the total resistance of a lightning-rod system, including the earth connection, not being sufficient to cause rapid damping of such oscillations. On the other hand, great care should be taken that the resistance of the earth connection be not too high on account of voltage drop, which, as heretofore shown, may be very large. With a lightning flash having a maximum current of 25 000 amperes, and an earth connection of 15 ohms resistance, the potential drop across the earth connection would be about 375 000 volts. Such a drop would be somewhat excessive, and, where possible, the resistance of the earth connection should be reduced considerably below 15 ohms. In some instances, however, resistances below 15 ohms can not be provided without going to excessive expense, and it is therefore necessary in such cases to exercise extraordinary care in placing rods so as not to bring them into too close proximity with metallic objects to which they are not connected.

In arranging earth connections, to obtain the lowest possible resistance consistent with economy and other considerations, there are several facts of which knowledge has been obtained from experiments and calculation which should be kept in mind. One of these is that the resistance of an earth connection is due for the most part to the resistance of the layers of earth immediately surrounding the rod or plate; hence, increasing the diameter of the rod does not decrease the resistance of the earth connection in the same proportion. It has been found that for a rod of given length doubling the diameter, and consequently the area, reduces the resistance from 6 to 12 per cent.[25] On the other hand, the combined resistance of two earth connections of the same size made with rods is approximately 50 per cent of one of them alone if they are 6 feet or more apart. The resistance of a number of such earth connections in parallel is approximately inversely as the number of grounds, provided they are 6 feet or more apart as just stated, and the distance between them increases as the number of earth connections increases. Theoretically the parallel resistance of a number of grounds would be exactly inversely as the number only when they were at an infinite distance apart, but the decrease in resistance in the first few feet as the rods are moved away from each other is so rapid that the difference between the parallel resistance of the rods at an infinite distance apart and at a short distance apart is negligible as far as practical purposes are concerned. The variation of resistance of the rod type of earth connection with depth follows quite closely a logarithmic law after a depth of several feet has been attained. For practical purposes the law of variation of resistance with depth may be expressed by saying that increasing the depth of a rod from 5 to 6 feet decreases the resistance one-sixth; increasing the depth from 6 to 7 feet decreases the resistance one-seventh, and so on.

For earth connections made with 1-inch pipe driven to a depth of from 6 to 8 feet in normally moist earth the resistance was found by Creighton to be from 15 to 50 ohms for a single connection, depending on the condition of moisture. Eight ohms is an unusually low value for a pipe earth of the kind just mentioned, and if the earth is unusually dry the resistance may be several hundred ohms. It is the practice in some quarters to reduce the resistance of earth connections by mixing salt (NaCl) with the earth which immediately surrounds them. This reduces the specific resistance of the earth and serves the purpose very well until the salt has disappeared by diffusion and seepage. This practice is not to be recommended in connection with earth terminals for lightning rods, however, because of the tendency to corrode the

[25] E. E. F. Creighton, The Ground Connection in Lightning Protection Systems; Gen. Elect. Review, v. 15, pp. 12 and 66.

metal if the rod is of iron, and, what is more important, because such a reduction of resistance is temporary and as a result of the of the neglect to which lightning rods are subject the effects of the salt probably would have all disappeared at the time they were needed. The better practice is to increase the number of earth connections until the desired resistance is obtained with normal soil.

The resistance of an earth connection varies rapidly with the variation in the moisture content of the earth immediately surrounding it. Unless this earth is kept uniformly moist there can be no certainty that the results of a measurement of resistance made at one time will correspond in any way with one made at another time. For this reason any deductions from the results of resistance measurements of earth connections should, perhaps, be confined solely to judging from the measurements and other conditions whether the system is likely to be satisfactory or not. That is, if a system of rods is installed during a very rainy season, while the ground is wet, a sufficient number of earth connections should be installed to bring the resistance of the system against ground to 1 or 2 ohms, or even less, provided that some condition does not interfere to make a resistance of that order impracticable of attainment. If the ground is very dry a much higher resistance, 15 or 20 ohms, for example, may be considered satisfactory. More definite figures than these can hardly be given because of the widely varying conditions encountered at different places, but where practicable there should be a reasonable assurance that during an ordinarily dry season the combined resistance of the earth connections will not rise much above 15 or 20 ohms.

2. METHODS OF MEASURING THE RESISTANCE OF EARTH CONNECTIONS

Of the various methods in use for measuring the resistance of earth connections the two which appear the simplest and most expedient for field work are the ammeter-voltmeter method and the oscillating-current Wheatstone bridge method. For the ammeter-voltmeter method there is required, in addition to electrical measuring instruments of the proper range, a source of power, either direct current at 100 volts or more or alternating current at any convenient voltage. If direct current is used in the ammeter-voltmeter method, the counter electromotive force of polarization (1 or 2 volts) is sufficient to introduce appreciable errors at low voltages, so a difference of potential of 100 volts or more is necessary to overcome them to a sufficient extent to make them negligible. With alternating current, polarization does not occur to an appreciable degree. The Wheatstone bridge method requires a bridge of portable type, a telephone receiver, a small transformer, and four or five dry cells in series with a 4-ohm buzzer to produce an oscillating current. The bridge method is a little more convenient for general use than the ammeter-voltmeter method, even where power is available, and where power is not available, except by portable generator sets, etc., the bridge method is far more convenient. The bridge method fails, however, where there are alternating currents flowing in the earth, because of noises in the telephone receiver. Both methods require that two earth connection besides the one to be measured be available, and that the three connections be at some distance from each other, say 50 feet or more.

The measurements and calculations are as follows: Let the resistances of the three earth connections be designated by R_1, R_2, and R_3; let the measured resistances of the different pairs in series, R_1+R_2, R_1+R_3, and R_2+R_3, be A, C, and B, respectively. Then $R_1+R_2=A$, $R_1+R_3=C$, and $R_2+R_3=B$. If R_1 is the combined resistances of the earth terminals of the lightning-rod system, the solution of these equations gives $R_1=\frac{A-B+C}{2}$. In the same way $R_2=\frac{A+B-C}{2}$, and $R_3=\frac{B-A+C}{2}$. In this manner approximate results are obtained which are sufficiently accurate for field work. As just remarked, it is important that these earth connections be at some distance apart. If they are within 6 feet of each other very appreciable errors may be introduced into the calculations, and if quite close the equations lead to absurd results for the individual resistances when the results of the measurements are substituted in them. At 50 feet, however, any errors due to proximity of the various earth connections are entirely negligible.

3. MATERIALS AND CONSTRUCTION OF RODS FOR EARTH TERMINALS

In selecting materials for rods for making the rod type of earth terminal the main considerations are low cost and great resistance to soil corrosion. Copper and cast-iron undoubtedly meet these requirements in greater degree than most other metals, unless it be aluminum. Aluminum has not been thoroughly tested in soil, however, and will not be further considered here. Cast-iron is the lowest in cost and resists corrosion by ordinary soils very well, the corrosion which first takes place forming a coating of rust and graphite on its surface which protects it to a marked degree from further corrosion. In using iron it is important that no cinders, coke, or other materials which will form a galvanic couple with the iron are mixed with the soil which comes in contact with the rod. Seepage of various kinds, as heretofore mentioned, are also to be avoided. The presence of these materials will cause rapid pitting and corrosion, but under ordinarily favorable conditions cast-iron pipe has been known to resist coil corrosion successfully for from 50 to 70 years.

If no extremely unfavorable conditions exist in soil, copper will resist corrosion in it practically indefinitely. An examination of a copper lightning rod which had been in place on a barn 18 years showed that no appreciable corrosion had taken place at the surface of the ground where such corrosion is likely to be the most severe. Seepage from barnyards, however, has a detrimental effect on copper and should be avoided. Other chemical solutions in soils, as heretofore mentioned, may also be present and attack copper, and should be guarded against.

There is no way to arrive at a definite size of rod for the purpose of making earth connections, but it seems that a three-fourths inch copper rod or heavy tube, or a 1½-inch cast-iron rod, would be amply large for the purpose. A choice between the two metals would depend largely upon the requirements of the individual case. The copper, of course, has a large advantage over iron in resistance to corrosion; hence, the difference in size; but at the same time the iron rod would have a slight advantage in cost, and also the advantage of 6 to 12 per cent less resistance as an earth terminal because of its larger size.

The connection of the rod on the building to the rod in the ground can be made in a number of ways. If the ground rod is made of cast-iron, the top of the rod can be drilled and tapped for a brass plug to which the copper cable can be soldered, or the top of the ground rod can be drilled to a depth of 2 or 3 inches, the end of the cable inserted, and the hole filled with melted lead and calked. For an iron star-section rod the latter method will be found as satisfactory as for cable. To protect the connection from corrosion and breakage it can be surrounded by concrete as suggested heretofore. From the top of the concrete a strong wooden box, fastened securely to the wall of the building, should surround the rod for a distance of three feet or more. This will protect the rod from damage. An examination will show that practically all of the lightning rods which have been in service for a number of years, and are not so protected, have at some time had something thrown against them with sufficient force to cause serious damage.

In boring the hole in the earth in which the rod is to be inserted an ordinary soil auger can be used. In boring the hole an auger should be used which is no larger than the rod. It is preferable that some driving be necessary to get the rod into place. The reason for this is that if the hole is larger than the rod the resistance will be found to be very high, and this high resistance will be retained until the earth has had time to settle around the rod, which may be several months.

IX. AERIAL TERMINALS WITH POINTS FOR LIGHTNING RODS

At the present time the use of aerial terminals with points for lightning rods is quite general in the United States and most of Europe, but there is a difference of opinions as to whether their use is necessary. In Austria, and also in other countries of Europe, the contour system of lightning rods, as heretofore described in this paper, is in successful use, and in it aerial terminals are dispensed with entirely. From the facts reported concerning the use of the contour system it is plain that the use of aerial terminals with points is not absolutely necessary, but at the same time it must be granted that certain advantages are obtained in their use which outweigh the disadvantages; and these advantages are not present in the contour system. The chief disadvantage that has been urged against the use of aerial terminals with points is that their presence increases, to a certain extent at least, the probability of a building being struck; that is, more strokes are likely to fall on a building equipped with rods having points than if the points were not present. There are some experimental data on record which bear out this statement,[26] but it can not be said definitely to what extent it may be the case. Aside from these data, the known facts concerning the introduction of sharp points into spark gaps used in the laboratory also point to the same conclusion. It is well known that an electrical discharge occurs with greater ease across an air gap between points than between flat plates or spherical surfaces, and the same is doubless the case with lightning flashes between clouds and lightning rods, although probably to a much less degree. This is not an unmixed evil, however, as will appear later from a consideration of the discharging power of points and the tendency of electrical discharges to follow streams of ionized air particles.

Another disadvantage encountered in the use of aerial terminals is found in the difficulty of bracing them in such a manner that they will remain permanently erect. As now installed aerial terminals seem almost invariably to fall over within a few years, which not only impairs their usefulness seriously, but also causes them to present a slovenly appearance. Nevertheless, this is a mechanical difficulty which can be overcome, and hence is not of great importance.

One of the several advantages obtained in the use of points is that in cases where the accumulation of static electricity is comparatively slow in forming, a very appreciable quantity may be discharged from the points in the form of brush discharge before the stroke occurs, enough perhaps to considerably reduce the violence of the stroke if not to prevent it entirely. This fact was

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[26] L. A. De Blois, Some Investigations of Lightning Protection for Buildings, Proc. A. I. E. E., April, 1914, p. 563.

observed by Franklin, and the circumstances of its observation are described by him as follows: [27]

In Philadelphia I had a rod fixed to the top of my chimney and extending about 9 feet (2.74 m) above it. From the foot of this rod a wire (the thickness of a goose quill) came through a covered glass tube in the roof and down through the well of the staircase; the lower end connected with the iron spear of a pump. On the staircase opposite my chamber door the wire was divided; the ends separated about 6 inches (15.25 cm) a little bell on each end; and between the bells a little brass ball suspended by a silk thread, to play between and strike the bells when clouds passed with electricity in them. After having drawn sparks and charged bottles from the bell of the upper wire I was one night awakened by loud cracks on the staircase. Starting up and opening the door, I perceived the brass ball, instead of vibrating as usual between the bells, was repelled and kept at a distance from both; while the fire passed sometimes in very large quick cracks from bell to bell, and sometimes in a continued dense white stream, seemingly as large as my finger; whereby the whole staircase was enlightened as with sunshine, so that one might see to pick up a pin.

Other observers have noted even greater quantities of electricity being discharged from the points of lightning rods.[28] That this discharge is not enough to prevent strokes in all cases, however, is a matter of common knowledge, and is especially well illustrated by the record of the Washington Monument. The protective system of the Washington Monument is of particular interest because of the care taken in making the installation and also because of the large number of points used. In view of these facts, and also for the reason that it is the most conspicuous example of its kind in the country of which a complete record has been kept, a detailed account, in the form of extracts of the reports of engineer officers in charge of public buildings and grounds in Washington (1885 to 1912), is given, as follows:

The lightning conductors, as established for the Monument, were commenced in January, 1880, and were finished in January, 1885. These conductors consist of the four hollow wrought-iron Phoenix columns standing in the well of the shaft, and which support the elevator machinery and guide the car. These columns are 6 inches (15.25 cm) in exterior diameter, five-eighths of an inch (1.59 cm) in thickness, and are made up of sections 20 feet (6.1 m) in length, fastened together with long inside couplings, which fit tightly into the columns and are fastened to them by 16 screw bolts. The bottoms of these four columns rest upon and are bolted to cast-iron shoes, which in turn stand upon the floor of the large drum pit beneath the floor of the Monument. The shoes are connected to three-quarter inch (1.92 cm) soft copper rods led to the bottom of a well in the center of the foundation. This well

[27] Franklin's Works, vol. II, p. 203.

[28] See Dr. Priestly's History of Electricity, first edition, pp. 354 to 356.

is 32 feet 10 inches (10.01 m) in depth below the bottom of the drum pit and 15 feet 8 inches (4.57 m) below the bottom of the masonry foundation, and the water stands in it permanently 2 feet 8 inches (86.5 cm) above its bottom. After the copper rods were inserted the well was filled with clean sharp sand for a depth of 15 feet 8 inches (4.57 m), or up to the level of the bottom of the old rubble-stone 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. No disruptive discharge of electricity was experienced during those five years.

When the walls were completed, in December, 1885, and the upper extremities of the columns were covered in by the marble pyramidion, four copper rods, three-quarters of an inch (1.92 cm) in diameter, were run, one from each column, to the topstone, and there united in a 1½ inch (3.81 cm) copper rod, which, passing vertically through the stone, was screwed into a solid metal terminal of aluminum. This metal was selected for the terminal because of its whiteness, and the probability that its polished surfaces would not tarnish upon exposure to the air. It was a square pyramid in shape, similar to the pyramidion of the obelisk, and, fitting upon the topstone, completed the apex. This terminal weighed 100 ounces (2.84 kg) and was slightly over 8.9 inches (22.6 cm) in height, and 5.6 inches (14.32 cm) in width at the base. The angle at the vertex between two opposite sides was about 34° 48′.

The conductors, as above described, when tested gave an electrical resistance of one-tenth of an ohm from the tip of the terminal to the copper rods at the base, and $2\frac{2}{10}$ ohms for the ground connections, making a total resistance of $2\frac{3}{10}$ ohms for the conductor. The system was entirely completed and connected on January 20, 1885.

On the 5th of April, 1885, during the passage of a heavy thunder cloud over the Monument, at least five immense sparks or bolts of electrical light were seen within a period of 20 minutes to flash between the terminal and the cloud, without audible sound to the observers. A careful examination of the conductors and shaft after these phenomena failed to reveal any effects from these discharges.

On the 8th of June, however, during a thunderstorm, a 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 topstone, extending through the block in a line nearly parallel to the northeast corner, and about 8½ inches (21.6 cm) from it. The fragment was pressed outward about three-quarters of an inch (1.92 cm) at its bottom, chipping a small piece off the lower corner of the topstone into which it was locked, and was easily forced back to place, and bolted to the solid stone from which it had been torn.

Under the circumstances of this damage, and to devise if possible some plan by which the obelisk could be more effectually protected from lightning, Profs. H. A. Rowland, of the Johns Hopkins University, Simon Newcomb, of the United States Navy, and T. C. Mendenhall, of the United States Signal Service, were invited to inspect the conductors and recommend any modifications in them, which, in their judgment, would be proper for the end required. This they kindly consented to do, and after a careful examination recommended, in substance, 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. The additions, as devised by them, consist of four one-half inch (1.27 cm) copper rods, fastened by a band to the aluminum terminal and led down the corners to the base of the pyramidion; thence, passing through the masonry, they extend inward, and are joined to the iron columns above described. As these exterior rods are each over 60 feet (18.3 m) long, they are also connected at two intermediate points of their lengths with the iron columns by means of copper rods one-half (1.27 cm) and three-quarters of an inch (1.92 cm) 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 (1.525 m) of their lengths with copper points 3 inches (7.56 cm) in length, gold plated, and tipped with platinum. There are 200 of these points in all.

June 27, 1892. Monument struck by lightning. Current followed the lightning conductors and wires down into the engine room. The only damage done was the burning out of two electric lamps. Current followed Phoenix columns to 20 feet (6.1 m) from floor, where it left the conductor and jumped, in the form of a ball of fire as large as one's fist, to an iron plate in the floor of the shaft. It then jumped to the heater pipe adjacent and continued to the engine room with damage as above mentioned. The machinery was charged and the assistant engineer, in the act of opening a valve on the engine, received a severe shock, but sustained no injury. Later, on the same day, the performance was repeated with the current apparently leaving the columns at the same place and jumping to the floor.

Sept. 18, 1895. During a violent thunderstorm there was a magnificent display of lightning at the apex of the pyramidion. No damage was done to the shaft.

July 13, 1899. During an electrical storm lightning struck the Monument. The fluid followed the conducting columns in the interior of the shaft down to the 50-foot (15.25 m) landing, where it left the northwest column, struck the floor plates in rear of elevator, and exploded, thence into the engine room on the pipes or wires, where the only damage done was the burning out of the magneto coil of the telephone, which broke the connection between the engine room and boiler house. It is a coincidence that each time the Monument has been struck by lightning the fluid has left the columns about the same place. During this storm the lightning also went into the lodge house on the telephone wires and burnt out the magneto coil of the telephone.

May 3, 1900. During an electrical storm a man who was standing on the lower floor of the monument and leaning against one of the iron columns which support the stairways received a heavy shock of electricity in his arm and shoulder and two men who were looking out of one of the windows at the top at the same time reported that the flash seemed to come in the window over their heads. They were blinded for a moment. No damage was done. The iron columns referred to act as lightning conductors, the lightning rods on the outside of the pyramidion being connected with them for that purpose.

July 14, 1903. The Monument was struck by lightning. No damage was done to the Monument, but the lightning entered the motor room from the shaft, burned the insulation from the telephone wires, jumped to the switchboard, burned out the underload coil for the I. T. E. circuit breaker and relay coil, thereby stopping the running of the elevator until the relay coil was rewound. Both wattmeters in the dynamo room at the power house were also burned out.

April 27, 1904. The shaft was again struck. The bolt entered at the top, burned out the telephone there, then passed down the iron columns to the lower floor through the shaft alley to the motor room, where it burned out a relay coil on the switchboard, thence along the electric cable to the dynamo room in the power house, where it entered the ground. No other damage than that reported was done. Lightning arresters were at once placed in the motor room at the Monument to protect the switchboard and machinery there, and to protect the machinery in the pit and on the bottom floor of the shaft a one-half inch (1.27 cm) copper cable was connected with the bottom of one of the iron columns in the drum pit and grounded to the water pipe in the motor room. To protect the switchboard of the generating plant in the power house a No. 6 copper wire was grounded to water pipe in the lower engine room, and when the plant is not in operation the wire is connected with the switchboard.

June 30, 1904. The Monument was again struck by lightning, burning out the fuse on the telephones and the lamps in the elevator car. No damage was done to the machinery. The bolt entered at the top, passed down the shaft to the motor room, thence through the cable tunnel to the engine room in the power house, passing off to ground through the lightning arresters mentioned in the preceding paragraph.

It is a notable fact that for 10 years (1904 to 1914) there is no record of lightning having struck the Monument. It is quite possible, however, that it may have been struck at such an hour, and with so little damage of the kind just described, as to have escaped notice.

As previously indicated, the principal conclusion to be drawn from the records of the performance of the protective system of the Monument is that the discharge from points is not always sufficient to prevent strokes entirely. Moreover, if this is the case in a system in which such a large number of points is used, it seems as if it would be the case to a still greater degree in a system having but a few points. Another feature of the performance of this protective system that commands interest is that prior to the connection of the columns to the water-pipe system the stroke almost invariably left the columns near the bottom and jumped to a floor plate. A possible explanation for this is as follows: From the description just given it is seen that at the time these phenomena were observed the actual contact of the rod with permanent moisture took place at a distance of 30 or 40 feet below the top surface of the stratum of permanently moist soil, which, in the region of the Monument, is near the surface of the ground. From this point of contact to the surface of the ground the rod is surrounded with sand and masonry, both of which are of high electrical resistivity. Now, it is more or less generally agreed that the larger part at least of earth charges in lightning phenomena reside at or near the top of the stratum of permanently moist earth, and if this is the case it is not unlikely that the stroke would leap from the columns near the surface of the ground to the nearest object in contact with this stratum in preference to traveling the entire distance to the bottom of the well and thence back to the surface of the stratum of permanent moisture. This would be in accord with the well-known performance of lightning in turning a right angle in a conductor; it almost invariably leaps across through air several inches from the corner in preference to following the conductor over a path a little longer than the one through air which it picks out for itself.

A second advantage to be found in the use of aerial terminals with points for lightning rods is the directive effect which the stream of ionized air particles passing off from a point during a discharge of static electricity may have upon a lightning stroke. This is a well-known effect observed in the laboratory in the case of spark gaps, and it is quite conceivable that in the same way a flash of lightning may be caused to follow a path leading to a point which lies at a considerable distance from the line of steepest potential gradient which the stroke would naturally follow if the point were not present. In this way a point may establish an area of protection; that is, an area in which the lightning will strike the rod in preference to other objects. In the past much has been said concerning this area of protection, and attempts have been made to devise more or less empirical formulæ by means of which it could be calculated. The impossibility of this is evident, however, from a consideration of the fact that it will vary between wide limits with the topography of the surface surrounding the rod, with the velocity of the wind at the instant of the stroke, and with many other factors which are impossible to include in a study of each individual case, to say nothing of an empirical formula intended to apply to all cases. The failure of these formulæ to apply in many cases has caused some persons to assert that there is no area of protection afforded by a lightning rod. This assertion does not seem reasonable, however, unless it be in the case of the B-flash described by Sir Oliver Lodge, in which the discharge is supposed to occur so suddenly that there is no time for preparation of the path by ionization and brush discharge, and it is therefore as likely to strike a flat surface a few

Fig. 6.—*Points for lightning rods*

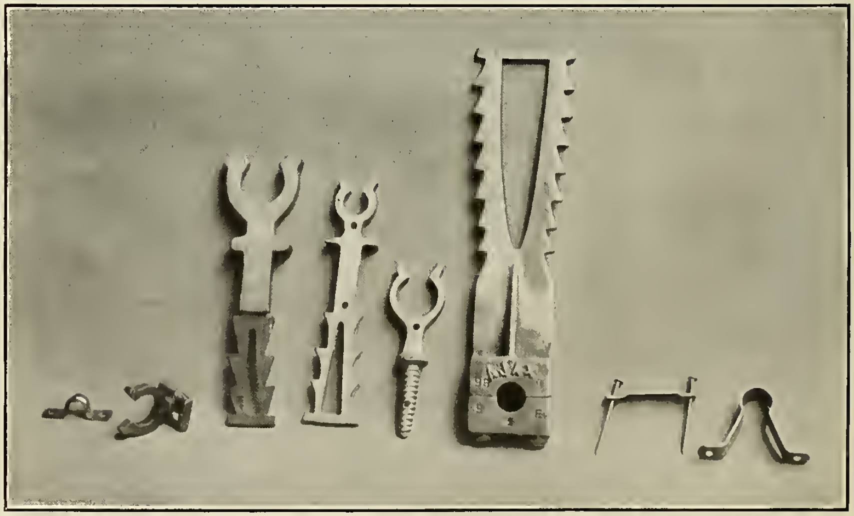

Fig. 3.—*Fasteners for rods*

feet from a rod as to strike the rod itself. This effect is producible in the laboratory with metallic conductors, but there is, however, no direct evidence that it occurs in nature where the clouds and the earth serve as conductors. On the contrary, the high efficiency of lightning rods, as observed and reported in all quarters, point to the conclusion that if the B-flash does occur, it occurs so rarely as to be practically negligible.

A third advantage derived from the use of aerial terminals with points is that they serve to receive the stroke, and thus fusing where the stroke enters the rod is confined to a place where it does not impair the continuity of the conductor. This fusing in some cases may be very severe, and it is the source of a strong objection to the contour system, in which the conductors may easily be fused in two where the stroke enters, which makes immediate repairs necessary or, if repairs are neglected, seriously reduces the effectiveness of the system for future service.

1. POINTS

There are two general forms of points which are being put out by manufacturers of lightning rods at the present time, viz, single points and multiple points. A number of these points are illustrated in Fig. 6. The single points can be divided into two classes, i. e., shell points and solid points. The shell points are in most cases made of copper in the form of a hollow cone surmounting a short section of tube. They are made to slip on over a length of copper tube which elevates the point to the desired height above the horizontal conductor. These points are about 20 centimeters in height (7.88 inches) and weigh from 45 to 55 grams (0.099 to 0.121 pound). This quantity of metal does not seem to be sufficient to give even a reasonable assurance that they will not fuse when struck, and in fact when they are struck it is in many cases necessary to replace them. Fig. 7 shows one of these points that has been struck by lightning. The specimen on the right shows the form of the point before it was srruck.

The solid points are of better construction, containing a greater quantity of metal and are used mostly in connection with iron rods having screw joints. These points are from 20 to 25 cm in height (7.88 to 9.85 inches) and weigh from 100 to 200 grams

(0.22 to 0.44 pound). Various metals and alloys of metals enter into their construction, chiefly copper and bronze, although nickel is used in some cases.

The multiple points are generally made with five to a dozen or more small points arranged about a common center. The chief advantage claimed for these points is that they do not fuse as readily as single points when struck, for the reason that there are several points to receive the discharge. In the case of most of the manufacturers of rods who use these points this claim is substantiated by the assertion that they have never had one fused in service. To learn to what extent this statement may be relied upon, however, would require further investigation. In discharging static electricity it is obvious that multiple points would have an advantage over single points, although the individual points are too close together in most cases to allow the quantity of discharge to be in direct proportion to their number as compared with the discharge from a single point.

Nearly all manufacturers plate the points which they make with nickel or gold, and in many cases platinize the tips. The plating is intended to prevent corrosion, and to a certain degree is beneficial in this respect, although if the point is made of copper or bronze this is hardly necessary. Plating with gold, even though it prevents corrosion admirably, seems to be a needless expense. Nickel would serve as well and is much cheaper. Platinizing the tips is done for the ostensible purpose of making the tip more resistant to fusion, but to secure any appreciable benefits in this respect from the use of platinum tips such a large quantity of platinum would have to be used that the expense would be prohibitive.

2. AERIAL TERMINALS

In Fig. 8 is shown a complete aerial terminal which represents, in a general way, the form and construction of aerial terminals as they are at present installed by most lightning-rod companies. There are variations from this general form for various purposes, but the type shown is used for ridges, parapets, and flat spaces by most companies. The height to which the points of aerial terminals should be elevated above the object to be protected has long been a matter of question. The modern practice is to use a

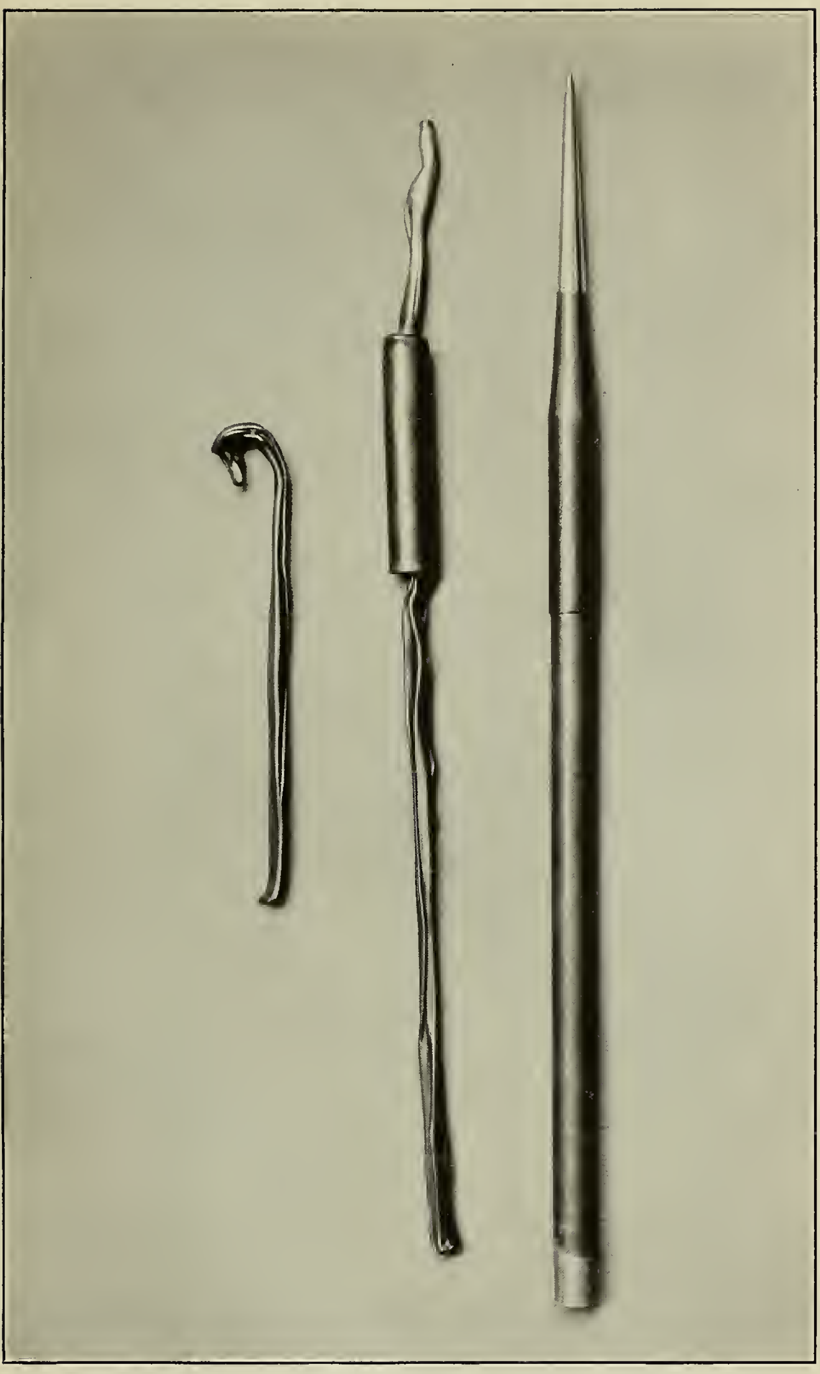

FIG. 7.—*Example of a shell point and tubular elevation rod fused by a lightning stroke*

(Specimen submitted to the Weather Bureau by Mr. West Dodd, of Des Moines, Iowa. Photographed by courtesy of Dr. Humphreys, of the Weather Bureau)

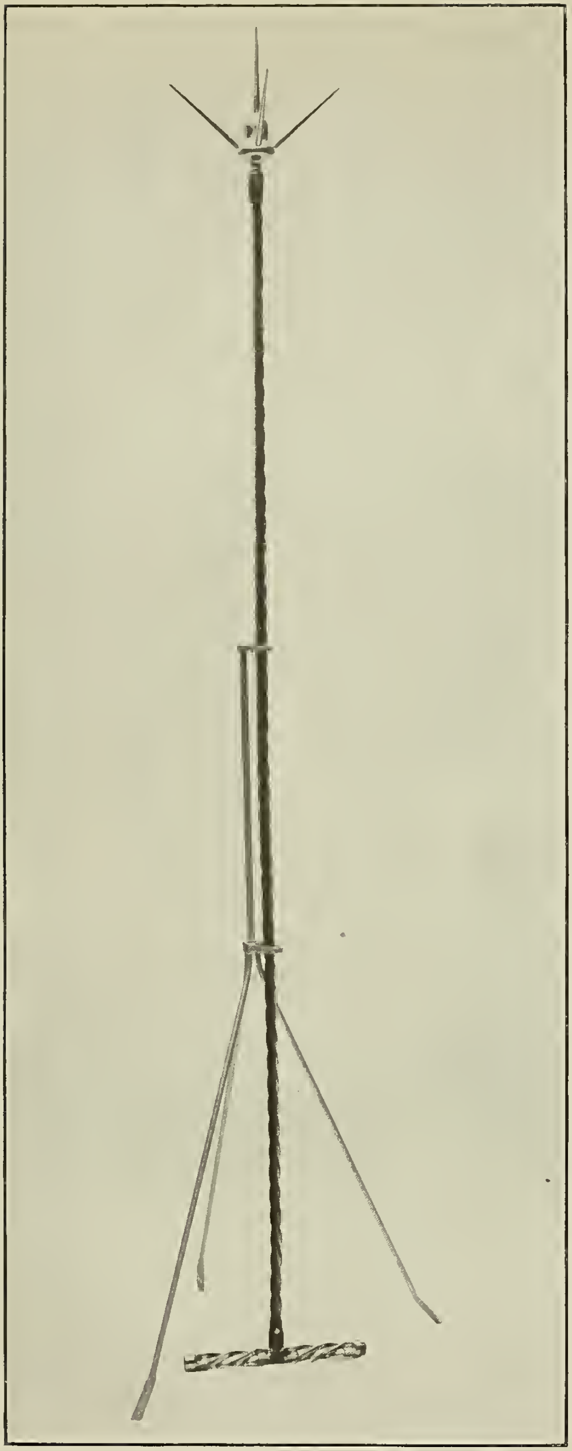

Fig. 8.—*Aerial terminal*

terminal 4 or 5 feet (1.22 or 1.52 m) in height on flat surfaces and ranging from that height down to a height of a foot or so (0.31 m) for sharp peaks, according to the ideas of the person who makes the rods. On chimneys a height of 12 or 18 inches (30.48 or 40.7 cm) above the top of the chimney is usually allowed. It is obvious that raising the point of an aerial terminal to a great height above surrounding projections causes it to predominate over them and invite a stroke to itself in preference, but the protective effect on surrounding projections of a lofty terminal has been found to be unreliable. For this reason points are placed on all projections of a structure, and it is therefore not necessary to elevate points more than a short distance above the projections they are intended to protect. For sharp peaks a terminal a foot in height (30.48 cm) seems sufficient. For flat surfaces and along ridges a greater height is desirable, and 4 or 5 feet (1.22 or 1.52 m) has proved satisfactory.

The subject of bracing of aerial terminals is one to which a great deal of care and attention should be given. The current practice is to use a tripod brace of galvanized iron similar to the one shown in Fig. 8, which in most cases is fastened to the roof with nails. These braces appear to be easily blown over by the wind, and it is a common sight to see them lying flat on the roof. The weakest part of their construction is undoubtedly the way in which they are attached to the roof; nails are soon loosened by strain and vibration caused by wind. When the rod is copper, corrosion of the iron is also likely to occur. For permanent work copper-clad iron or steel would be a far preferable material for braces used in connection with copper rods. With galvanized-iron rods galvanized-iron braces would, of course, be satisfactory. In fastening braces to the roof expansion screws or bolts should be used instead of nails. The bolts are preferable for wooden roofs and should be long enough to pass through the roof and be provided with a nut and washer on the inside; when they are screwed up they should be upset with a riveting hammer to a sufficient extent to prevent the nut from coming off. The material of which the bolt is made should be the same as that of the brace. Expansion screws serve very well on concrete roofs or brick parapets. The screws should be of the same material as the brace and should penetrate the concrete or masonry to a depth of at least 3 inches (7.61 cm). The whole construction of the brace should be carried out with a view to strength and rigidity, and when this is done an aerial terminal will remain upright as long as is necessary.

X. ARRANGEMENT OF RODS AND AERIAL TERMINALS ON BUILDINGS, AND THE INTERCONNECTION OF METALLIC MASSES

As a subject for protection against lightning almost every building presents a problem which is peculiar to itself; hence, no general rule as to the location of aerial terminals and rods, and the interconnection of metallic masses, can be laid down which would give correct results in all cases. On the contrary, the distribution about a building of rods and aerial terminals in such a way as to secure a maximum of protection without going to excessive expense is largely a matter of judgment based on available knowledge concerning high-frequency electrical phenomena. At the same time, however, there are certain features of the practice of protection against lightning concerning the location of aerial terminals and rods, and the interconnection of metallic masses, which are fairly general in application, and which experience indicates should be observed wherever possible. Such information along this line as appears available has been collected and is summarized below:

1. LOCATION OF AERIAL TERMINALS

In view of the fact that no reliance can be placed on an "area of protection," as described heretofore, the general practice in recent years has been to place aerial terminals at all chimneys, ventilators, gables, or other projections which present a peak or corner toward which a stroke of lightning might be directed. Along straight ridges and parapets aerial terminals are placed at distances apart of not more than 25 feet. If there is a portion of a ridge or parapet between two projections which is more than 25 feet in length, it is considered good practice to place an aerial terminal in the middle of this distance even though it exceeds the limit of 25 feet by but a few feet. There seems to be no fixed rule with regard to flat surfaces. On flat-roofed buildings lightning strikes in most cases, if at all, along parapets or edges; consequently, it is not the usual practice to place aerial terminals on such surfaces unless there are projections, such as ventilators, etc. Nevertheless, if the expanse is very great, even though unbroken, it seems advisable to give it a certain degree of protection, at least, for the reason that flashes of lightning are sometimes shifted by the wind, as heretofore shown, and may strike a flat surface as well as a ridge or a parapet. In such a case aerial terminals might be placed at the intersections of lines drawn at right angles to each other and laying off squares of 50 feet on a side, or even in closer arrangement if need be.

Metal roofs, as a rule, are provided with aerial terminals in the same manner as other roofs, but the roof serves as the conductor instead of rods, the aerial terminal being put in electrical connection with the roof and the roof connected to earth. It might seem that connecting the roof to earth would be sufficient, but the use of aerial terminals makes a provision for the reception of the discharge in such a way as not to injure the roof, and at the same time assures some other advantages as described heretofore.

In most of the protective systems designed for smokestacks, which are built of material other than metal, aerial terminals are placed about the rim of the stack at intervals of from 6 to 10 feet. In the best installations these terminals are lead covered and vary in height from 2 to 5 feet, but it seems that terminals of the greater height would be preferable because of the fact that they must divert the discharge from the smoke column to themselves. In some cases the foregoing procedure in regard to stacks is departed from and an aerial terminal is formed by placing a hemispherical or conical-shaped cage of lead-covered metal over the entire top of the stack. Although far more expensive, for large stacks the latter form of terminal is doubtless preferable for the reason that lightning strokes exhibit a strong tendency toward following streams of smoke, and in that way might miss entirely a ring of aerial terminals of the ordinary type placed at the rim of the stack. Moreover, in view of the financial consequences which, as a rule, are attendant upon the destruction of a stack it seems justifiable to go to a considerable expense to avoid it as far as possible.

2. LOCATION OF RODS

In the cases of roofs other than metal, when the location of the aerial terminals has been decided upon, rods should be run along ridges, parapets, and over flat surfaces if need be, in such a way as to connect each terminal to all the rest, with cross connections at advantageous points to make as complete a network as possible consistent with economical use of material. Down conductors should then be run in such a way that a stroke on any terminal will have at least two parallel paths from the foot of the terminal to earth. One path from a terminal to earth has been found to be unsafe, and more than two is preferable. The reason for this is found in the fact that the greater the number of widely separated paths to earth the less the inductance and the greater the capacity, and consequently the less the danger of oscillations in the lightning rod system; also the smaller the potential drop in rods and over grounds which lessens static inductive effects. It is very important that sharp turns in conductors be avoided; all corners should be rounded in a curve of at least 1-foot radius. The same rules hold for smokestacks, steeples, etc., i. e., two or more down conductors should be run along routes as widely separated from each other as possible, and around the top of the structure a heavy conductor should form a ring connecting all of the terminals together. In some cases, if the height of the structure is very great, the down conductors are connected together at intervals by encircling the structure with a ring similar to the one at the top.

3. INTERCONNECTION OF METALLIC MASSES

In the most approved modern installations of lightning rods all external metallic masses on a building are made a part of the protective system. It should be stated, however, that they are not to be considered as a substitute for a portion of the rods, but as an addition to them. On houses, for example, the valleys are connected by a stout wire to the rod nearest their upper ends, using soldered connections. The valleys are soldered to gutters, gutters to down spouts, and down spouts thoroughly earthed. Extended metal porch roofs or ornaments are connected to the nearest rod at one end and earthed at the other end. On barns, where rods cross metallic gutters, the rods and gutters are electrically connected and the down spouts earthed in the same manner as in the case of houses. The same procedure is followed in the case of any extended piece of metal on the exterior of a building. Small detached pieces of metal, however, do not need to be considered. It should, perhaps, be stated here that it is preferable to use rods and external metallic ornaments and roofs of the same kind of metal, as the danger of electrolytic corrosion at points of connection is in that way eliminated.

A pipe or other extended metallic object which comes near to or projects from the roof of a building and passes vertically partly or wholly through the building itself should be connected to the rod nearest its upper end and the lower end earthed, the whole length being made electrically continuous. Any pipe, or other extended piece of metal within the building, which passes parallel to a rod for a considerable distance, and is not at a sufficient distance from the rod at all points to eliminate the possibility of sparks, say, from 8 to 10 feet, should be connected to the rod at one end and earthed at the other, even though there is a thick wall between the rod and the metal. Examples of such metallic masses are soil pipes, water tanks in attics, etc., including iron tracks in the roofs of barns, and windmills on barns which have iron pump rods extending to the lower floor.

In the case of earthed metallic masses on the interior of a building which are not of an extended form they can, in general, be left disconnected from the rods, provided the distance between rods and metal is 6 feet or more. There is no fixed limit of distance in this respect, but 6 feet seems ample for safety in buildings which are not extraordinarily liable to fires and explosions from small sparks, such as may be the case in oil tanks and powder magazines. It seems to be generally regarded as safest to electrically interconnect and earth all metallic masses on the interior of a building, provided they are not of such character as to require that they be connected to the rods in the manner just described.

With regard to steel-frame buildings, the experience up to the present time has been that they are not affected to any great degree by lightning and consequently no attention has been given to their protection. In some quarters it is recommended, however, that pains be taken to see that the frame is properly earthed and provided with aerial terminals to receive discharges, but no direct evidence is at hand to show that this is necessary.

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XI. QUESTION OF COST

In discussing the question of whether an investment in lightning rods will pay, the subject must be considered under two heads: (*a*) Those cases where a risk to human life is involved, and (*b*) those cases where a risk only to property is concerned. In a preceding part of this paper it has been shown that in regions where thunderstorms are frequent and violent the risk to human life is a matter which merits serious consideration. For the reason that the value of a human life can not be estimated in terms of dollars and cents it seems that, regardless of cost and in order to make the risk as small as possible, lightning rods ought to be installed in the most approved manner on all dwelling houses and other buildings which are much frequented by human beings during thunderstorms. As a matter of fact, however, a lack of protection is not excusable on the score of expense except in rare cases, because the cost of installation and maintenance of a system of rods suited to the average dwelling is insignificant in comparison with the possible consequences in the way of deaths or injuries in the event of a stroke on an unprotected house. Moreover, in view of the high degree of protection which seems to be obtainable with a modern system the expense will doubtless be more than repaid in a sense of security from lightning, especially in cases of persons who stand in great fear of thunderstorms. In fact, in the case of dwelling houses, the greatest portion of the return on the investment is doubtless to be expected in this way, because the property risk from fire by lightning is not great if ordinary precautions are observed in regard to the storage of inflammable substances, and in most cases insurance companies will assume all risk from damage to unprotected dwelling houses by lightning for but a very small premium.

With regard to cases where only property is at risk, it can be shown that the total loss caused by lightning is not sufficient to justify universal protection on that score alone. Thus, the total loss caused by lightning has been shown to be about $8 000 000 or $10 000 000 per year. The census tables show that there are about 10 000 000 rural dwellings in the United States; that is, dwellings in towns and villages having 2500 inhabitants or less and in country places. It is in these regions that practically all of the property loss by lightning occurs, and, counting buildings of all kinds, it may therefore be roughly estimated that the total number of buildings exposed to lightning is 20 000 000. The cost of installing rods would range from $20 to $100 apiece, or an average of $60. To rod the entire number of buildings would, therefore, require an expenditure of $1 200 000 000. At 4 per cent interest per annum on the investment, and 2 per cent depreciation, the outlay per year to maintain these installations would be $72 000 000. As this seems to be a conservative estimate, it obviously would not pay indiscriminately to rod all property exposed to lightning, even though that situated in regions where thunderstorms are infrequent, which is included in the foregoing figures, were excluded from consideration; discrimination must be used in selecting the property to be protected in order not to make protection against damage by lightning more expensive than insurance.

In making such a selection Table 8 will be of some assistance, but in addition to a knowledge of the order of susceptibility to fire or other damage from lightning of different classes of property, there must also be a consideration of the secondary consequences of a stroke of lightning. Thus, in the case of a smokestack the loss resulting from a shutdown of the plant may be many times the amount of damage to the stack, much of which, such as demoralization of the working force, loss of possible sales, etc., is intangible and can not always be covered by insurance. In such a case thorough protection against lightning would be the most economical insurance in the end. In the case of barns, oil tanks, churches, and other structures which are extremely liable to fire or other damage by lightning, protection is also undoubtedly more economical than insurance. In addition to the actual dgree of security against damage from lightning there is also a sense of security enjoyed by the owner which must be considered. Many owners of rods declare that after rods were erected on their barns and other property they could sleep soundly through a thunderstorm at night, whereas before they felt obliged to be on watch until the disturbance was over, and this feeling of security was no doubt well worth the cost quite apart from the actual protection afforded.

The actual cost of lightning rods is a quantity which depends upon the character of the rod, the character of the building upon which it is erected, and the thoroughness with which the work is done. The price at which agents seem to be able to dispose of their goods is also a variable quantity depending in many cases upon the salesmanship of the agent and the persistence of the buyer in holding out for a lower price. These prices range from 25 to 45 or 50 cents per foot of erected rod, with aerial terminals thrown in. Ornaments and other more or less useless accessories are generally extra, however, and the skill with which the average agent disposes of worthless glass and tinware to hang on aerial terminals and other parts of the system markedly increases the cost of the rod to the purchaser. In view of the character of the work done in most cases these prices are highly excessive and altogether out of proportion to the actual cost of the material and erection. If the erection of rods were placed upon an engineering basis and more stress laid upon features of installation which were calculated to promote the efficiency of the protection, instead of appealing to the imagination of the purchaser with useless "ground points" and other fanciful devices, the lightning-rod salesman might be removed from the class of the patent-medicine vendor and his usefulness to the community much enlarged. There has been much improvement in this respect in recent years, but a great deal of progress can still be made in this direction.

XII. PROTECTION OF LIVE STOCK IN FIELDS

The loss of live stock by lightning in some localities, especially in the Middle Western States, has been sufficient to cause considerable concern, and in many cases precautions have been taken to prevent it. The greater portion of the loss is caused by cattle drifting against wire fences during thunderstorms and being struck by lightning, which may be collected by the fence at a distance and brought to the herd with sufficient force to kill them. It is not often that cattle are killed by direct stroke unless it be under trees where they have gathered for shade and to fight flies during the excessively warm period which usually precedes a summer thunderstorm.

In many instances attempts have been made to obviate the danger from wire fences by the simple and inexpensive expedient of earthing the wires at intervals by means of an iron or copper wire stapled to the posts in contact with the fence wires and extending 3 or 4 feet (0.91 or 1.2 m) into the ground. This, however, makes an earth connection of high resistance and is soon broken off or corroded away. A much more permanent, but also more expensive earth connection is made with a post of galvanized iron with clamps for holding the wires, which is made especially for the purpose. These posts may be placed from 50 to 100 yards (45.7 to 91.4 m) apart, according to the condition of dampness of the soil. If the soil is dry, they should be placed rather close together, say at 50 yards (45.7 m), in order that the resistance to earth may not be too high. If the soil is damp, they may be placed at 100 yards (91.4 m) or even more. An excellent earth connection, which is less expensive than that obtained with the posts, can be obtained with one-half or three-quarter inch (1.27 or 1.9 cm) galvanized-iron pipe extending 5 or 6 feet (1.32 or 1.83 m) in the ground and attached to each fence wire by wrapping with galvanized-iron wire. The pipe earths may be spaced at the same distances as the iron posts mentioned above.

To simply connect the fence to earth, however, is not sufficient. It is also necessary that the electrical continuity of the fence be broken up. This can be accomplished by inserting at intervals of 300 yards (274.2 m), or so, 2 by 2 inch (5.08 by 5.08 cm) strips of hardwood a yard (0.914 m) in length to the ends of which the ends of the disconnected fence wires are made fast. In this manner a bolt of lightning striking any section of the fence will be confined in large measure, at least, to that section, and thus its transmission to a distant part of the fence will be prevented, even though the resistance of the earth connection is rather high. The strips of wood may be staggered in a vertical direction to a sufficient extent to make it not easy for stock to reach through the fence between the strips where there are no barbs to prevent it.

In the case of trees which it is desirable to preserve on account of the shade they afford to stock the danger from lightning may be reduced by fencing around the trunk at a few feet from it and rodding the tree with a three-eighths inch (0.95 cm) copper cable extending from the topmost branches to a sufficinet depth in the ground to reach permanent moisture. Where trees are isolated and the vicinity is much frequented by stock this may be a wise precaution.

XIII. SAFEGUARDING HUMAN LIFE

LOCATION OF GREATEST SAFETY DURING A THUNDERSTORM

The question is often asked as to the location of greatest safety during a thunderstorm. In this respect it may be said that there is no place or object in the path of a thunderstorm that is not liable to a stroke of lightning. Places or objects may be more or less liable to a stroke of lightning according to their relative exposure, etc., but no place in the path of a thunderstorm is to be considered as one upon which a stroke of lightning is not likely to fall. The location of complete safety during a thunderstorm is, therefore, one in which, even though a stroke of lightning does fall upon it, no harm will come to the occupants. From what has been said in the foregoing portions of this paper it is evident that such a location may be found only in a space entirely surrounded by a metal network, in a steel-frame building, or in an underground chamber. With the exception of places similar to these three, there does not seem to be any place where absolute safety may be obtained. The next degree of safety is undoubtedly to be found in houses or other buildings which are protected by lightning rods, but, although the degree of safety which can be attained by using rods may be very high, the risk can not be entirely eliminated.

In the event of a stroke on an unprotected building there is considerable danger to life, but there is no doubt that an unprotected house is preferable to the open, under trees, or in unprotected outbuildings. As heretofore shown from the news clippings in H. F. Kretzer's Lightning Record, when a stroke falls on an unprotected house sheltering a family of the average number of persons, the minimum chances of escape are 45 in 100. In all probability, however, the chances of escape are much greater than this. In 254 instances of casualties in unprotected houses which are given in this record there were 117 cases of death and

137 cases of injury. From the same source it is found that in 153 cases of persons struck in open fields 116 were killed and 37 were injured. In 33 cases of persons struck under trees, 32 were killed and 1 injured. In 9 cases of persons struck near wire fences, 8 were killed and 1 injured. It seems, therefore, that it is far better to take shelter in a house which is not protected against lightning than to take chances in the open, where everything is damp and hence the liability to shock or injury far greater than in a dry place.

The news reports just mentioned show that when unprotected houses are struck people are injured or killed in almost every conceivable location in the house. It seems that there is no place in a house to which lightning will not penetrate, although many statements to the contrary have been made. Some places in a house are undoubtedly more dangerous than others, however, among such places being the vicinity of stoves, places between masses of metal on the exterior of the building, and metallic masses on the interior of the building, whether earthed or not, and near chimneys. An example of a place between metallic masses of the character of those just mentioned would be between a down spout and a steam or hot-water radiator. Other dangerous places in a house during a thunderstorm are at telephones, or touching screen doors or other metallic bodies which connect with the exterior of the building.

Out of doors the most dangerous places are evidently in open fields, under isolated trees, and near wire fences. Small sheds and other shelters are almost equally as dangerous as isolated trees, especially if the sheds are in the open, away from larger buildings. Thick timber is undoubtedly the safest place to seek out of doors, for the reason that a single tree under which a person might take shelter in a forest area is not as likely to receive a stroke as a single object or a person in an open space of equal area.

XIV. SUMMARY

The substance of the foregoing paper, and the conclusions from it, may be summarized briefly as follows:

(1) The property loss by lightning for the entire country is approximately $8 000 000 per year, of which by far the greater part occurs in rural districts.

(2) During each year there are approximately 1 500 persons affected by lightning stroke in the United States, about one-third of this number being killed and the rest subjected to injuries which in many cases are permanent. Nine-tenths of these accidents occur in rural districts.

(3) Such evidence as is available on the effectiveness of lightning rods indicates that, taking rods as they come in the general run of installations, they reduce the fire hazard from lightning by 80 to 90 per cent in the case of houses, and by as much as 99 per cent in the case of barns. The same is undoubtedly true in the cases of other buildings having characteristics similar to those of barns and houses.

(4) There is a more or less general opinion among persons who have given attention to the subject of protection against lightning that failures of lightning rods to give adequate protection are in many cases due to neglect to make extended metallic masses in proximity to the rods a part of the lightning-rod system. When these metallic masses are included in the system in the proper manner the danger of a flash leaving the rod and penetrating the building is much reduced.

(5) The matter of the proper metal for lightning conductors has been much discussed, especially with respect to resistivity; but, inasmuch as the resistance of the metallic portion of a lightning-rod system is in most cases small in comparison with the resistance of the earth connection, the resistivity of the metal used is not of paramount importance; at least the difference of resistivity in the metals commercially available for lightning rods are not great enough to make one metal preferable over another.

(6) There are two systems of protection in successful use, i. e., the contour system and the point system. Both systems present certain advantages, but it seems that the advantages obtained in the use of points outweigh the advantages of the other system. The chief mechanical difficulty present in the point system, which is not met in the contour system, is the mechanical one of keeping aerial terminals upright.

(7) Insulators in clamps fastening lightning rods to buildings are no longer used except in localities where prejudice in their favor still demands that their use be continued.

(8) The maximum current of a lightning flash may be more than 20 000 amperes.

(9) A flash of lightning consists in most cases of a number of consecutive discharges of varying character which follow each other along the same path with very short-time intervals between them. The duration of a complete flash may vary in different cases from a very few thousandths of a second to half a second or more. The intervals of time between consecutive discharges in the same flash may vary from a few thousandths to one or two tenths of a second. The duration of each of the consecutive discharges of a flash is probably not more than two or three hundred-thousandths of a second in most cases.

(10) The rate of variation of current at any point of the path of each of the consecutive discharges of a flash of lightning is probably in most cases such as to make its effects similar to those of currents of frequencies of the order of several hundred thousand cycles per second, with the wave train so rapidly damped as to make it practically a unidirectional discharge. The magnetic effects observed in many instances point to either a unidirectional discharge or rapid damping. In fact, there seems to be no good reason for believing that a lightning discharge is oscillatory, although secondary effects from lightning discharges in neighboring conductors may be of an oscillatory character.

(11) The path of a flash of lightning may be shifted by the wind while the flash is taking place, such shifting having been observed photographically to have taken place to the extent of at least 11.1 meters (36.4 feet).

(12) The heating effects of a lightning stroke on a rod of ordinary size, i. e., a rod weighing 0.5 kg per meter (5½ ounces per foot) or more, is not likely to be appreciable except at the place where the stroke enters the rod. It may also be appreciable at high-resistance joints.

(13) The instantaneous potentials which may be set up between rod and earth by a flash of lightning because of the resistance of the earth connection may easily reach half a million volts or more with earth connections of the resistance of those ordinarily met within practice.

(14) Assuming a sine wave of electromotive force, high current density, wave-fronts equivalent to frequencies of from 100 000 to 500 000 cycles per second, and constants as given heretofore in this paper, the skin effect in a cylindrical iron rod appears to be less than the skin effect in a copper rod of the same dimensions.

(15) No system of protection for oil tanks has been devised which is accepted by oil companies as giving a degree of protection which is at all commensurate with the cost. It may be well to add in this connection that the systems of protection for powder magazines at present in use are not considered satisfactory; at least this is the impression to be gathered from published information. Much experimental work has been done, but the difficulty of preventing explosions seems to be almost insurmountable.

(16) In the event of equal and large numbers of unprotected barns and houses being struck by lightning, about four times as many barns as houses would be fired.

(17) There are no data to show that different objects equally exposed to lightning as to height, configuration, and other characteristics are not equally liable to be struck. From theoretical considerations it would appear that highly conducting bodies are more likely to be struck than insulating bodies; but there are no data available to show to what extent this is the case. The impression that some objects are more liable to lightning stroke than others undoubtedly arises from the fact that some are more susceptible to damage by lightning than others.

(18) Such statistics as are available seem to show that when a stroke of lightning falls upon an unprotected house sheltering a family of an average number of persons the chances are about even that one or more of the members will be injured or killed, but because of the fact that cases of lighning stroke on houses in which no severe damage to the building nor injury to persons occurs are very unlikely to be reported it is quite likely that the chances are much less than even.

(19) The metals commercially available as materials for lightning rods and which meet all of the other requirements in greater or less degree are copper, aluminum, and iron.

(20) The most important property which must be possessed by the metal of which a lightning rod is made is resistance to

atmospheric and soil corrosion. To impart this property to iron it must be galvanized.

(21) Good mechanical construction is quite essential to permanency in a lightning-rod system, but at the present time it is not as a rule being given the attention it should have. The impression that a defective rod is necessarily a menace, however, is false; even a defective rod is generally better than no rod at all.

(22) In constructing a lightning rod, contact between metals which occupy different positions in the electromotive series should, in general, be avoided. An exception to this is contact between copper and lead.

(23) Corrosion of copper rods by smoke and gases can be effectively prevented in most cases by covering the rod with lead.

(24) The rods sold at the present time which seem preferable are star-section iron rod and tightly twisted copper cable. Copper cable is sold woven in tubular form, but weaving copper cable in this form does not materially decrease the high-frequency resistance over that of a tightly twisted cable of the same number and size of wires. It does cause a slight decrease in self-inductance, but in a lightning-rod system a decrease of inductance can be better accomplished by offering the flash a greater number of widely separated parallel paths to earth than is usually the case.

(25) The most economical and satisfactory earth connections are made with cast-iron or copper rods extending into the earth to a depth of from 6 to 10 feet, or to a point well below the foundation walls of the building to be protected.

(26) The resistance of the earth connection should be made as low as practicable, in most cases it being impossible to get too low a resistance. A resistance which rises much above 15 or 20 ohms at any time should be considered as excessively large.

(27) Aerial terminals with points should be located at all chimneys, gables, points, or other projections toward which a stroke of lightning might be directed. This is because a point can not be relied upon to protect objects other than the one upon which it is placed.

(28) Down conductors should be run in such a way that a stroke on any aerial terminal on a structure will have two or more widely separated paths from the foot of the aerial terminal to

earth. One path from an aerial terminal to earth has been found unsafe and more than two is preferable.

(29) The return on an investment in lightning rods may be expected in two ways: In a sense of personal security from lightning and in actual security to both life and property. The property loss by lightning is not sufficient to cause protection against lightning always to be a paying investment. Protection against lightning is justified as an investment only where risk to human life is involved and where the property risk is high enough to make protection against lightning cheaper than insurance.

(30) The loss of live stock in fields can be reduced by earthing wire fences by means of galvanized-iron pipe or posts at intervals of 100 yards or so, and breaking up the electrical continuity of the fence at intervals by inserting sections of nonconducting wood in place of the wire.

(31) No place to which a person may ordinarily retire can be considered absolutely safe from lightning. The place of greatest safety which is ordinarily accessible is a well-rodded building; the next safest is undoubtedly an unprotected house, which may be regarded as much safer than in the open or in small unprotected outbuildings.

WASHINGTON, July 17, 1915.

APPENDIXES

Appendix I.—RULES CONCERNING THE INSTALLATION AND MAINTENANCE OF LIGHTNING RODS

Below are given some of the rules and recommendations concerning the installation and maintenance of lighting rods that have been adopted by various authorities or technical organizations in England, Germany, and the United States. They are given here as examples of what the various organizations referred to regard as the best practice in protection against lightning.

A. ENGLAND

THE PHOENIX FIRE OFFICE RULES[29] FOR LIGHTNING RODS

IDEAL METHOD OF PROTECTION

In the report issued by the Lightning Research Committee in 1905, it is pointed out that lightning discharges are of two distinct characters, named the A and B flash, respectively. The A flash is of simple type; it can be prevented, or its violence diminished, by the silent discharge which goes on during a storm from various points of a building. Its path is prepared beforehand by ordinary electrostatic considerations, and it strikes pointed conductors in preference to others. The usual system of two or more conductors, if properly constructed, affords sufficient protection against a flash of this kind.

The B flash is a disruptive discharge of much greater suddeness, which falls on a building without preparation; it may strike the building in several places at once, and is no more likely to select points than knobs. A column of hot air, like that of a chimney, is the path most favored by this kind of discharge. Points are no protection against it; the only way to obtain absolute security is to inclose the structure in a metal framework, constituting what has been described as the "bird-cage" system of conductors.

In a modification of this system for an ordinary building a sufficient practical approach to ideal conditions can be attained by taking advantage of the extent of metal work outside it and adding a few other conductors, so as to surround it and imitate roughly a metallic inclosure. Under expert supervision this can generally be accomplished by utilizing the rain-water pipes and gutters as part of the system.

[29] Taken from Modern Lightning Conductors, by Killingworth Hedges. The Phoenix Fire Office Rules, for the erection of lightning conductors, were drawn up after consultation between Sir Oliver Lodge, D. Sc., F. R. S., principal of the University of Birmingham; Mr. Killingworth Hedges, M. Inst. C. E., M. I. E. E., honorable secretary to the Lightning Research Committee, 1901 to 1905; and Mr. S. G. Castle Russell, M. I. E. E., electrical adviser to the Phoenix Assurance Company (Ltd.).

Joints in the pipes and gutters act more securely when bonded together or made electrically continuous. The ordinary conductors must be fixed in addition, and the whole system of pipes, etc., together with the special conductors, may advantageously be interconnected by a horizontal conductor taken round the buildings, either 2 or 3 feet above the ground level or buried in the ground.

The complete system should then be efficiently connected to earth at several places.

A building with trees adjacent to it, or dominated by a steeple or other lofty building, must not be considered as immune. A discharge is seldom solitary, along one single path; it is often an assemblage or bush of flashes, and all points in the neighborhood are liable to be struck by some of the subsidiary or accompanying discharges. Even underground cellars have been so invaded.

Rule No. 1.—CONDUCTORS

Material of Conductor.—Material should be of copper tape at least 1 by one-eighth inch, or of a stranded copper rope of not less area; no cable to be smaller than that composed of seven strands, each of one-eighth inch diameter, or of soft iron cable, properly galvanized or sheradized; the total sectional area of iron cable need not be greater than that of copper, except for chemical reasons and permanence. In inaccessible places, and atmospheres where chemical corrosion may be feared, copper should be used of larger sectional area than 1 by one-eighth inch.

Copper conductors are generally accepted as being more lasting and less subject to deterioration by atmospheric influences, etc., although iron is electrically more efficient than copper, since it carries off the discharge with less tendency to disruptive effect. Any conductor may be given a protective coat of paint—painting or otherwise coating a conductor does not detract from its efficiency.

Method of Running.—Conductors should be run in as direct a line to earth as convenient, and sharp bends and joints avoided; they should be kept a certain distance away from the walls. The object of keeping conductors a certain distance away from walls is to prevent accumulation of dirt, and to avoid sharp bends when passing over cornices, etc., but they must not be insulated from the walls.

Conductors should, as far as possible, be run in single lengths.

Conductors should be protected at earth level by galvanized iron tubing or casing carried 5 feet above the surface; this casing should be made water-tight where the conductors enter and leave.

Conductors running underground and connected to the earth plate or tubular earth should be embedded in a wooden trough filled in solid with bitumen to prevent chemical corrosion.

Vertical conductors should be connected to all the metal work on the roofs, such as rain-water pipes and gutters, metal roofs, flashings, ridgings, finials, cowls, etc. All exposed metal work on the outside of the building should form with the conductors a complete network. As far as practicable it is desirable to connect the conductors to exposed and elevated masses of metal, such as bells and metal clocks; or it may be preferred to protect clocks by providing a sufficiency of outside conductors to act as a screen, which should be interconnected and carried to a sufficient number of earth connections.

Conductors must be kept at least 12 feet from all gas pipes and from the meter, the ingoing and outgoing service gas pipes should be connected together by a short piece of metal.

All telephone wires, or any exposed system of wires entering the interior from the outside, must be provided with a special lightning guard or arrester where they enter.

Joints in Conductors.—For tape conductors all joints must be carefully soldered and made electrically and mechanically continuous, screwed together or clamped. Stranded cable conductors should be connected by lineman's joints and soldered or united by a special joint box. After the strands of the cable are twisted together, the box should be filled in with molten solder.

Rule No. 2.—ELEVATION RODS

Elevation rods should be of solid copper or galvanized iron of ample section and fixed at least 2 feet above that portion of the building to which they are attached by a sleeve joint soldered and pinned, or by means of a box joint filled with solder and pinned. In the case of chimney stacks the rod must be at least 1 foot above the highest chimney in the group which forms the stack.

The elevation rod should have three or more points which must be firmly screwed into the solid casting, or it could be united by a box containing pockets which receive the points, the whole being filled with solder.

Rule No. 3.—HOLDFASTS

Holdfasts should be of gun metal or brass for copper conductors or of malleable iron for iron conductors and let into the wall in such a manner as to support and keep the conductor away from the structure at such a distance as will avoid anything like sharp bends round cornices and projections.

Rule No. 4.—NUMBER OF CONDUCTORS AND AREA OF PROTECTION

This depends on the size of the building and the comparative heights of its structural parts. There is no special area below an elevation rod which can be considered as actually protected; so that "area of protection" really can not be defined, and no definite rule can be laid down as to the number of rods necessary to protect a building. The consideration of the extent of protection afforded must bear some relation to the value and importance of the building concerned. It should be the practice to provide at least two or more rods on any building. The best known system of protection is referred to above.

It should be noted that any chimney stack is liable to be struck; each, therefore, should have its own elevation rod connected to the nearest conductor leading to earth. Special attention should be paid to kitchen chimneys, as a column of hot air will often be selected as a path for the flash.

Rule No. 5.—EARTH CONNECTIONS, AND NUMBER

The earth connection should be made either by means of a copper plate buried in damp earth, or by the tubular earth system, or by connection to the water mains. The number of connections should be in proportion to the ground area of the building, and there are few structures where less than two are necessary; if it is thought desirable to use the modified "bird-cage" system, described heretofore, each side of the building should have its own earth. Church spires, high towers, factory chimneys, etc., having two down conductors should have two earths, which may be interconnected.

If a copper plate is used it should not be of less than 3 square feet in area and not less than one-eighth inch thick, and rectangular in shape, with saw edges and surrounded with broken coke or graphite. If coke is used, it must be thoroughly washed to eliminate any sulphur which may destroy the copper. The conductor should be firmly attached so as to make a permanent mechanical and electrical joint.

The earth connections should be kept at least 12 feet from gas mains.

The use of copper plate is not recommended unless it can be sunk into the earth at such a depth as to insure it always being in water or in moist earth.

The tubular earth system is as follows, and is recommended for use where the ground can not be disturbed for burying a plate, or where permanent moisture is at a considerable depth. A perforated pipe furnished with a steel spike is driven into the ground until it reaches moisture, and then lengthened up to the surface, to a casting which marks the position of the earth. The copper conductor is inclosed in the pipe, and carried to the bottom of the tube, which is packed with granulated carbon. A connection is made by means of an iron or lead pipe to the nearest rainwater pipe, so that a small quantity of rain is diverted to insure moisture, or a similar pipe may be opened up into a funnel shape at the surface of the ground, so that rain will enter, or water can be poured down.

Where conditions permit, connection to a water main is a satisfactory plan, provided that the main is not insulated by hydrant joints, or periodically disconnected.

Rule No. 6.—TEST AND EXAMINATION OF EARTH CONNECTIONS

The earth resistance of each of the earth connections should not exceed 5 ohms. For the purpose of testing, a special disconnection joint should be made in the conductor near the ground level, so that the earth can be tested separately from the system of the conductors on the building by disconnecting the joint.

A test and examination should be made once annually by a competent expert.

Rule No. 7.—SPECIAL RISKS

Churches.—In the case of churches or building having long roofs, and where more than one conductor is used, the down rods should be connected together by a horizontal rod (fitted with aigrettes, say from 20 to 30 feet apart) running along the ridge or flat of the roof, and held about 3 inches away by holdfasts. From this rod subsidiary conductors should be run to earth. All exposed and elevated masses of metal, such as church bells and metal clocks, should be connected with the conductors.

Factory Chimneys.—In the case of factory chimneys the elevation rod should take the form of a circular band of metal around the top of the shaft, preferably below the actual outlet and furnished with long spikes. The points should be fixed at an angle of about 45°, point outward; or an arch of metal, provided with points, may be fixed across the mouth of the chimney.

Two vertical conductors at least, kept away from the brick wall by holdfasts, should be carried down to a thorough "earth"; and if there are two earths, as is preferable, they should be connected by a metal band.

If a factory chimney has an internal metal shaft part of the way up, this should be well earthed at the bottom, but should not be connected to or form part of the lightning conductor system which is intended to receive and carry off the flash.

After a church or other uninhabited building has been struck by a flash, or whenever there has been a flash in the near neighborhood, it should be carefully examined and attended to for some time to see that no actual ignition of gas has occurred, owing to the puncture of a compo pipe by a residual spark causing and igniting an accidental leak; for such a trifling flame, if unattended to, may spread.

Every building in the immediate neighborhood of a flash is liable to such small residual sparks; they can occur even between well-earthed systems such as gas and hot-water pipes, or where a gas pipe is crossed by a bell wire.

FLAGSTAFFS ON BUILDINGS.—Flagstaffs on buildings should be provided with their own conductors efficiently connected to earth, or be connected to the system of lightning conductors erected on the same building.

CHURCH SPIRES AND LOFTY TOWERS.—These should preferably be protected by two conductors.

RULES FOR THE ERECTION OF LIGHTNING CONDUCTORS, AS ISSUED BY THE LIGHTNING ROD CONFERENCE IN 1882; WITH OBSERVATIONS THEREON BY THE LIGHTNING RESEARCH COMMITTEE,[30] 1905

LIGHTNING ROD RULES, 1882

POINTS.—The point of the upper terminal should not be sharp, not sharper than a cone of which the height is equal to the radius of its base. But a foot lower down a copper ring should be screwed and soldered on to the upper terminal, in which ring should be fixed three or four sharp copper points, each about 6 inches long. It is desirable that these points be so platinized, gilded, or nickel plated as to resist oxidation.

LIGHTNING RESEARCH COMMITTEE'S OBSERVATIONS, 1905.

It is not necessary to incur the expense of platinizing, gilding, or electroplating. It is desirable to have three or more points beside the upper terminal, which can also be pointed; these points must not be attached by screwing alone, and the rod should be solid and not tubular.

UPPER TERMINALS.—The number of conductors or points to be specified will depend upon the size of the building, the material of which it is constructed, and the comparative height of the several parts. No general rule can be given for this; but the architect must be guided by the directions given. He must, however, bear in mind that even ordinary chimney stacks, when exposed, should be protected by short terminals connected to the nearest rod, inasmuch as accidents often occur owing to the good conducting power of the heated air and soot in the chimney.

This is dealt with below in suggestion 3.

INSULATORS.—The rod is not to be kept from the building by glass or other insulators, but attached to it by metal fastenings.

This regulation stands.

FIXING.—Rods should preferentially be taken down the side of the building which is most exposed to rain. They should be held firmly, but the holdfast should not be driven in so tightly as to pinch the rod, or prevent the contraction and expansion produced by changes of temperature.

In most cases it would be advantageous to support the rods by holdfasts (which should be of the same metal as the conductor) in such a manner as to avoid all sharp angles. The vertical rods should be carried a certain distance away from the wall to prevent dirt accumu-

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[30] Report of the Lightning Research Committee, Journal of the Royal Institute of British Architects, 3d series, vol. 12, 1904–5, p. 414.

lating, and also to do away with the necessity of their being run round projecting masonry or brickwork.

FACTORY CHIMNEYS.—These should have a copper band round the top, and stout, sharp, copper points, each about 1 foot long, at intervals of 2 or 3 feet throughout the circumference, and the rod should be connected with all bands and metallic masses in or near the chimney. Oxidation of the points must be carefully guarded against.

As an alternative the rods above the band might with advantage be curved into an arch provided with three or four points. It is preferable that there should be two lightning rods from the band carried down to earth in the manner previously described. Oxidation of the points does not matter.

ORNAMENTAL IRONWORK.—All vanes, finals, ridge ironwork, etc., should be connected with the conductor, and it is not absolutely necessary to use any other point than that afforded by such ornamental ironwork, provided the connection be perfect and the mass of ironwork considerable. As, however, there is risk of derangement through repairs, it is safer to have an independent upper terminal.

Such ironwork should be connected as indicated below in suggestion 3. In the case of a long line of metal ridging a single main vertical rod is not sufficient, but each end of the ridging should be directly connected to earth by a rod. Where the ridge is nonmetallic a horizontal conductor (which need not be of large sectional area) should be run at a short distance above the ridge and be similarly connected to earth.

MATERIAL FOR ROD.—Copper, weighing not less than 6 ounces per foot run, and the conductivity of which is not less than 90 per cent of that of pure copper, either in the form of tape or rope of stout wires—no individual wire being less than No. 12 B. W. G. Iron may be used, but should not weight less than 2¼ pounds per foot run.

The dimensions given still hold good for main conductors. Subsidiary conductors for connecting metal ridging, etc., to earth may with advantage be of iron and of a smaller gauge, such as No. 4 S. W. G. galvanized iron. The conductivity of the copper used is absolutely unimportant, except that high conductivity increases the surges and side flashes, and therefore is positively objectionable. It is for that reason that iron is so much better.

JOINTS.—Although electricity of high tension will jump across bad joints, they diminish the efficacy of the conductor; therefore every joint, besides being well cleaned, screwed, scarfed, or riveted, should be thoroughly soldered.

Joints should be held together mechanically as well as connected electrically, and should be protected from the action of the air, especially in cities.

PROTECTION.—Copper rods to the height of 10 feet above the ground should be protected from injury and theft by being inclosed in an iron pipe reaching some distance into the ground.

PAINTING.—Iron rods, whether galvanized or not, should be painted; copper ones may be painted or not according to architectural requirements.

CURVATURE.—The rod should not be bent abruptly round sharp corners. In no case should the length of the rod between two points be more than half as long again as the straight line joining them. Where a string course or other projecting stonework will admit of it, the rod may be carried straight through, instead of round the projection. In such a case the hole should be large enough to allow the conductor to pass freely, and allow for expansion, etc.

The straighter the run the better. Although in some cases it may be necessary to take the rod through the projection, it is better to run outside, keeping it away from the structure by means of holdfasts, as described above.

Extensive masses of metal.—As far as practicable it is desirable that the conductor be connected to extensive masses of metal, such as hot-water pipes, etc., both internal and external; but it should be kept away from all soft metal pipes, and from internal gas pipes of every kind. Church bells inside well-protected spires need not be connected.

It is advisable to connect church bells and turret clocks with the conductors.

Earth connection.—It is essential that the lower extremity of the conductor be buried in permanently damp soil; hence proximity to rain-water pipes and to drains, is desirable. It is a very good plan to make the conductor bifurcate close below the surface of the ground, and adopt two of the following methods for securing the escape of lightning into the earth. A strip of copper tape may be led from the bottom of the rod to the nearest gas or water *main*—not merely to a lead pipe—and be soldered to it; or a tape may be soldered to a sheet of copper 3 feet by 3 feet and one-sixteenth inch thick, buried in permanently wet earth, and surrounded by cinders or coke or many yards of the tape may be laid in a trench filled with coke, taking care that the surfaces of copper are, as in the previous cases, not less than 18 square feet. Where iron is used for the rod, a galvanized-iron plate of similar dimensions should be employed.

The use of cinders or coke appears to be questionable owing to the chemical or electrolytic effect on copper or iron. Charcoal or pulverized carbon (such as ends of arc-light rods) is better. A tubular earth consisting of a perforated steel spike driven tightly into moist ground and lengthened up to the surface, the conductor reaching to the bottom and being packed with granulated charcoal, gives as much effective area as a plate of larger surface and can easily be kept moist by connecting it to the nearest rain-water pipe. The resistance of a tubular earth on this plan should be very low and practically constant.

Inspection.—Before giving his final certificate the architect should have the conductor satisfactorily examined and tested by a qualified person, as injury to it often occurs up to the latest period of the works from accidental causes, and often from the carelessness of workmen.

Inspection may be considered under two heads:

A. The conductor itself.

B. The earth connection.

A. Joints in a series of conductors should be as few as possible. As a rule they should only be necessary where the vertical and horizontal conductors are connected, and the main conductors themselves should always be continuous and without artificial joints. Connections between the vertical and horizontal conductors should always be in places readily accessible for inspection; visible continuity suffices for the remainder of circuit. The electrical testing of the whole circuit is difficult, and needless.

B. The electrical testing of the earth can in simple cases be readily effected. In complex cases, where conductors are very numerous, tests can be effected by the provision of test clamps of a suitable design.

Collieries.—Undoubted evidence exists of the explosion of fire damp in collieries through sparks from atmospheric electricity being led into the mine by the wire ropes of the shaft and the iron rails of the galleries. Hence the headgear of all shafts should be protected by proper lighting conductors.

The investigations of the Committee warrant them in putting forward the following practical suggestions:

1. Two main lightning rods, one on each side, should be provided, extending from the top of each tower, spire, or high chimney stack by the most direct course to earth.

2. Horizontal conductors should connect all the vertical rods (*a*) along the ridge or any other suitable position on the roof; (*b*) at or near the ground line.

3. The upper horizontal conductor should be fitted with aigrettes or points at intervals of 20 or 30 feet.

4. Short vertical rods should be erected along minor pinnacles and connected with the upper horizontal conductor.

5. All roof metals, such as finials, ridging, rain-water and ventilating pipes, metal cowls, lead flashing, gutters, etc., should be connected to the horizontal conductors.

6. All large masses of metal in the building should be connected to earth either directly or by means of the lower horizontal conductor.

7. Where roofs are partially or wholly metal lined they should be connected to earth by means of vertical rods at several points.

8. Gas pipes should be kept as far away as possible from the positions occupied by lightning conductors, and as an additional protection the service mains to the gas meter should be metallically connected with house services leading from the meter.

B. GERMANY

RULES REGARDING THE PROTECTION OF BUILDINGS AGAINST LIGHTNING

[Issued by the Elektrotechnischen Verein and accepted at the yearly meetings of the Verband Deutscher Elektrotechniker in 1901 and 1913.]

1. Lightning rods afford protection to buildings and their contents against damage or fire by lightning. Their increased use should therefore be encouraged by simplifying their installation and lowering their cost.

2. A lightning-rod system consists of (*a*) aerial terminals or receivers for the lightning stroke, (*b*) conductors, and (*c*) earth connections.

(*a*) Aerial terminals or receivers should consist of projecting metallic bodies, surfaces, or conductors. Those points at which lightning is known by experience to strike, such as tops of towers, gables, roof ridges, chimneys, and other high parts of the building, should be converted into aerial terminals or have aerial terminals installed upon them, depending upon whether or not they are of metal which would permit of such an arrangement.

(*b*) The conductors which form the metallic connection between the aerial terminals and the earth connections should go around the building, the roof especially, and if possible on all sides, and then be led to the earth connections by the shortest path, avoiding as much as possible all sharp curves.

(*c*) The earth connections should consist of metallic conductors connected to the lower ends of the conductors on the buildings and should descend into the ground and extend as far as practicable, preference being given to places where the earth is damp.

3. The metallic parts of buildings and masses of metal in and upon them—especially those in contact with the earth and offering large surfaces (such as pipes)—should, as far as practicable, be connected together and to the conductors.[31]

Special aerial terminals and conductors are rendered unnecessary if these metallic parts of the building comply with the requirements mentioned in paragraphs 2, 5,

[31] Lightning rods which are not connected to such metallic masses, such as pipes, lines, etc., are always incomplete since lightning sometimes flashes over to the latter. The words "as far as practicable" apply to those cases in which such connections may be permitted only under restrictions or not at all, due to conditions existing at the particular place in question.

and 6. Both for perfecting the system and for decreasing cost, the question of utilizing pipes as conductors should be considered when erecting new buildings, making use also as much as possible of all the metallic parts of the building for protective purposes.

4. The protection afforded by a lightning-rod system is the greater the more completely all prominent parts of the building are supplied with aerial terminals, the larger the number of aerial terminals and conductors, and the greater the extent of the earth connections. As a rule extended metallic parts of buildings, especially those which lead from the higher points to earth, contribute to the lessening of damage by lightning, even if these parts have been installed without regard to their use in protection against lightning. There is no increase of danger to be anticipated because of the incompleteness of a lightning-rod system.

5. Interconnected conductors of iron should not be less than 50 square mm in cross section; conductors which are designed to carry an entire lightning stroke should not be less than 100 square mm in cross section. If the conductors are of copper one-half of this cross section is sufficient; for zinc about one and one-half, and for lead about three times the cross section of iron should be used. The form of conductors should be such as to resist weathering or corroding, and should be fastened firmly to the building.

6. Connections of and to conductors should be permanent, strong, of good electrical contact, and of large surface where possible. Unwelded or unsoldered joints should possess metallic contact surfaces of not less than 10 square centimeters.

7. The lightning rods should be periodically inspected in order that their good condition may be preserved; and when alterations are made in the buildings the necessity of alteration in the lightning-rod system should be considered.

C. UNITED STATES

SUGGESTIONS OF THE NATIONAL BOARD OF FIRE UNDERWRITERS FOR PROTECTION AGAINST LIGHTNING AS RECOMMENDED BY THE NATIONAL FIRE PROTECTION ASSOCIATION (EDITION OF 1913)

Protection against lightning is usually advisable on country buildings, on isolated buildings, and on all buildings wherever located having elevated features such as tall chimneys, steeples, high-peaked or gabled roofs, and flagpoles.

Since the amount of protection which any building should have will depend upon its location, construction, nature of its occupancy, and the value of the building as compared with the expense necessary to provide the protection, definite rules can not be laid down for the installation of lightning conductors, but the following general suggestions should, if carried out, give under most conditions reasonable protection.

The ordinary conditions causing a lightning discharge is a cloud charged with electricity at a greatly different potential from that of the earth. The difference of potential is finally sufficient to "break down" the stratum of air between earth and cloud, and an electrical discharge takes place. The resistance of the air stratum being generally less between cloud and tops of buildings and other structures than between cloud and earth, such high points take the discharge, and unless some less resistive path is provided from these points to the ground than the structure to be protected, the lightning will follow the next best course to earth, generally causing damage to the structure and frequently starting a fire. It is also of importance to note that the discharge leaves a column of heated air between earth and cloud. This hot-air column may be blown in one or another direction and very likely become the path of a second discharge, since it has less resistance than the surrounding cooler air. This may account for lightning striking a structure below the high points.

It is therefore desirable to so locate the conductors forming the lightning protection that the lightning will strike these and be carried to earth instead of tearing through the structure on its way to ground. Such an arrangement of conductors suggests an enclosing cage with the bars, of course, considerably separated. The idea of protection is, therefore, a metallic cage with air-terminal projections at the high points of the structure and the whole protecting cage thoroughly grounded. Just what material is employed is not of great importance provided it has good electrical carrying capacity, is strong, can be bent and jointed readily, and is not liable to be seriously affected by corrosion. Undoubtedly copper in tape form or ordinary galvanized-iron pipe best meets these conditions.

Just how far apart the conductors should be will depend very considerably upon conditions, and no general rule can be given for the number of square feet of ground area protected by one rod which will safely cover all cases. Since in addition to the high points the most exposed parts of a structure are the outposts and projections, extra protection is needed here, while a much wider spacing of rods might be sufficient along the sides of the structure.

In general, all-metal buildings, metal chimneys or stacks need only to be grounded.

GENERAL SUGGESTIONS APPLYING TO ALL STRUCTURES

(*a*) Conductors.—*Note.*—Either copper or iron is satisfactory for conductors. One advantage of iron over copper is its higher fusing point, but iron should not be used in locations difficult of access where corrosion is likely or possible, owing to the necessity of frequent painting to guard against such corrosion.

1. Conductors when made of copper to be soft-drawn in the form of either tape or stranded cable. Except as noted below, the conductor in each case to weigh not less than 6 ounces per foot. Where cable form is used, no single copper wire to be less than No. 12 B. & S. gauge, while if of tape form the thickness to be not less than three thirty-seconds of an inch.

With copper conductors having a total weight of 6 ounces per foot, and the above dimensions, the cable will contain 19 No. 12 wires and the tape will be 1 inch wide by three thirty-seconds of an inch thick.

When used on residences, barns, stables, stores, and similar buildings where the maximum height of any point does not exceed 60 feet, and where corrosion is not liable to occur to any extent, copper cable to weigh not less than 3 ounces per foot, no single wire being less than 0.046 inch in diameter.

2. Conductors when made of iron to be in the form of either heavy tape or pipe. The tape conductor to weigh not less than 1½ pounds per foot and to be not less than three thirty-seconds of an inch thick. If pipe is used, the standard weight of three-fourths-inch pipe would be satisfactory. Iron used in any form should be thoroughly galvanized to prevent corrosion, and may also be painted if desired.

Heavy tape is specified to guard against the use of thin sheet which would be more easily destroyed by corrosion. Pipe is specified as an alternative for the tape as it is cheaper, is readily obtainable, and can be easily installed using the ordinary pipe fittings. The fittings should, of course, be galvanized as well as the pipe, and all pipe ends and unused outlets on fittings should be tightly plugged in order to prevent the entrance of moisture inside the pipes.

3. Conductors to have as few joints as possible, these to be mechanically and electrically secured and to be protected from corrosion.

It is essential that the conductors be continuous and, therefore, the fewer the joints and the better these are protected from corrosion, the less chance of crippling the protection due to a break in the conductors.

4. Conductors never to be insulated but to be fastened securely in place, suitable allowance being made for expansion, by clamps of same material as conductor, the vertical rods being carried a sufficient distance from the wall to avoid sharp bends around projecting masonry or brickwork. In all cases as straight a run as possible should be provided and the conductors should incline downward. The conductors should never be run through iron pipes.

Sharp bends and loops in an upward direction are liable to cause the lightning discharge to leave the conductors at these points, and as these side flashes may be dangerous, care should be taken that the conductors should run as straight as possible. Since the effect of the lightning discharge in the conductors is practically the same as that produced by an alternating current, it is obvious that the conductors should not be run through iron pipes, which would tend to choke back the discharge due to induction in the pipe.

5. Conductors to be run as far as practicable from interior piping.

If the conductors are run too near the interior pipe system, there is a chance that the discharge may jump from the conductors to the pipe, and in doing so, start a fire. The best way to avoid this is evidently to keep the two systems as far apart as practicable.

(*b*) Air Terminals.—To be solid, not less than three-fourth inch in diameter except on residences, barns, stables, stores, and similar buildings where they may be of tubing not less than five-eights inch in diameter with wall thickness not less than 0.031 inch. Terminals to extend not less than 18 inches above the point protected.

The distance of 18 inches specified is the minimum for smaller buildings. On larger buildings it is desirable to have the rods longer.

(*c*) Connections to Metal Work of Structures.—1. All exterior metal work, such as metal roofs, gutters, ventilators, railings, chimney hoods, etc., to be connected with the lightning-rod system below the line of the metal work itself or to be separately grounded by regular conductors.

Unless all such metal work is well grounded the discharge is liable to jump from this part to other conducting parts and possibly set fire to intervening combustible material.

2. All interior masses of metal such as girders, beams, water piping, and any structural iron or steel, though under no consideration gas piping, is to be securely connected to the system at their highest and lowest points, the connecting bonds being the regular conductor.

This suggestion is made for the same reasons as that regarding exterior metal work. (See sec. c–1 preceding.)

The electrical resistance of pipe joints may occasionally be sufficient to permit a high-voltage current melting the pipe at that point, which would be especially dangerous in case of gas pipes, for the arc would probably at the same time ignite the escaping gas. The same result might be obtained by arcing between the gas pipe and other conductors which might be carrying a lightning discharge. It is therefore best not to connect gas piping to the lightning-rod system, as this might be the means of leading the discharge on to these pipes where otherwise they might not be affected.

It, however, would be advisable to securely bond around the gas meter the iron pipe on both sides on the meter, being careful to make secure electrical connections between the pipe and the bond.

(*d*) Grounding.—*Note.*—A permanent and reliable ground is absolutely essential, and by far the best ground can usually be secured by connection to underground metallic water piping. When this is impracticable, ground plates, driven pipes, or the equivalent, are recommended.

1. Connection to piping to be made preferably by soldering the conductor into a brass plug and forcibly screwing the plug into the pipe fitting, or, when the pipes are cast iron, into a hole tapped into the pipe itself; or, by sweating the conductor into a lug attached to an approved clamp and firmly bolting the clamp to the pipe after the rust and scales have been removed.

In the case of a farm building having a well outside and a pump-suction pipe running to the building, a reasonably good ground may be obtained by connecting the conductor to the pipe, provided the pipe at some point is in earth below permanent moisture level.

The idea is to get as good and permanent connection to the underground piping as possible, and one that will best withstand the effects of corrosion. It is desirable to connect to two or more lengths of pipe in order to guard against crippling the protection by injury to or deterioration of a single connection.

2. Connection to ground plates to be made by riveting and soldering, and the connection to be thoroughly protected against corrosion by painting. The ground plates to be of copper and not less than No. 16 Stubb gauge, about 3 feet square, and buried below the permanent moisture level with about 2 feet of crushed coke or charcoal above and below it.

A heavy iron casting having a superficial area of at least 12 square feet could be used in place of the plate. The conductor should be connected to the casting by riveting and soldering, and the casting buried the same as the ground plate above described.

3. Connection to driven pipe to be made by soldering the conductor into a brass plug and forcibly screwing the plug into a couple on the upper end of the pipe. The lower end of the pipe to be well below permanent moisture level.

A ground plate or a driven pipe properly put into the ground is undoubtedly the most satisfactory alternative for the underground water-pipe system, but is not advised when the pipe-system ground is available.

TALL CHIMNEYS, STACKS, STEEPLES, AND SIMILAR STRUCTURES

(*a*) Two or more main lightning rods equally spaced about the structure to be provided, extending from the top by the most direct course to the ground.

The proper number of rods in any given case will vary somewhat with the conditions. For example, a flagpole would not require more than one rod, while chimneys 150 feet or more high should have one rod for each 50 feet of height. The higher the chimney the greater the cross-sectional area at any given distance from the ground, and the additional rods are desired in order not to expose too great an unprotected vertical area to a discharge.

(*b*) To have a band of copper or iron not smaller than the lightning rods around the top with air terminals securely attached thereto extending 3 feet above the highest point. The air terminals to be placed at intervals not exceeding 4 to 6 feet around the circumference of the band.

(*c*) Additional bands to be provided around the structure at or near the ground line and at intervals of 25 to 50 feet, all such bands being securely connected to the lightning rods.

In the same way that additional vertical rods reduce the size of the unprotected vertical areas, these additional bands limit these areas horizontally. The bands also serve to connect the rods together at frequent intervals, so that an accidental break in one rod is not liable to be as serious as might otherwise be the case. In other words, the vertical rods are thus made to connect in combination rather than separately.

STRUCTURES OTHER THAN CHIMNEYS, STEEPLES, ETC.

(*a*) Two or more lightning rods should be provided extending from the top by the most direct course to the ground, so spaced that they will not be over 50 to 75 feet apart.

The proper number of rods and their exact spacing will depend very largely upon the conditions, such as shape of structure, the exposure with reference to both severity of lightning storms and direction from which these storms usually come. In general, the most exposed parts of a structure are the outposts and projections, and here it would be advisable to place the rods somewhat nearer together than along the sides of the structure. In general, it would not be advisable to carry the rods through the center of a structure, for if for any reason it becomes broken it would be the direct means of carrying the lightning to a point inside the structure where it would be almost sure to set fire.

(*b*) Horizontal conductors to be provided connecting the vertical rods along the ridge or any suitable position on the roof and at or near the ground.

The horizontal bonding of the vertical conductors is desirable for much the same reasons as given for the horizontal bands around chimneys, and these horizontal conductors serve to tie the system together, thus carrying out the idea of a protecting cage. It is considered important that at least the upper and lower ends of the vertical rods be thus connected, and, in general, intermediate bonding would not be necessary except possible for very high structures.

(*c*) The upper horizontal conductor should be provided with air terminals at intervals of 20 to 30 feet, and in addition air terminals, connected with the horizontal conductor to be provided for gables or other projections above the top of the main structure. Air terminals should in all cases extend well above roofs or chimneys and be firmly secured in an upright position.

Air terminals assist in diverting the lightning discharge to the lightning-rod system, and therefore it is an advantage to have them placed at fairly frequent intervals.

(*d*) Where trees stand so close to a building that branches overhang or approach very close to the roof, a conductor with proper earth terminal to extend along the trunk of each of several such trees to the highest branch top fastened by a band around the branch or trunk, would probably give all necessary protection under average conditions. It, however, would be advisable to connect these rods together at the bottom by a substantial conductor laid underground.

Care should be taken to protect as far as possible this underground bond connection against corrosion. Probably well-galvanized three-fourths-inch iron pipe, or copper in tape form would best serve the purpose.

The above method might be used for the protection of trees wherever located.

SUGGESTED LIGHTNING PROTECTION FOR OIL TANKS BY THE LOUISIANA FIRE PREVENTION BUREAU

The following recommendations apply in general to all large tanks located above ground such as are used for the storage of crude petroleum or fuel oil, and are intended to describe an acceptable method of placing on the tanks a system of conductors which will insure a low-resistance path, other than the tank or its connections, for a lightning discharge to the earth.

Materials used and methods employed should, where not specified in detail herein, conform to the Suggestions of the National Bureau of Fire Underwriters for Protection Against Lightning, a copy of which suggestions will be furnished on request.

Conductors used should be of soft-drawn copper, weighing not less than 6 ounces per foot. It is suggested that a conductor be placed on and around the top of the tank as near the edges as possible, the ends jointed together to form a circle. Two other conductors should be passed over the top through the center and at right angles to each other, the four ends carried vertically down the sides of the tank into the earth, there terminating in a satisfactory and permanent ground connection. It is absolutely essential that a permanent and reliable ground be secured, and connection to an underground piping system is by far the best that can usually be obtained. Where this is impracticable ground plates or equivalent are recommended. Ground plates or other ground terminals must be well below the level to which oil has penetrated, and in no case less than 15 feet below the surface. Plans for obtaining ground connections should be submitted for approval before being carried out.

Wherever conductors cross each other they should be firmly connected together, and a vertical air terminal of heavier copper and not less than 5 feet high should be placed at each crossing point and connected to both conductors; also an air terminal should extend 3 feet above the vent pipe, or any other vertically projecting portion or attachment of the tank, and connected by the shortest line to the conductors on the top of the tank; all conductors to have a downward trend where possible. The vent pipe should preferably be carried down into the ground and terminate some distance away, not less than twice the diameter of the tank, and its outlet covered with copper gauze. If this can not be done, the vent pipe should terminate in a T fitting with short pieces of pipe extending in each direction and an elbow fitting placed on each end so as to give the horizontal arms a downward turn, the end of each arm being covered with copper gauze. The object of this arrangement is to distribute the column of vapor or gas from the vent pipe, as it is thought that this column of gas tends to attract a lightning discharge. The copper gauze is intended to prevent the firing of the contents of the tank by a discharge.

In installing the conductors there should be as few joints as possible, these and all connections to be mechanically and electrically secured and to be protected from corrosion.

Conductors should be firmly attached to the surface of the tank by means of clamps of same material as conductor, making secure mechanical and electrical connection, the distance between supports to be not more than 4 feet. Care should be taken to avoid all sharp kinks or bends, and vertical rods should be carried a sufficient distance from the side to avoid a sharp bend or curve where carried from the side to the roof of the tank. Conductors should never be run through iron pipes.

CLAUSES REGARDING PROTECTION AGAINST LIGHTNING FROM BUILDING AND CHIMNEY CONTRACTS OF THE UNITED STATES NAVY DEPARTMENT

LIGHTNING PROTECTION FOR BUILDINGS

Lightning protection shall consist of ½-inch copper cables, seven strands of seven wires 0.057068 inch diameter, secured to walls and roof in an approved manner. All sharp junction angles shall be avoided, and all splices shall be long and soldered. One point shall be placed at each end of ridge and one at each ventilator. Points at ventilators shall be secured to the side of same in an approved manner. Points shall extend 36 inches above tops of ventilators or apex of roof, as the case may be. All points shall be connected to main cable along apex or roof, ventilator points being double or Y connected. Main cable shall be electrically connected to steel trusses at two points. Aerials shall consist of ¼-inch galvanized-iron pipe and couplings topped with ½-inch galvanized wrought-iron point 6 inches long. Grounding shall be made through four cables grounded where the rain leaders discharge. The two intermediate cables shall be double or Y connected to main cable. Grounds shall be made as follows: Separate the strands of the cable for a distance of about 1 foot. Copper rivet and solder to the end of each strand a sheet-copper plate 0.05 inch thick, 6 inches wide, and 36 inches long. Assemble the plates edgewise, radially, and pack in about 6 inches broken coke, walnut size, thoroughly wetted and tamped. Grounds shall be 4 feet below finished grade unless rock is encountered at a less depth. All work under this head shall be in general accordance with similar work already installed at the magazine and shall be subject to approval of the officer in charge.

CHIMNEYS

Lightning Conductors.—The chimney shall be protected against lightning by two conductors terminating at the top of the chimney in six points 6 feet long and connected at the ground with two well-grounded copper plates of ample dimensions. The two cables for lightning conductors shall each be composed of 49 pure-copper wires, 72 mils in diameter, divided into seven strands with the strands twisted together to form cables ⅝ inch in diameter. The riser or vertical portions of the two conductor cables shall be secured to the outside of the chimney; two horizontal circles made of the same kind of cable as the main conductors shall be permanently secured to the chimney, the upper one at an elevation near the top of the chimney and the lower one about 10 feet above the foundation; the risers shall be permanently secured to the chimney.

Conductor Grounds.—The contractor shall furnish, place, and connect a copper ground plate for each of the two conductors, the plates to be of ample proportions and be efficiently connected and grounded. The elevation of mean low water is 25 feet below the top of the chimney foundation.

Conductor Points.—The upper horizontal conductor circle shall be fitted with six equally spaced vertical point rods, each ⅝ inch in diameter, 6 feet long, with tips. The tips shall each be of hard bronze, 2 feet in length, the upper foot to be covered with pure platinum. All splices and contacts shall be hard soldered in a manner to secure most perfect contact.

Conductor Fasteners.—Conductor points, circles, and those portions of the risers which are elsewhere specified to be permanently secured to the chimney shall be fastened in place with Bajohr's patent or equal bronze anchor fastenings, the fastenings to be inserted in the joints of the masonry work during the construction of the chimney and be at intervals of not over 18 inches for the horizontal and 5 feet for the vertical portions, respectively.

Appendix II.—FIRST AID TO PERSONS INJURED BY LIGHTNING

The injuries inflicted by lightning consist of electric shocks of greater or less severity which may be combined with burns, and in some cases tearing of the flesh, apparently by an explosive action of the discharge. First-aid treatment for injuries by lightning is the same as that for other electric shocks and burns. The following paragraphs describing the essentials of first-aid treatment for persons who have been subjected to electric shocks and burns have been taken from the American Red Cross Abridged Textbook on First Aid, by Maj. Charles Lynch, Medical Corps, United States Army:

SYMPTOMS OF ELECTRIC SHOCK

Sudden loss of consciousness when the electrical current passes through the body.

Shallow breathing and weak pulse.

Burns of parts of the body are common. Little difficulty should be experienced in making out cause of injury.

HOW TO TREAT PATIENT

Many cases of electric shock from powerful currents will be hopeless from the beginning. It is impossible to tell this at first, however, and in every case, therefore, an attempt should be made to save the life of the patient by prompt treatment.

Send for a doctor.

Loosen clothing around neck, chest, and abdomen. Place the patient on his back with a rolled-up coat, a small log, or some other object of the same shape under the shoulders so as to throw the chest up. Press on the left chest and upper part of the abdomen about 20 times per minute. Pressing down firmly, then taking off pressure, and then applying it again. This stimulates the heart, as well as helps to start breathing. Pull out tongue by grasping it with dry cloth. Have some one else hold it out. Or if alone, if possible, tie in this position with a bandage or rubber over the tongue and under the jaw. The reason for pulling the tongue forward is because in an unconscious person it is likely to fall back and block the windpipe. Perform artificial respiration. The Sylvester method is one of the best. Kneel just above patient's head, catch both his arms just below the elbows. Draw the arms outward and upward gently and steadily and hold them as far as they will go above head for about two seconds. This motion opens and expands the chest to the greatest possible extent. This is due to the fact that certain muscles are attached to both arms and ribs, and when the arms are raised these muscles raise the ribs and so enlarge the chest. Then bring the arms down till the elbows press against the chest; a little pressure will diminish the size of the elastic chest as much as possible. Do this for about two seconds. Continue these motions about 15 times per minute. Keep this up till the patient begins to breathe himself. Artificial respiration when done properly is hard work for the operator and he should be relived by some one else as soon as he grows tired.

Another excellent method of artificial respiration is called the prone pressure method. The patient lies face down. The operator kneels by his side, places his hands across the lowest ribs and swings his body forward and backward so as to allow his weight alternately to fall vertically on the wrists and to be removed; in this way hardly any muscular exertion is required. The size of the chest being diminished forces the air from the lungs. The elastic chest then springs back and the air enters the lungs. The rate is 15 per minute.

Artificial respiration should be kept up for at least an hour. Ammonia on a sponge or handkerchief put under but not on the patient's nose will help revive him. At the same time that one or two persons are performing artificial respiration, without interfering with them, others should cover the patient with a dry coat or blankets. As soon as the patient begins to breathe himself, but not before, his limbs should be well rubbed toward the heart under the blankets. This will help to restore the circulation.

When the patient is partially restored, he may have a chill and vomit. If he vomits while on his back, he must be turned on his right side so that the vomited matter will not enter the windpipe. He should afterwards be put to bed well covered and surrounded with hot bottles. The windows should be opened so that he may have plenty of air. After the danger is over the patient should be allowed to sleep quietly. He will feel very nervous and shaken for a time and should be given absolute rest till he recovers from this condition. No food except hot beef tea should be given for several hours. Hot coffee, however, is useful as soon as the patient can swallow and retain it. It is possible for those who have received an electric shock which does not render them unconscious to perform artificial respiration of a sort on themselves and so to recover without further treatment. This is done by raising the upper extremities and lowering them again and again while taking deep breaths.

WARNING

If the breathing stops at any time after it has begun, you must immediately start again with artificial respiration.

BURNS AND SCALDS

Burns result from exposure of the body to dry heat, such as a fire, while scalds are produced by moist heat in the form of hot water, steam, etc. With either, the injury may be confined to the skin alone or it may extend deeper. With burns all the tissues of the body may be charred down to the bone and with scalds all the tissues may be actually cooked. With either the danger will depend upon the depth, extent, and part injured, as well as on the age of the injured person. Both burns and scalds of the throat and windpipe are especially dangerous, as the swelling of the injured part is likely to result in suffocation.

PUTTING OUT FIRES

A fire almost anywhere may be easily put out when it starts, whereas a very few moments' delay may result in so big a fire that nothing can be done to subdue it until it has burned everything inflammable within reach. It is clear, therefore, that everyone should act promptly in case of fire.

At first a fire may be smothered by a few buckets of water or by throwing blankets or woolen clothing upon it. Sand, ashes, or dirt will all quickly smother a fire. One of these should always be used instead of water on burning oil, as water will spread the oil and the fire. Anything hanging should, when possible, be pulled down before attempting to smother the fire in it. A bucket brigade will often prove valuable in putting out a fire. This should consist of two lines of men from the nearest water supply to the fire. The men in one line pass buckets, pitchers, or anything else that will hold water from one to another till the last man throws the water on the fire. He returns the buckets to the water supply by the other line. Remember that a draft will fan a fire, and therefore keep everything closed as much as possible to prevent drafts.

RESCUE OF PERSONS AT FIRES

While searching through a burning place it will be best to tie a wet handkerchief or cloth over the nose and mouth. Remember that the air within 6 inches of the floor is free from smoke, so when unable to breathe crawl along the floor with the head low, dragging anyone you have rescued behind you. Crawl backward in the same way down a staircase or any slope.

EXTINGUISHING BURNING CLOTHING

If your own clothing catches on fire when you are alone, do not run for help, as this this will fan the flames and make them burn fiercer.

Lie down on the floor and roll up as tightly as possible in a rug, shawl, overcoat, blanket, or other woolen cloth, leaving only the head out. If nothing can be obtained in which to wrap up, lie down and roll over slowly, at the same time beat out the fire with the hands. If another person's clothing catches fire, throw him to the ground and smother the fire with a coat, blanket, rug, or the like.

SYMPTOMS OF BURNS AND SCALDS

Severe burning pain. Depending on depth of injury: Reddening of skin; formation of blisters, or destruction of the skin and some of the tissues beneath it. Shock.

TREATMENT

When the skin is simply reddened: Exclude air by a thin paste made with water and bicarbonate of soda (baking, not washing soda), starch, or flour. Ordinary vaseline or carbolized vaseline, olive or castor oil, and fresh lard or cream are all good. One of the substances mentioned should be smeared over the burned part and on a cloth used to cover it. A light bandage should be put on to hold this dressing in place. The services of a doctor will hardly be required for such injuries.

When blisters have formed: Treatment may be the same, but if the blistering is very extensive it will be best to show this injury to a doctor.

Destruction of the skin and some of the tissues beneath it: Deep burns require prompt attention from a physician. Pending his arrival they may be treated by the application of the dressing which has been described or like an open wound. A specially valuable dressing material for such burns, or in fact for all burns, is picric acid gauze, which is applied in the form of a compress, which should be bandaged in place like any other compress.

Besides the burns which have been described, burns are frequently caused by strong acid and alkalies. The symptoms of burns by acids and alkalies are the same as of burns caused by heat.

With either, wash off as quickly as possible; best under a water tap.

Acids: While washing injury, have limewater procured or make a mixture of baking soda and water or get soapsuds and apply freely. If acid has entered the eye, wash it as quickly as possible with water and then with limewater.

Alkalies: Wash in same way as with acid burns. Neutralize with vinegar, lemon juice, or hard cider. Lime burns of the eye should be washed out with a weak solution of vinegar and water or with olive oil.

With both acid and alkali burns, after neutralizing, treat like other burns. In severe burns of this character always see a doctor, and when either acid or alkali has entered the eye secure the services of a doctor as soon as possible. Treat shock.

ELECTRIC BURNS

The subject of electric shock is treated at length under the proper heading. Here, however, it is necessary to call attention to the fact that the local effect produced by contact with an electric current is a burn. This burn may be superficial or deep, depending on the strength of the current and the duration of contact. Frequently such burns are deep. Treatment of electrical burns should be exactly the same as for other burns.

WARNING

In all burns, whatever the cause, use care in removing the clothing. When the clothing sticks to a burn, do not drag it off, cut around the part that sticks and soak it off later with oil.

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