Bulletin No. 26.—W. B. No. 197. Price 50 cents.

U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.

LIGHTNING AND THE ELECTRICITY OF THE AIR.

IN TWO PARTS.

Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

BY

ALEXANDER G. McADIE AND ALFRED J. HENRY.

WASHINGTON:
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., February 27, 1899.

Hon. James Wilson,
Secretary of Agriculture.

Sir: I have the honor to transmit herewith a paper entitled Lightning and the Electricity of the Air, in two parts, and to recommend its publication as a bulletin of the Weather Bureau.

Part I deals with the electrification of the atmosphere and the best methods of protecting life and property from lightning stroke, being in large part a revision of Bulletin No. 15, Protection from Lightning, the edition of which is about exhausted. Part II gives statistics of actual losses of life and property, including live stock in the fields, sustained in the United States during 1898.

The aim of the paper is to furnish information of practical value to all persons, especially those who may have occasion to seek protection from lightning.

Very respectfully,

Willis L. Moore,
Chief U. S. Weather Bureau.

Approved:
James Wilson,
Secretary.

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ACKNOWLEDGMENTS.

In the following pages generous use has been made of articles published by the author in The Century Magazine, Harper's Magazine, Appleton's Popular Science Monthly, Terrestrial Magnetism, and Bulletins of the United States Weather Bureau, and a grateful acknowledgment is here made of my indebtedness to these sources. I must also acknowledge the kindness of my friend Mr. Alexander J. Wurtz, of the Westinghouse Company, who cheerfully put at my disposal his notes covering many years' experiments upon the protection of electrical apparatus from lightning.

Alexander G. McAdie.

PART I.

LIGHTNING AND THE ELECTRICITY OF THE AIR.

BY

ALEXANDER G. McADIE.

FRANKLIN'S KITE EXPERIMENT.

One hundred and sixty years ago a ragged colonial regiment drew up before the home of its philosopher-colonel and fired an ill-timed salute in his honor. A fragile electrical instrument was shaken from a shelf and shattered. Franklin doubtless appreciated the salute and regretted the accident. In the course of his long life he received other salutes, as when the French Academy rose at his entrance, and he constructed and worked with other electrometers; but for us that first experience will always possess a peculiar interest. The kite and the electrometer betray the intention of the colonial scientist to explore the free air, and, reaching out from earth, study air electrification *in situ*. He made the beginning by identifying the lightning flash with the electricity developed by the frictional machine of that time. A hundred patient philosophers have carried on the work, improving methods and apparatus, until to-day we stand upon the threshold of a great electrical survey of the atmosphere. It is no idle prophecy to say that the twentieth century will witness wonderful achievements in measuring the potential of the lightning flash, in demonstrating the nature of the aurora, and in utilizing the electrical energy of the cloud. The improved kite and air-runner will be the agency through which these results will be accomplished.

Franklin's Electrical Machine.

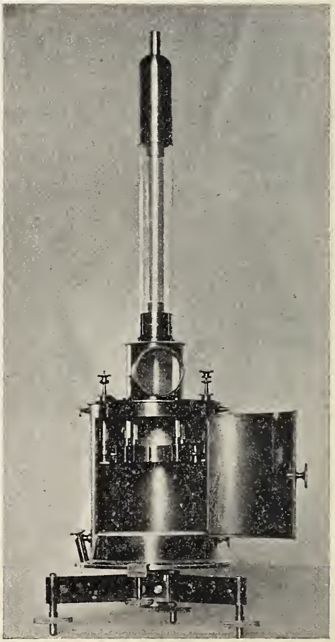
The famous kite experiment is described by Franklin in a letter dated October 19, 1752:

> Make a small cross of light sticks of cedar, the arms so long as to reach to the four corners of a large, thin silk handkerchief when extended. Tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite which, being properly accomodated with a tail, loop, and string, will rise

in the air like those made of paper, but being made of silk is better fitted to bear the wet and wind of a thunder gust without tearing. To the top of the upright stick of the cross is to be fixed a very sharp-pointed wire rising a foot or more above the wood. To the end of the twine next the hand is to be tied a silk ribbon, and where the silk and twine join a key may be fastened. This kite is to be raised when a thunder gust appears to be coming on, and the person who holds the string must stand within a door or window, or under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window. As soon as the thunder clouds come over the kite, the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified, and stand out every way and be attracted by an approaching finger. And when the rain has wet the kite and twine you will find the electric fire stream out plentifully from the key on the approach of your knuckle.

Now, how would we perform this experiment to-day, and with what results? Having flown big kites during thunderstorms, it may perhaps be best to describe step by step two of these experiments, and then speak of what we know can be done, but as yet has not been done.

Our first repetition of Franklin's kite experiment was at Blue Hill Observatory, some 10 miles southwest of Boston, one hundred and thirty-three years after its first trial. There were two large kites silk-covered and tin-foiled on the front face. These kites were of the ordinary hexagonal shape, for in 1885 Malay and Hargrave kites were all unknown to us. Fifteen hundred feet of strong hemp fish line were wrapped loosely with uncovered copper wire of the smallest diameter suitable, and this was brought into a window on the east side of the observatory, through rubber tubing and blocks of paraffin. Pieces of thoroughly clean plate glass were also used. Materials capable of giving a high insulation were not so easily had then as now. We knew very little about mica; and quartz fibers and Mascart insulators could not be obtained in the United States. Our electrometer, however, was a great improvement upon any previous type, and far removed from the simple pith-ball device used by Franklin. Knowing that an electrified body free to move between two other electrified bodies will always move from the higher to the lower potential, Lord Kelvin devised an instrument consisting of four metallic sections,



Mascart Electrometer.

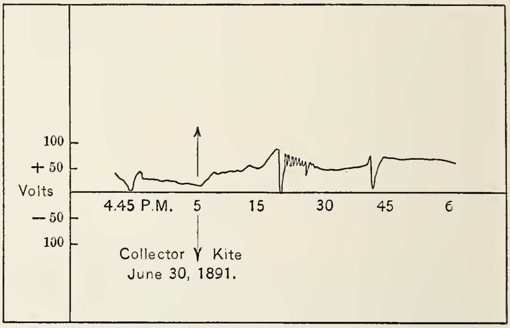
symmetrically grouped around a common center and inclosing a flat free-swinging piece of aluminum called a needle. The end of the kite wire is connected with the needle and the sections or quadrants are alternately connected and then electrified, one set with a high positive potential, say 500 volts, and the other with a corresponding negative value, say 500 volts, lower than the ground.

Perhaps the most noteworthy result of these earlier experiments was the discovery (for such we think it was) that showery or thunderstorm weather was not the only condition giving marked electrical effects. The electrometer needle would be violently deflected and large sparks obtained at other times. Day after day as we flew the kite we found this high electrification of the air, and we had no trouble in getting sparks even when the sky was cloudless. One other discovery was made, and this would have delighted Franklin more than the other, for he was always most pleased when a practical application was in sight. Seated within the instrument room of the observatory, with his back to the open window through which came the kite wire carefully insulated, and the kite high in air, the

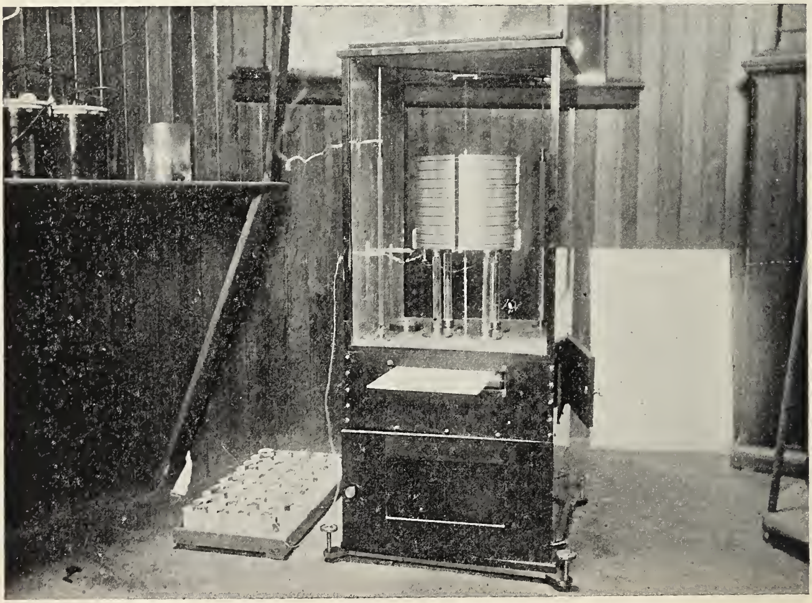
Mascart Electrometer, with Photographic Register, July, 1892.
Blue Hill Meteorological Observatory.

observer closely watching the index of the electrometer could tell positively, and as quickly as one outside watching the kite, whether it rose or fell. When the kite rose, up went the voltage, and vice versa. In other words, the electric potential of the air increased with elevation. It must be confessed that the kites made to-day would have behaved better and flown with more steadiness than the one we used. It may have been the varying wind, or more likely wrong proportions in the kite and tail; but our old hexagonal kite would dive even when high in air. Once we kept the kite aloft from the forenoon until late at night, but that was something unusual.

Passing now over six years in which we had been busy measuring the electrification of the air under all conditions, and discovering, for example, that a snowstorm was almost identical with a thunderstorm in its tremendous electrical changes, we come to the year 1891, when we again flew kites for the purpose of electrically exploring the air. Our experiments at the top of the Washington Monument in 1885 and 1886 (especially those during severe thun-

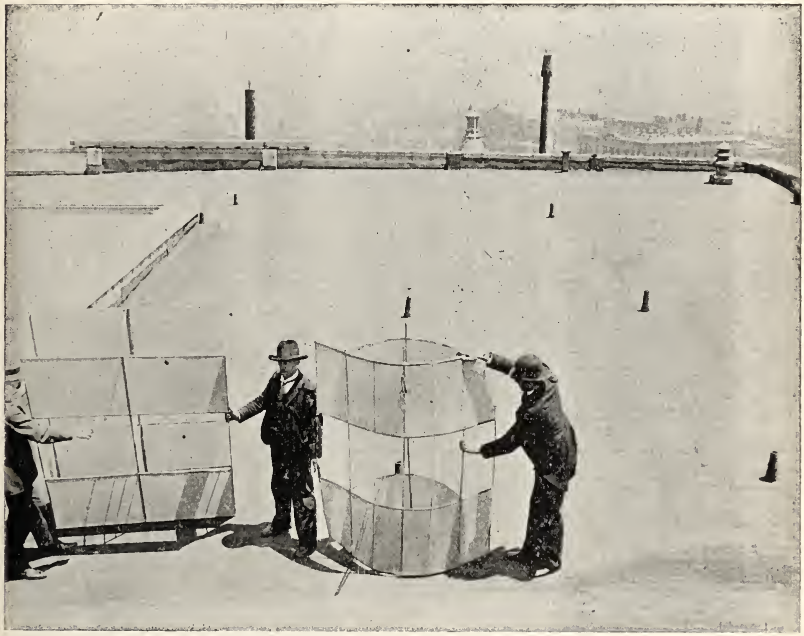


Electrical Potential of the Air. Small collector about fifteen feet from ground; kite about five hundred feet from ground.



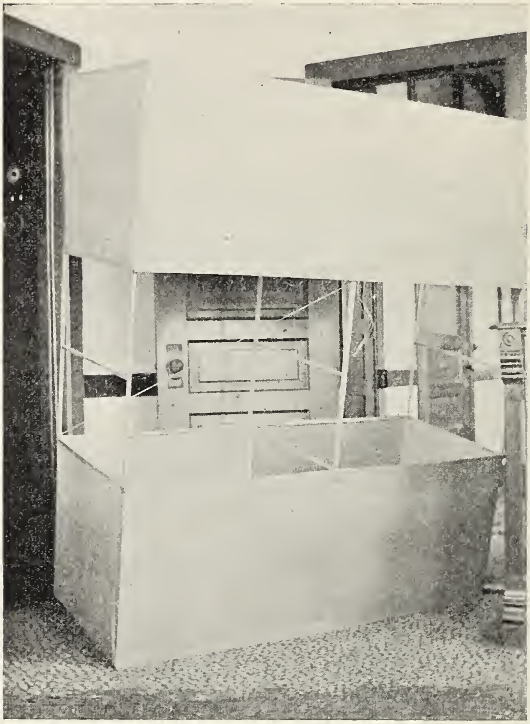
Multiple Quadrant Electrometer, July, 1892. Blue Hill Observatory.

derstorms, when we obtained potentials as high as three and four thousand volts just before the lightning), had given us an insight into the strains and stresses in the air, and taught us what to expect at such times. There was still little improvement in the kite, but much better electrical apparatus was at hand. It may seem ridiculous, but we hauled nearly a wagon load of electrical apparatus to the summit of the hill, and found occasion to use all of it. Our insulators were delicate glass vessels, curiously shaped, containing sulphuric acid, and able to hold with little leakage the highest known potentials. Besides these fine Mascart insulators, we had hundreds of distilled-water batteries and two electrometers, one a Mascart quadrant, the other a large multiple quadrant. The chief aim that year was to secure by mechanical means (discarding the photographic and eye methods) a continuous record of the potential. When we can study the potential at any moment and still have a record of it, the relation of the electricity of the air to the pressure, temperature, and moisture will be more easily investigated. Among our records that year there is one date, June 30, 1891, where a direct comparison of the electrification of the air 15 or 20 feet from the ground and at a height of about 500 feet is shown. In one, the potential was obtained by a water-dropper collector from a second-story window in the observatory, and in the other was obtained by means of the kite. It will be seen how much higher the kite values are, although the kite was a much slower accumulator of



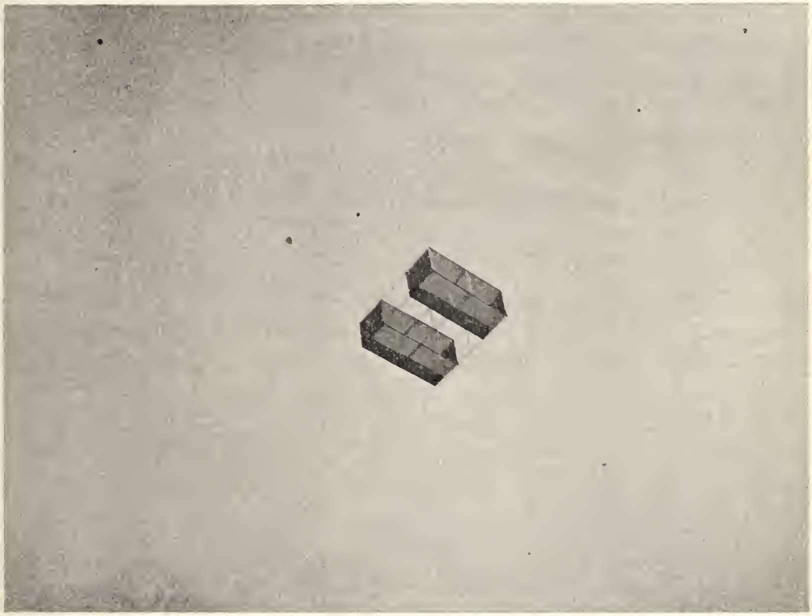
Kite-flying on Roof of City Building.

electricity. In the next year, 1892, the kite was flown several times during thunderstorms, but generally during afternoon storms; and in the lull preceding the wind rush the kite would fall. It was not until August 9 that we succeeded in going through a storm with the kite still flying. About 11 a. m. the kite was sent aloft, and it remained aloft until after 10 p. m. From the observatory one can see to the west 50 or more miles, and a thunderstorm came into view just about sunset. The kite was flying steadily, and whenever a finger was held near the kite wire there was a perfect fusillade of sparks. As the darkness increased, the polished metallic and glass surfaces in the large electrometer reflected the sparks, now strong enough to jump across the air gaps, and the incessant sizzling threatened to burn out the instrument. The vividness of the lightning in the west also made it plain that the storm was one of great violence, and as the observatory itself would be jeopardized, one of the four men present proposed to cut the wired string and let the kite go. But even that was easier said than done, for to touch the string was to receive a severe shock. It was necessary, however, to get out of the scrape, and one of the party took the kite string and broke the connection with the electrometer and insulators. While he was in the act of doing this,



Hargrave Kite.

the others, who by this time were outside the building, saw a flash of lightning to the west of the hill. The observer who was undoing the kite wire did not see this flash. He saw a brilliant flare up in the electrometer, and at the same instant felt a severe blow across both arms. Notwithstanding, he loosened the wire, and, dropping an end without, it took but a few moments to make it fast on the hillside some distance away from the observatory. There it remained for the rest of the night. A 105-volt incandescent lamp was placed between the end of the kite wire and a wire running to the ground. There was some light, but no incandescence of the filament. It was more in the nature of a creeping of the charge over the outer glass surface of the lamp. Stinging sparks were felt whenever the kite wire was touched. The storm gradually passed over, the lightning being vivid and frequent in the west and north, and, as we learned next day, doing considerable damage. The nearest flash to the hill, however, as well as we could determine by the interval between thunder and flash, was 4,500 feet away, so that the discharge which the observer felt while loosening the wire must have been a sympathetic one. We obtained a photograph of the prime discharge, and very curiously this shows a remarkable change of direction.



Hargrave Kite in Air. Same kite as in preceding cut.

This year, in some interesting experiments made on the roof of the Mills Building at San Francisco, it was noticed that the roof, which has a covering of bitumen, was a good insulator. Ordinarily one may touch the reel on which the kite wire is wound without being shocked, but if a wire be connected with the ventilating pipes running to the ground there are small sparks. Introducing a condenser in the circuit, the intensity of the spark is increased. It only remains to construct an appropriate coil of the kite wire and place within it another independent coil. In the outer coil a quick circuit breaker may be placed, and theoretically, at least, we shall transform down the high potential and low amperage charge of the air to a current of less potential and greater amperage. This can be put to work and the long-delayed realization of Franklin's plan of harnessing the electricity of the air be consummated.

ELECTRIFICATION OF THE ATMOSPHERE.

Franklin, in addition to many other experiments upon the electrification of the air, erected upon his house an iron rod with two bells. When the rod was electrified the bells were rung. By charging Leyden jars and testing the sign of the electrification, he came to the conclusion that " the clouds of a thunder gust are most commonly in a negative state of electricity."

A detailed history of most of Franklin's colaborers may be found in the accounts given by Exner,[1] Hoppe,[2] Mendenhall,[3] Elster, and Geitel.[4] The author[5] of this book has also given a brief summary.

The following table will give at a glance the work of the chief investigators from the time of Franklin to the end of the eighteenth century. Passing Peter Collinson, of London, who introduced to the notice of the Royal Society the experiments of Franklin, and the three less known workers—J. H. Winkler, who wrote in 1746 on the electrical origin of the weather lights; Maffei, 1747; and Barbaret, 1750—we have:

DATE.	NAME.	EXPERIMENTS.	REFERENCES.
1751	Franklin	Effects of lightning	Phil. Trans., xlvii, p. 289
1751	Mazeas	Kite experiments	Phil. Trans., 1751, 1753
1752	Nollet	Theory of electricity	Recher. sur les causes, 1749–1754
1752	Watson	Electricity of clouds	Phil. Trans., 1751, 1752
1752	De Lor De Buffon	Iron pole 99 feet high, mounted on a cake of resin 2 feet square, 3 inches thick, Estrapade, May 18, 1752	Letter of Abbe Mazeas, dated St. Germain, May 20, 1752

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[1] Ueber die Ursache und die Gesetze der atmosphärischen Electricität. Von Prof. Franz Exner. Repertorium der Physik. Band XXII. Heft 7.

[2] Ueber Atmosphärischen und Gewitter Electricität. Meteor. Zeits. 1, 2, 3, and 4, 1885.

[3] Memoir of National Academy of Sciences.

[4] (*a*) Report of the Chicago Meteorological Congress. Part II. August, 1893. (*b*) Zusammenstellung der Ergebnisse neuerer Arbeiten über atmosphärische Electricität, Von J. Elster und H. Geitel. Wissen. Beilage zum Jahresbericht des Herzoglichen Gymnasiums zu Wolfenbüttel, 1897.

[5] (*a*) Observations of Atmospheric Electricity. American Meteorological Journal. 1887. (*b*) Terrestrial Magnetism. December, 1897.

DATE.	NAME	EXPERIMENTS.	REFERENCES.
1752	D'Alibard	Sparks from thunder clouds, 40 foot pole in garden at Marly; also wooden pole 30 feet high, at hotel de Noailles	Mem. l'Acad. r. des Sci., May, 1762
1752	Le Monnier	Observations of air charge	Mem. de Paris, 1752
1752	De Romas	Observations of air charge; kite experiments	Mem. Sav. Etrange II, 1755
1752	Mylius Ch	Observations of air charge	8 vo, Berlin, 1752
1752	Kinnersley	Observations of air charge	Franklin's letters, Phil. Trans., 1763, 1773
1752	Ludolf and Mylius	Observations of air charge.	Letter to Watson
1753	Richman	Electrical gnomon	Phil. Trans., 1753
1753	Canton	Electricity of clouds	Phil. Trans., 1753
1753	Beccaria, G. B.	Systematic observations with an electroscope	Lett. del Elet. Bologna, 1758
1754	Lining	Kite experiments	Letter to Chas. Pinckney
1753	Wilson	Experiments	Phil. Trans., 1753, p. 347
1755	Le Roi	Experiments	Mem. de Paris, 1755
1756	Van Musschenbroek	Kite experiments	Intro. ad Phil. Nat., 1762
1759	Hartmann	Origin of electricity	
1769	Cotte	Memoirs on meteorology	Journ. Phys., xxiii, 1783
1772	Roynayne	Fog observations	Phil. Trans., 1772
1772	Henley	Quadrant electrometer	Phil. Trans., 1772
1775	Cavallo	Fogs, snow, clouds, and rain; kite experiments	Treatise on Elec., 1777
1784	De Saussure	Observations	Voyage dans les Alps
1786-7	Mann	Daily observations with an electrical machine, timing the revolutions to produce a given spark with a record of the weather	
1788	Volta	New electroscope	Lettere sulla Meteor, 1783
1788	Crosse	Experiments with collectors	Gelb. Ann. Bd., 41
1791	Reed	Insulation and conductors	Phil. Trans., 1791
1792	Von Heller	Observations	Green's Jour. d. Phys., 2 Bd., 4
1792	Schübler	Observations with weather rod	J. de Phys., lxxxiii

At the beginning of the nineteenth century, Schübler at Tübingen, systematically observed for twenty years and worked out a curve of diurnal variation. Double maxima and minima were determined; the first maximum about 8 a. m., and the second about 8 p. m. The minima occurred before sunrise and about sunset. Correlating the values with weather conditions, Schübler found in 110 cases of rain, 63 negative values and 47 positive ones; while in 33 cases of snow, 27 were positive and 6 negative.

Peltier's modification of the electroscope and his views on the origin of atmospheric electricity led to a series of observations by A. Quetelet, beginning in August, 1842, at the observatory at Brussels. After some improvements in the electroscope were made, another set of observations was made in 1844, and it appeared that no negative values were observed except during rain. Indeed, negative values were rare, only 23 cases being recorded in four years. Passing the observations made at Dublin by Clarke, in 1839, we come to those made at the observatory at Munich by Lamont, in 1850–51, with a Peltier electrometer and methods about the same as at Brussels.

The monthly and annual means are given in Poggendorff's Annalen, LXXXV, 1852, pp. 494–504, and LXXXIX, p. 258, et seq. In general, the winter months show a value nearly twice that of the summer months. About the same time, observations were made at Kreuznach by Dellmann. The yearly values nearly agree, but the mean monthly values differ considerably. A minimum occurs in May and a maximum in December. The air was generally positively electrified. Smoke and fog gave high positive values, and dust caused a change from positive to negative for several hours and to a degree exceeding the positive. Rain gave sometimes high positive and sometimes high negative, the latter often when the rain had just ended. Snow almost always gave high positive.

Everett, at Windsor, N. S., made observations, generally three per day, and the results of these and later observations have been widely published, and are too well known for extended notice now. During the same time, Wislizenus, at St. Louis, Mo., made observations, and has given the annual and diurnal curves of these. Two maxima and two minima are shown in the diurnal curve and a maximum in winter. In all, Wislizenus made some 25,000 observations, and his conclusions are therefore of more weight than those of any other observer up to that time. The normal state of the air is positive, and negative is an exceptional and temporary condition. Marked disturbances were experienced at times of thunderstorms. Fog was occasionally accompanied by negative indications, but after fine drizzling rain, fog as a rule was accompanied by positive values, often very high. A full discussion of the observations may be found in the American Meteorological Journal for 1887.

We have not space to do more than simply mention most of the other observers. W. A. Birt has given an elaborate discussion of the Kew Observations of 1845–1847 in the Report of the British Association, 1849, p. 113. At Gaud, Duprez studied the observations made from 1855 to 1864, and brings out particularly the relation to cloudiness. Palmieri, at Vesuvius, in 1850, and later with simultaneous observations at Naples and Vesuvius, found that the potential was lower at the higher station. In this conclusion he is at variance with all other observers. Some observations that are worthy of notice were made with a water-dropper collector at Pernambuco, from October, 1876, to February, 1877. On the rare occasions in which a negative potential was recorded, there were heavy rains and more or less cloudiness. We now come to the very important observations made at Paris by Mascart and others under his direction. The apparatus was installed at the College de France in February, 1879, and continuous records covering some years were obtained. In general, the potential of the air was positive. Rain was almost always accompanied by large negative values. The change in character occurs previous to the rain, and sometimes the rain is followed immediately by high positive values. A very full discussion of the observations made by the United States Signal Service is given in the Memoir of the National Academy of Sciences by Prof. T. C. Mendenhall. It is to be regretted that this discussion is not more generally known, for there are many valuable suggestions in it concerning mechanical collectors, best forms of electrometers, proper exposures, and details of methods to be followed, of great benefit to those who are to take observations. There is also an elaborate discussion of the question, "In the present state of meteorological science, can the observations of atmospheric electricity be utilized in forecasting the weather?" A very thorough set of observations was made by Müller and Leyst, in Russia, with a Carpentier form of Mascart electrometer. The mean values for bihourly observations made at Pawlowsk in 1884 are given in Annalen des Phys. Cent. Obs., Part I, 1884. Other observations are those made by C. Michie Smith, in Madras, in 1883 and 1884; Abercromby, at the Peak on the Island of Teneriffe; Dr. Fines, at Perpignan, with photographic apparatus of the Mascart pattern, which were continued for a number of years. Roiti, Magrini, and Pasquilini have two years' complete records at Florence. Exner's extensive experiments on the potential gradient, Andree's observations near the pole while on the Swedish expedition, and the work on the Sonnblick by Elster and Geitel, bring us down to the present state of the problem.

Recently experiments have been undertaken at Kew[1] to verify Exner's law, that a building reduces the potential of the air precisely as if it formed an integral part of the earth's surface. A portable electrometer was carried to five stations near the observatory, and the mean values of the several ratios found to be approximately constant. The meteorological elements are then discussed, and particularly the moisture, to see whether the potential gradient is so closely connected with the aqueous vapor as Exner claims. The results do not support the theory. The influence of bright sunshine in reducing the potential gradient, as shown by Elster and Geitel, seems more likely. The potential was lower after long sunshine. The evidence "in favor of a connection of high potential with low temperature is just about as strong as that in favor of a connection of high potential with little previous sunshine." Higher potential was found to be associated with higher pressure in the forenoon observations, but to a less marked degree in the afternoon observations. Adopting 11 miles as a limiting value of the wind velocity, it was found that with a mean velocity of 19.6 miles per hour there was a mean potential of 153, and with a mean velocity of 6.8 the mean potential was 175.

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[1] Observations on Atmospheric Electricity at the Kew Observatory. By C. Chree. Proc. Royal Soc., vol. 60.

The author does not seem to be aware of the observations made in the United States upon similar lines. An attempt was also made to investigate the relation of the potential to cyclonic and anticylonic weather. In five cases out of the seven considered the mean potential for the anticyclonic condition exceeded that for the cyclonic. In Dr. Chree's words, "There is something to be said for the hypothesis; but individual occurrences of high potential in cyclonic weather and of low potential in anticyclonic weather were not infrequent."

The recent paper of J. Elster[1] and H. Geitel is a most comprehensive review of recent investigations in the subject. For painstaking and systematic study of the potential as influenced by water vapor, sunlight, dust, and height, it cannot be excelled.

The views of von Bezold and Arrhenius concerning a photo-electric action of the solar radiation have been in part confirmed by these investigators. It has been experimentally shown that the sun's rays act on certain substances in such a way as to cause a loss of negative electricity. Our authors make the potential gradient vary with exposure to ultraviolet light. The marked disturbances occurring with precipitation are considered as disturbances of the normal field. They also think that Palmieri is right in his statement that whenever negative electricity is observed rain falls close by. Sohncke and Luvini have shown how dry ice crystals were positively electrified through friction with dust-formed water, and Maclean and Goto, and more recently Lenard and Kelvin, have discussed the question of electrification through falling water. "When waterdrops strike on a fixed moist substratum or a larger water surface the surrounding air at the time of impact shows itself as negatively electrified." And our authors think, with Lenard, that it is very probable that the negative values so prevalent during rainy weather are in part due to this. With the building of mountain observatories, the electric phenomena of the air, and more especially the silent discharges, come more readily under our observation. Elster and Geitel themselves have collected a number of observations relating to the appearance of St. Elmo's fire on the Sonnblick. It would seem that the phenomena are closely connected with climatic conditions and are to be studied in their development precisely as thunderstorms.

Elster and Geitel have rendered a great service to future students of atmospheric electricity by clearly pointing out the difference between the normal field or fair-weather electricity and the *accidental* field, if it may be so called, when the electrical measurements are greatly influenced by dust, snow, clouds, precipitation, whirling air or smoke, spattering water, etc. "Certainly it is an improve-

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[1] Review of Recent Investigations in Atmospheric Electricity. By J. Elster and H. Geitel. Extract from Part II of the Report of the Chicago Meteorological Congress, August, 1893, pp. 510–522.

ment," they say, "to diminish the influence of the lower dusty strata of air through the employment of kites, as introduced by McAdie at Blue Hill, and later by Weber at Kiel, though it is questionable if the advantage is not too dearly bought by the impossibility of determining the height." Marked improvements have been made in kite methods since these words were written. Another important matter touched upon by our authors is the circulation of electricity from the earth into the atmosphere and back again to earth. Theories are not wanting, but experimental determinations are. It is not improbable that a link in the chain of processes may be the aurora, and investigations in this direction are therefore greatly desired. Through such will the relation between the electric and magnetic fields be brought out. The following problem is suggested for investigation: "*How are the magnetic elements and the electrical currents of the air related?*"

Professor Schuster in a recent lecture[1] has given a most interesting résumé of the experimentation of Franklin's time with the modern lecture apparatus for studying the conduction of gases. The question of the breaking down of the air as an insulating medium is touched upon, and the effect of light and of the discharge itself considered. Electric sparks are liable to succeed each other along the same path, and Schuster thinks this points to a higher conductivity of the air along the path of the previous discharge. Schuster also thinks that the location of the positive charge, corresponding to the earth's negative charge, can only be ascertained through the agency of balloon and kite experiments. "Observations made up to heights of about 1,000 feet seem to indicate a strengthening of the electric field, i. e., the fall of potential per meter is greater at a height of, say, 200 meters than on the surface of the earth." The observations of Dr. Leonhard Weber and Dr. Baschin are referred to, the former as showing how the fall of potential at a height of 350 meters was six times that at the earth's level; and the latter showing that at a height of 3,000 meters no fall could be determined, while at 760, 2,400, and 2,800 meters, respectively, the fall in volts per meter was 49, 28, and 13, respectively. It seems, therefore, likely that the lines of force of the normal electric field of the earth end within the first 10,000 or 15,000 feet. Schuster advances the somewhat startling view that the semidiurnal variation of atmospheric electricity is connected with "the same circulation in the upper regions of the atmosphere which shows itself in the corresponding changes in pressure." He refers to Exner's formula: $P = \frac{A}{I + kp_0}$, where $A = 1{,}300$, $k = 13.1$, $p_0 =$ pressure of aqueous vapor present, in centimeters, and $P =$ the electric force;

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[1] "Atmospheric Electricity." Lecture delivered before the Royal Institution of Great Britain, February 22, 1895, by Professor Arthur Schuster.

and notes the agreement between vapor pressures 0.23 and 0.95. It is the amount of vapor, and not the humidity, which controls. Elster and Geitel's ultraviolet radiation relation to electrification and amount of aqueous vapor present is also alluded to.

SOME MEASUREMENTS OF THE POTENTIAL OF THE AIR.

Experiments at the Smithsonian Institution.—In 1886 some investigations on atmospheric potential were undertaken at Washington, under the direction of General Hazen, Chief Signal Officer, and more immediately under the supervision of Professor Mendenhall. Experiments were made by the writer at the tower of the Smithsonian Institution. The electrical history of a summer afternoon thunderstorm may be read in the following record of the potential changes.

June 14, 1886; a showery and oppressive morning; the wind very light and coming in feeble puffs; southwest at 11:30 a. m.

Time.	Volts.		Remarks.
	+	−	
11:30 a. m	78	....	
35	54	....	
40	60	....	Wind southwest, light.
45	36	....	
50	54	....	
55	54	....	
58	78	....	
12:40 p. m	66	....	
45	72	....	
50	3	....	
52	....	66	
55	....	138	Wind from south-by-east, puffs, no particular cloud conditions.
57	....	168	
1:00	....	210	
02	....	90	Very light rain began at 1:02 p. m.
03	....	24	
05	120	....	
07	198	....	
09	216	....	Distant thunder at 1:09. Clouds in west looking like advance guard of thunderstorm, with some blue sky, however.
10	210	....	
11	198	....	
12	186	....	
13	156	....	
14	132	....	Thunder 1:13:25. Clouds also in northwest. Thunder from 1:16:20 to 1:17:40. Rain commenced 1:17; lasted 5 seconds.
15	108	....	
16	108	....	
17	96	....	
18	96	....	
19	78	....	
20	72	....	Rain commenced 1:20:15, light. Ended 1:22.
21	54	....	
21–22	54–72	....	Thunder at 1:22:20.
22	54	....	
23	30	....	
24	30	....	
25	30	....	
26	12	....	
27	6	....	Very light rain commenced 1:27:30.
28	....	12	
29	....	54	
30	....	78	
32	....	192	Very distant thunder.
33	....	246	
34	....	240	
35	....	252	
38	....	234	
39	....	180	Light rain.
40	....	174	Rain ended 1:39:20.
43	....	150	
44	....	120	

Time.	Volts.		Remarks.
	+	−	
1.45 p. m		72	
48		24	
50	12		
55	66		
58	78		
2:00	78		
01	78		Rain commenced 2:01 p. m.
05	78		
09	90		
10	90		
13	72		A very heavy cumulus cloud is moving up toward the place of observation from the river.
15	84		
17	96		
20	90		
21	66		
23	72		
25	66		
30	48		
35	48		
40	54		
45	30		
50	30		
55	24		
57	0.0		
58		12.0	Bright and sun shining; large, white cumulus clouds in south-southwest, southeast, and east, but the northwestern horizon is black and evidently a storm is coming.
3:00		114.00	
02		150	
03		186	First thunder 3:03:15 to 3:03:40; thunder 3:07:30 to 3:07:42; calm; thunder 3:09:10 to 3:09:13.
04		228	
05		276 288	
06		300	
07		312	
08			
09		348	Thunder 3:10:08 to 3:10:10.
10		360	
11		390	
12		396	Thunder 3:12:25 to 3:12:27.
13		420	
14		444	
15		438	Thunder 3:15:30 to 3:15:32.
16		444	
18		480 504	Thunder 3:17:30.

Experiments at the top of the Washington Monument.—The electrical history of a thunderstorm as indicated by an electrometer at the top of the monument is very interesting. The following is a description of one of many experiments thus made:

May 6, 1887. We are 500 feet above the city streets. It is a warm afternoon and looking from the west windows of the monument one sees through the near haze around Arlington and the Virginian hills far to the southwest a patch of dark cloud. It needs little experience to presage a thundersquall. It is about 20 miles away and will reach us in forty minutes, perhaps in less time. At ten minutes to three o'clock the clouds are overhead, and this is the last we shall see of the world outside until the storm is over, for it is necessary that the heavy marble door windows be swung to. All is dark in the monument save for the beam of reflected light traveling along the ground glass scale. The little mirror reflecting the light is attached to the electrometer needle, and in this way the most minute movement of the needle is made known. From the south window the nozzle of the water-dropping collector protrudes through a small opening. The wind rises,

Washington Monument. Struck June 5, 1885, and subsequently.

and we notice the needle moving steadily toward the point marked 1,000 volts, positive. This means that the pull upon the air is steadily increasing. Suddenly the needle flies to the other side of the scale and we know that the air, like a piece of over stretched rubber, has snapped and given way under the strain. The pull is now negative, i. e., in an opposite direction, and now the needle dances and we hear outside the rumble of distant thunder, all indicating the approach of the disturbance. Nearer comes the storm, if we may judge from the rapid fluctuations of the needle. Values of 3,000 and 4,000 volts are common.[1] The deflections are at times greater than the scale limits. With every flash of lightning we catch the fleeting reflection of a little spark in the electrometer. On one occasion running a wire from the iron work to within a small distance of the collector we counted more than 100 $\frac{1}{8}$-inch sparks in a minute. If we place the eye close, but not too close, to the little peep-hole through which the nozzle goes, we shall see the stream of water twisting and breaking into spray, and each time it lightens, becoming normal quick as the flash itself, but only to rapidly twist and again distort itself.

Increase of potential with elevation.—Some idea of the normal rate of increase of potential with elevation can be gained from the following table:

Time, a day in November. The two stations about 500 *feet and* 45 *feet respectively.*

Time.	Monument.	Signal Office.	Difference.
	Volts.	*Volts.*	*Volts.*
1:30 p. m	900	216	684
1:32 p. m	888	246	642
1:34 p. m	900	216	684
1:36 p. m	862	246	616
1:38 p. m	875	240	635
1:40 p m	825	222	603

THE ELECTRICITY OF THE UPPER AIR AS MANIFESTED IN AURORAL DISPLAYS.

One of the great mysteries of the upper air is the aurora. No paper treating of the electrification of the atmosphere can be complete without a more or less imperfect résumé of our knowledge of this most beautiful of all electrical displays. The following brief review is from an article published in the Century Magazine for October, 1897, somewhat modified to suit the requirements of the present publication:

WHAT IS AN AURORA.

On the first day of January, 1892, Dr. Brendel and Herr Raschen reached the Alten Fiord, Lapland, to remain several months, studying

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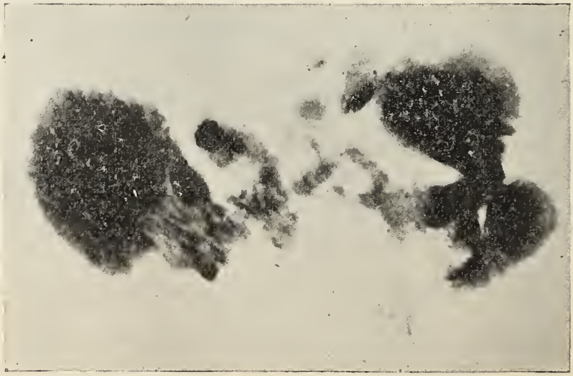
[1] At the Eiffel Tower values as high as 10,000 volts have been obtained.

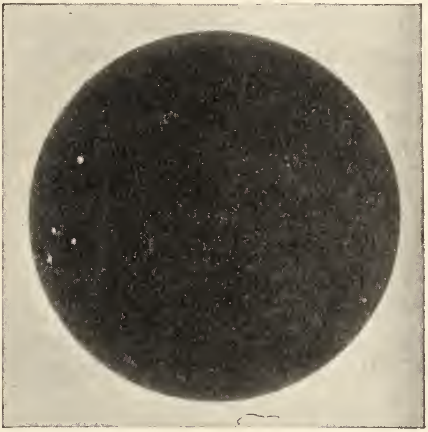
auroral displays and magnetic disturbances. Brendel succeeded in photographing the aurora, a very difficult thing to do, as all who have attempted it know. The deep reds, which are so beautiful to the eye, make little impression on the photographer's plate, and the light itself is generally feeble and flickering. Not unaptly have the quivering auroral beams been called "merry dancers." Even the bright displays are hard to photograph, as we may see from an entry in General Greely's notebook on January 21, 1882: "A most beautiful aurora," he says, "with intense light, at times sufficiently bright to cast my shadow on the snow. Rice exposed a sensitive plate without effect, but the constantly changing position of the aurora may have been the cause."

West End of an Auroral Band.
Photographed February 1, 1892, by Dr. Brendel, and sent by him to Mr. James P. Hall, and by him given to the writer.



Photograph of Sun Spots of August 8, 1893.
Made at Lick Observatory by Prof. C. D. Perrine.

Once the sun-spot period was clearly established, it was only necessary to ransack chronological lists of auroras to find how intimately auroras and sun spots were connected. Three patient investigators, Wolf, Fritz, and Loomis, soon proved that auroras were most frequent when sun spots were most numerous. The next step was to find individual relations. One bright September morning thirty-seven years ago, Carrington and Hodgson, separately studying the face of the sun, saw a remarkable outburst near the edge of a great spot. For some days the magnetometers at Kew showed unusual perturbation, and for several nights magnificent auroral displays were seen over two continents. It was long thought that a violent magnetic disturbance occurred *simultaneously* with the outburst, but recent examination of the records disproves this. In 1872 Professor Young noticed a disturbance in the chromosphere in the neighborhood of a sun spot, and upon asking the astronomers at Greenwich and Stonyhurst to examine their magnetic records, it was found that great disturbances had occurred about that time. Ten years later the astronomer at Greenwich sent out a message that read something like this: "Remarkable sun spot now visible. * * * Area of whole spot, $\frac{247}{1000000}$ of the sun's visible surface." Try to imagine what this means, and fancy yourself on the sun while that tremendous storm was in progress. We know that here on earth there was a magnetic storm with auroral displays that beggar description. Beginning a little before daylight on November 17, 1882, not a wire of the Western Union Telegraph Company could be used for three hours. The market quotations could not be sent. Late in the afternoon the trouble seemed to decrease, but at night there was a brilliant auroral display, and all telegraphic service was again interrupted. A very short cir-



Photograph of Sun Spots of August 29, 1893, showing relative size.
Made by Prof. C. D. Perrine, Lick Observatory. For purposes of illustration the spots are made white.

cuit from Boston to Dedham showed the disturbance equally with other circuits. The cables to Europe and the wires to Chicago were alike unworkable. A message was sent from Bangor to North Sidney, 700 miles, by cutting out the regular batteries and allowing the energy of nature to have its own way. The current was just as strong as if a hundred cells had been at work. At Albany the switchboard was ignited; and in telephone offices generally the annunciators dropped continually. Switchboards and wires were burned at Chicago. Incandescent lamps were illuminated in St. Paul, and even in far San Francisco the telephone operators were nigh distracted. Over half of North America, across the Atlantic, and on over northern Europe, it seemed as if legions of ethereal demons were busy inciting electric and magnetic apparatus to strange and mischievous antics.

It so happened that about the pole that year were clustered representatives from twelve nations. The Russian international expeditions were at the Lena Delta and Nova Zembla; the Norwegian at Bossekop; the Dutch at Dicksonhavn; the German at Kingua Fiord; the Finnish at Sodankyla; the Swedish at Spitzbergen; the Danish at Godthaab; the Austro-Hungarian at Jan Mayen; and the British at Fort Rae. France had two stations in the antarctic region, and our own country had the well-known Lady Franklin Bay party under Greely, and the Point Barrow party under Ray.

November 14–19, 1882, was a period never to be forgotten by these arctic prisoners. While we at home saw the display of a decade, the observers of the frozen north, turning their eyes southward or westward or eastward, saw visions glorious by *day* as well as by night, and felt perhaps some measure of recompense for their isolation and peril. Coming out of their dark quarters, they were startled and at first blinded, and General Greely writes: "The curtain appeared at one time so near our heads that Gardner and Israel speak of having unconsciously dodged to avoid it." In Ralston's diary is the entry: "The aurora appeared so low down that I raised my hand instinctively, expecting to bathe it in the light;" and Brainard relates a like impression. What a pity that under such conditions no electrometric apparatus was available. With Thomson water-dropping collectors and multiple-quadrant electrometers, records of the electrification of the lower air could have been obtained, and a few more threads raveled out from nature's tangled skein. Some observations of the potential of the air, made by Andrée, who was a member of the Swedish party at Cape Thordsen, Spitzbergen, seem to show that the electric potential diminished very rapidly during an aurora, and in fact became negative. As is well known, this same Andrée has lately attempted to reach the pole in an air ship. Not the least valuable result of the adventure will be the increase in our knowledge of the electricity of the air in polar regions We shall learn a little more about the height of auroras. We know now that while they are from 50 to 70 miles high in latitude 50°, the height decreases as we approach 68°. At Godthaab, Paulsen measured many with theodolites, and found that some were less than two-fifths of a mile high. Hildebrandsson and others have seen auroras below the clouds. Such results lead us to believe that the time is ripe to suggest a new classification of auroral displays. It has been further noticed that the colorless and quiescent auroras were *not* necessarily coincident with magnetic disturbances, while those of brilliant color and rapid change were. Many so-called auroras are probably what the Germans would call *wetter leuchten*, and akin to silent lightning.

Our little planet unquestionably responds to solar disturbances. The intense auroral displays that occur simultaneously over continents are, one may think, answering signals to the messages flashed from the sun through the quivering ether. But we may also have our own little storms and disturbances; and while appearances may be similar, the phenomena are of different origin. Some of the difficulties and discrepancies which have been met in tabulating sun spot, magnetic, and auroral phenomena can be thus explained. One wise remark by Professor Young should not pass unnoticed. "The solar tumult," he says, "may be the brother, and not the father, of our aurora." But this much is plain: the phenomena are closely allied, and mastery of the terrestrial displays will enable us to reach out and attempt the conquest of the solar ones. It may be frankly said that the man of science feels that the aurora has baffled his scrutiny.

PROTECTION FROM LIGHTNING.[1]

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

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

The recent remarkable experiments of Dr. Oliver Lodge, in his lectures before the Society of Arts, opposing and to some degree directly contradicting the empirical rules of the Lightning Rod Conference, have given support to the belief that the protection was uncertain. Indeed, realizing that his work might be misinterpreted, Lodge has stated "an idea at one time got abroad that my experiments

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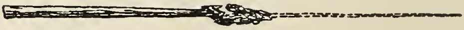
[1] From Bulletin No. 15, U. S. Weather Bureau.

proved existing lightning conductors to be useless or dangerous; this is an entire misrepresentation. Almost any conductor is probably better than none, but few or no conductors are absolute and complete safeguards. Certain habits of lightning rod practice may be improved and the curious freaks or vagaries of lightning strokes in protected buildings are intelligible without any blame attaching to the conductor; but this is very different from the contention that lightning rods are unnecessary and unless. They are essential to anything like security."[1]

What Lodge's brilliant experimental work does show is that the momentum of an electric current can not be overlooked in a lightning discharge. The old "drain-pipe" idea of conveying electricity gently from cloud to earth must give place to the new proposition, based upon recent discoveries, that even draining off must be done in an appropriate way to be effective. To illustrate, the rocks and trees upon a mountain side may influence and determine the course of a mountain stream, but even a good sized channel would not suffice to carry off safely an avalanche, or control the path of a landslide; so with lightning. In the past four years we have learned, through the work of Hertz and others, that when an electric current flows steadily in one direction in a cylindrical wire its intensity is the same in all parts of the wire; but if the current be of an oscillatory character, i. e., a current which rapidly reverses its direction, the condition no longer holds, and if the alternations are very rapid the interior of the wire may be almost free from current. If lightning then be a discharge of an oscillatory character, it may happen that the current down the lightning rod would be only *skin deep.* The experiments of Tesla and Elihu Thompson with currents of great frequency of alternation and very high potentials open the door to systematic study of discharges such as the ordinary lightning flash. In daily work currents of this type are coming more and more into prominence, and the time is not far distant when the lightning flash will be studied as an electrical discharge of this character. Protection entirely adequate for such discharges will then be forthcoming. Indeed, the reasons why present methods occasionally fail are now understood, and the proper remedies apparent.

LIGHTNING CONDUCTORS.

Beyond doubt, Franklin proved his case that lightning rods were efficacious in the protection of buildings. Buildings with conductors when struck by lightning suffered little damage compared with those without protectors.



Effect of the action of lightning upon a rod.

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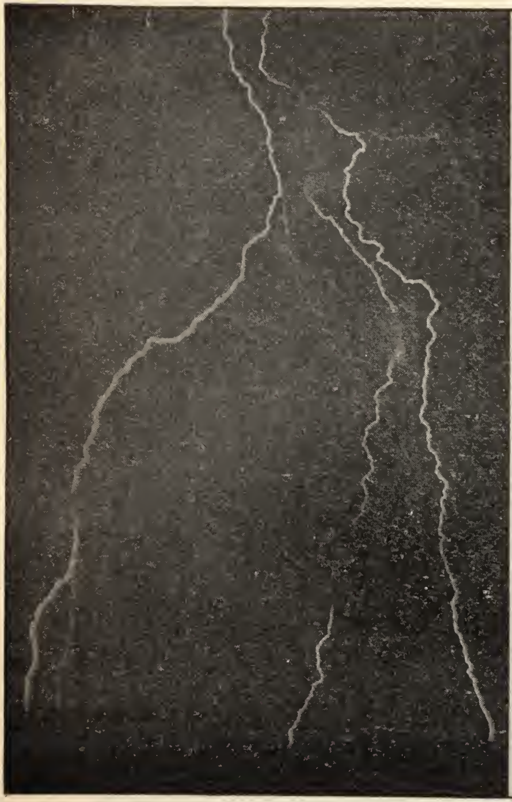
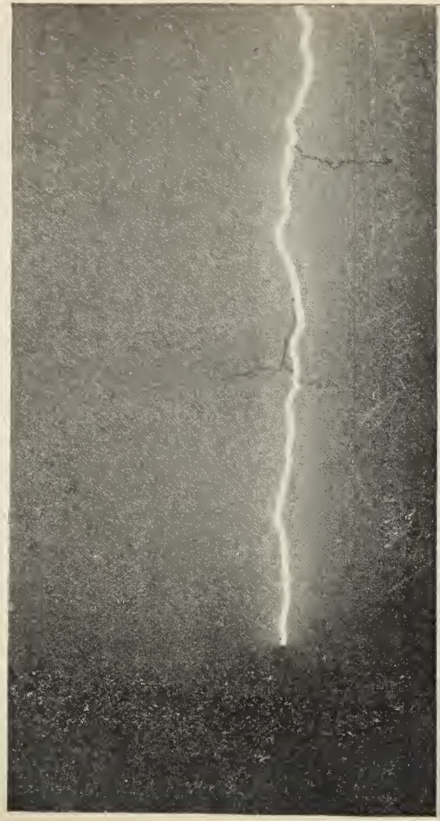
[1] Page VI. "Lightning Conductors and Lightning Guards."



Multiple Flash.
From Popular Science Monthly, 1893 McAdie,

Destructive Flash.
From photograph by McAdie.

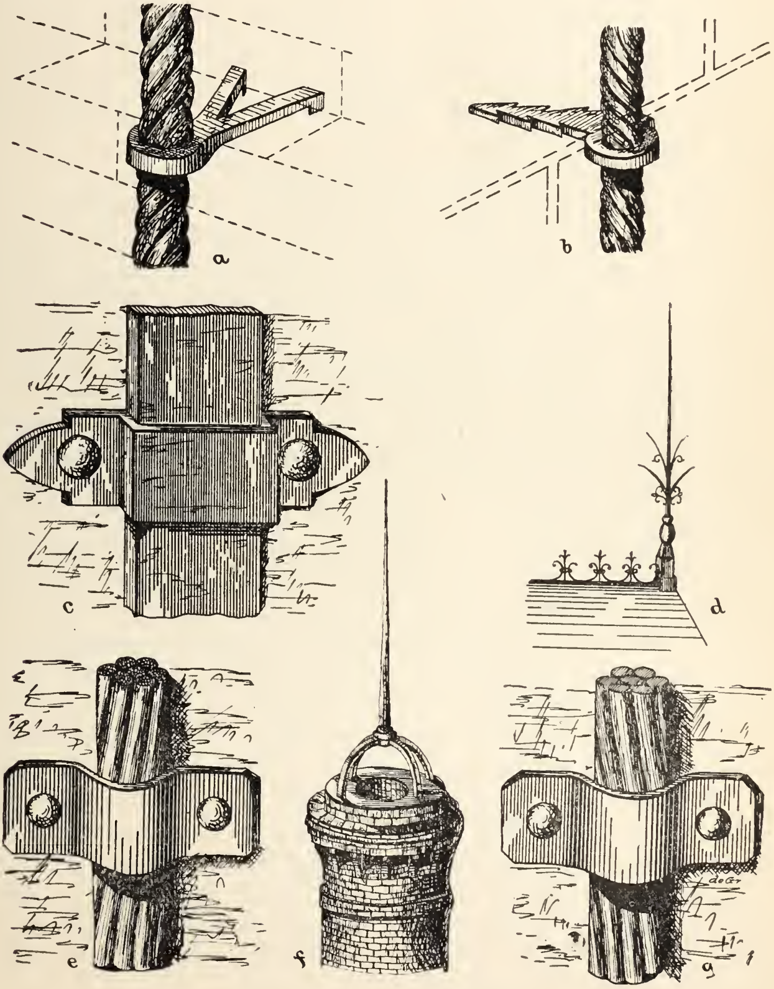
Cloud and Multiple Flash.
From photograph by McAdie.



Impulsive Rush and so-called Dark Flashes.
From Popular Science Monthly, McAdie.

Multiple Flash.
From Scribner's Magazine, A. Binden.

The chief defects likely to occur are blunted points and breaks in the continuity of the connection. The function of a lightning rod is twofold; first, that of conducting the charge to earth, and second, the prevention of a disruptive discharge by silent neutralization of the cloud electrification. The latter explains why a rod terminates in a point, and likewise why points in good connection with the ground are always *desirable* upon buildings. Indeed, points are somewhat like small water pipes connected with a large reservoir. If you have enough of them and a sufficient time you may drain the largest reservoir. Furthermore, when some sudden rise or flood occurs in the reservoir, these minute drains may be of service in keeping the height of the water down.



Conductors and Fastenings.
From Anderson, and Lightning Rod Conference.

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

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

In a letter[2] of an old British admiral there occurs a description of his being called upon to approve some specifications for a lightning conductor to be erected on a certain lighthouse. He was himself a believer in the "surface" theory of Harris; but thought that, to make sure, he would go and consult his friend Faraday. Faraday, who saw only the question of conductivity in the problem, said very positively that the solid rod was better than the tube (which gives greater surface with less copper), and that *solid volume was everything*, superficial area nothing. Moreover, if Harris says otherwise "then, he knows nothing whatever about it." The admiral straightway approved the solid rod conductor for the lighthouse. Within two or

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[1] Terms used by Professor Lodge.

[2] See report of Lightning Rod Conference.

three days he met Harris, and bringing up the question was told by Harris "*surface* area is most important, and if Faraday says otherwise, then he knows nothing whatever about it."

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

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

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

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

CHIMNEY, STRUCK JULY 29, 1890.
From Elec. Zeits., Grebel.

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

ERECTION OF RODS—GENERAL DIRECTIONS.

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

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

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

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

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

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

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

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

9. Chain or linked conductors are of little use.

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

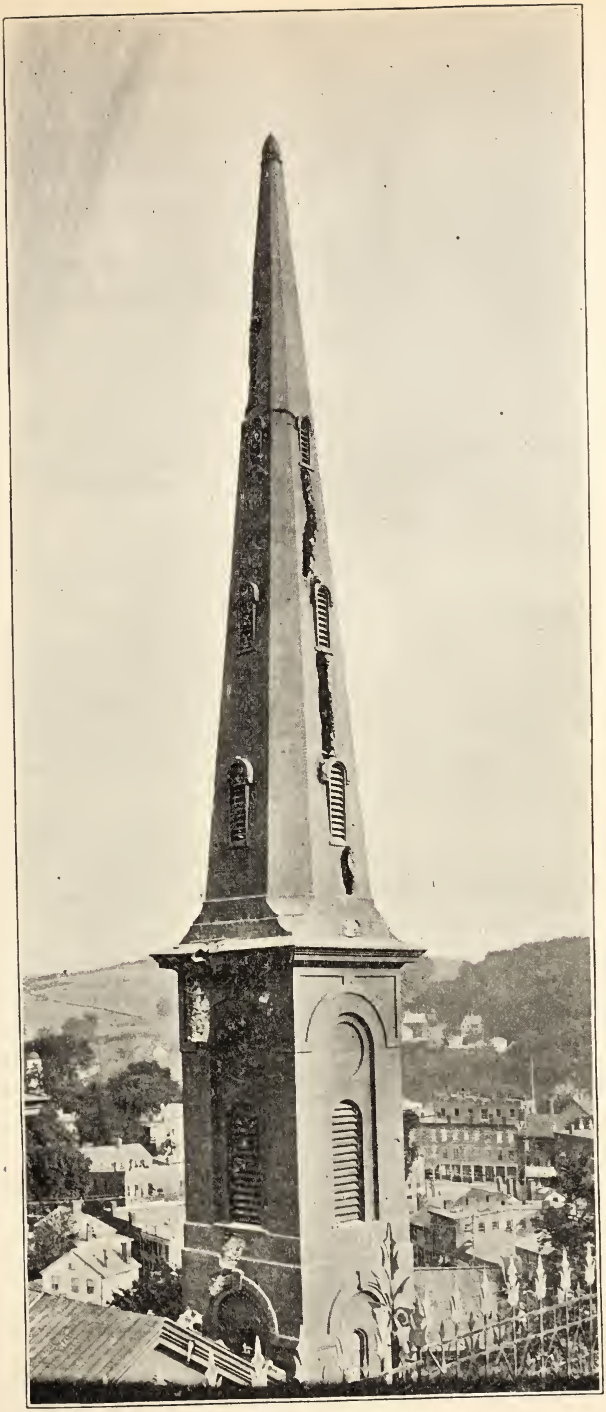
11. Return shock. Some uncertainty exists on this point. The so-called "return stroke" is caused by the inductive action of the charged cloud on bodies within its influence, and yet some distance away from the place of the direct discharge. As explained by Lord Mahon, who first called attention thereto,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

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

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

14. Any part of a building, if the flash be of a certain character, may be struck, whether there is a rod on the building or not. Fortunately, these are exceptional instances. The great majority of flashes in our latitudes are not so intense but that a good lightning rod, well earthed, makes the most natural path for the flash. We have many instances, however (not to be confounded with cases of defective rods), where edifices, seemingly well protected, have been struck below the rods.

15. Paradox of paradoxes, a building may be seriously damaged by lightning *without having been struck at all.* Take the famous Hotel



Spire of Broadway Church,[1] Norwich, Conn., damaged by lightning July 29, 1894, 1:30 p. m. Photographed by Mr. F. J. Moulton.

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[1] The spire is of brick, 198 feet high, with a cap of brownstone. It was not protected by a lightning rod. See Scientific American, September 8, 1898.

de Ville of Brussels. This building was so well protected that scientific men pronounced it the best protected building in the world against lightning. Yet it was damaged by fire caused by a small induced spark near escaping gas. During the thunderstorm, some one flash started "surgings" in a piece of metal not connected in any way with the protective train of metal. The building probably did not receive even a side flash. This is, therefore, a new source of danger from within, and but emphasizes the necessity of connecting metal with the rod system.

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

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

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

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

20. Finally, if you should be in the vicinity of a person who has just been struck by lightning, no matter if the person struck appears

to be dead, go to work at once and try to restore consciousness. There are many cases on record proving the wisdom of this course; and there is reason for believing that lightning often brings about suspended animation rather than somatic death. Try to stimulate the respiration and circulation. Do not cease in the effort to restore animation in less than one hour's time. For an excellent illustration of a case of severe lightning shock and recovery, due, it would seem, to prompt action by the medical gentlemen present, all who are interested may consult the Medical News, August 11, 1888. A number of cases corroborative of this view are on record in various medical journals.

No matter which method for respiration you use, it is important to maintain the warmth of the body, by the application of hot flannels, bottles of hot water, hot bricks, warm clothing taken from bystanders, etc.

Firmly and energetically rub the limbs upward so as to force the blood to the heart and brain. If an assistant is present let him attend to this. Remember above all things that nothing must interrupt your efforts to restore breathing.

When swallowing is established a teaspoonful of warm water, wine, diluted whisky or brandy, or warm coffee should be given. Sleep should be encouraged. In brief:

1. Make the subject breathe by artificially imitating the respiratory movements of the chest.
2. Keep body warm.
3. Send for a physician.

Of the visible effects of lightning stroke upon the human body little more can be said than that sometimes burns, usually superficial have been noticed, frequently red lines or markings, which are localized congestions of the small blood vessels of the skin. These from their irregularities and branchings have led to the fanciful idea of photographs of trees, etc.

In conclusion it may be said that lightning frequently causes a temporary paralysis of the respiration and heart beat which, if left alone, will deepen into death, but, intelligently treated, will generally result in recovery.

LIGHTNING ARRESTERS.

In his Experimental Researches,[1] Faraday describes the miniature house he had built to test the question of shielding bodies from electrical influences without. It was a hollow cube twelve feet high, wound around completely on the outside with wire. He says:

> I went into this house and lived in it; but though I used lighted candles, electrometers and all other tests of electrical states, I could not find the least influ-

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[1] Paragraph 1173.

ence upon them or indication of anything particular given by them, though all the time the outside of the cube was powerfully charged, and the large sparks and brushes were starting off from every point of its outer surface.

Maxwell, in 1876, suggested to the British Association a plan based upon the experiments of Faraday for protecting a building from the effects of lightning by surrounding it with a cage of wire or rods. The problems which the electrical engineers of to-day are called upon to solve are different from those of the time of Faraday or even Maxwell. Extensive light and power plants must be guarded with great thoroughness. Cables and telegraph lines have for years been provided with various forms of lightning arresters, but only in the past five years has the action of lightning been studied with some degree of success. The chief function of all of the old style lightning arresters has been to side track the flash, switching it out of the main circuit, and leading it as quickly as possible to earth. Cable, telephone and telegraph line protection have been systematically studied of late years by Prof. Oliver L. Lodge and others. In Lodge's excellent book upon Lightning Conductors and Lightning Guards the theory of lightning arresters is given at length. Satisfactory apparatus has been devised upon sound scientific principles for the protection of the delicate galvanometers and other instruments employed on cable, telephone, and telegraph lines. The principle applied may be stated in general terms to be " a succession of air-gap paths to earth, connected up by coils of well insulated wire, across the turns of which the lightning, weakened as it is by the first air gap to earth, is not able to leap."[1]

In protecting electric light and power plants, there is the further and very important question of preventing the formation of an arc across the air gaps or at any point on the circuit, thus short-circuiting these heavy currents. Many devices exist for automatically rupturing the dynamo arc thus formed. Some have many points of excellence, but the ideal protector must not only give a proper spark gap and also rupture any arc that may form, but better still should be so designed as to prevent the formation of an arc.

Mr. Alexander J. Wurts has for many years studied the problem of protecting electrical apparatus with a great measure of success. It is known that discharges do not pass readily through coils of wire, and Wurts has found that properly constructed choke coils connected in the circuit and used with arresters form a good combination for protecting against lightning. While experimenting along these lines Wurts discovered that if the electrodes of an arrester were made of zinc, the short-circuiting arc would not be maintained. There are five metals, zinc, bismuth, antimony, cadmium, and mercury, which are non-arcing metals. For alternating currents these non-arcing

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[1] Lightning Conductors and Lightning Guards. P. 419.

arresters are quite reliable. For direct current circuits an arrester is used in which the high potential discharge is made to pass over a surface discharge plane, e. g., a pencil line upon a block of marble, and by means of a second block firmly bound to the first, the vapors from the electrodes, upon which the arc feeds, are suppressed. Wood is now used instead of marble as at first, and shallow grooves take the place of the pencil line. It is also necessary to slot the upper block at right angles. This arrester is also a discriminating arrester in that it allows disruptive discharges to pass freely, but does not allow a dynamo current to follow. These are the points dwelt upon by Wurts in a lecture given before the Franklin Institute in June, 1895.

FUNDAMENTAL PRINCIPLES OF THE NONARCING RAILWAY LIGHTNING ARRESTER.

The fundamental principles of this device are based on the following facts:

1. That a static discharge will leap over a non-conducting surface, such as glass, wood, marble, etc., more easily than through an equal air space. If a pencil mark be drawn over this non-conducting surface the discharge will take place still more readily.

2. That a dynamo arc in order to be maintained must be fed by the fumes or vapors of its electrodes—conversely, therefore, that in order to avoid the formation of a dynamo arc between electrodes means must be taken to prevent the formation of these conducting fumes.

The electric crack.—An electric spark which springs across an air gap does not pass like ordinary moving matter gently pushing the air aside. Its passage is so instantaneous that the air is shattered, so to speak; the spark crashes its way through the air like a bullet through a pane of glass. If, however, the air be previously split—electrically split—the spark will pass with ease. A pencil mark over ground glass or a charred groove in a wooden surface forms an electrical crack or entering wedge through the air so that an electric discharge finds a much easier path over this surface and through this electrical crack than it does when it is forced to bore its own way through the air medium.

Discharge by disruption.—In the nonarcing railway lightning arrester the discharge is caused to pass between two brass electrodes separated by half an inch and over narrow grooves burned into a block of lignum vitae. It must not be understood that this charred surface in any way acts as a conductor in the ordinary sense of the word. The discharge takes place not by conduction, but by disruption, leaping between the electrodes and over the charred surface, the latter acting simply as an electrical crack through the air and thus greatly assisting the passage of the electrical discharge; neither does this charred surface leak dynamo current, for the ohmic resistance between the electrodes is more than 50,000 ohms. If now a solid lignum vitae block be firmly screwed down over the charred grooves and metal electrodes it will be impossible for conducting vapors to form and the device is at once a nonarcing lightning arrester.

CHOKE COILS FOR ALTERNATING CURRENT CIRCUITS.

A lightning discharge is of an oscillatory character and possesses the property of self-induction; it consequently passes with difficulty through coils of wire. Moreover, the frequency of oscillation of a lightning discharge being much greater than that of commercial alternating currents, a coil can readily be constructed which will offer a relatively high resistance to the passage of lightning and at the same time allow free passage to all ordinary electric currents.

Any coil will afford a certain amount of impedence to a disruptive discharge. Experience has shown, however, that there is one form which offers at once the maximum impedence to the discharge with the minimum resistance to the generator current.

Choke coils of this type connected in the circuit, when used in connection with nonarcing lightning arresters, offer a very reliable means of protecting well insulated apparatus against lightning. This arrangement is particularly suited for protecting station apparatus in power transmission systems. Coils can, however, be used to advantage on the line for the protection of the more expensive translating devices.

Tests made under actual working conditions indicate that for ordinary commercial voltages effective protection is obtained with four choke coils in series in each wire, with four lightning arresters intervening.

PART II.

LOSS OF LIFE AND PROPERTY BY LIGHTNING.

BY

ALFRED J. HENRY.

LOSS OF LIFE AND PROPERTY BY LIGHTNING.

There are many inherent difficulties in determining the number of lives lost by lightning in a domain so extensive as that of the United States. In the great majority of States and in all of the Territories systematic mortality returns are not made. In those States where such returns are required by local laws there is unfortunately a lack of uniformity both in the laws themselves and in their enforcement. It has been possible to obtain valuable material from the local authorities of three States only, viz, Massachusetts, Michigan, and Minnesota.

The statistics upon which this paper is based were obtained chiefly from press dispatches and manuscript reports by reliable persons.

Press dispatches are generally prepared with considerable haste and without, in some instances, sufficient time for independent verification; on the whole, however, they are fairly accurate as to the main facts, but very deficient as to important details. It would seem to be an easy matter to add a simple statement of the circumstances under which casualties by lightning occur; such, for example, as would answer the following questions: Was the person struck in a house or other building, under a tree or in the open? If in a building, was it provided with lightning rods; and, if so, were they in good condition? If under a tree, what kind of tree was it and were there other trees near by? If in an open field or road, were trees or other objects near or was the person near a wire fence?

An aggregation of facts relating to the above inquiries would enable us to speedily determine the places of danger in thunderstorms and thus minimize, in a measure at least, the loss of life by lightning.

Loss of life by lightning.—The loss of life by lightning in the United States during each month of the period 1890–1898 is shown in the table below. The number of deaths reported in 1890, the first year of the series, is considerably smaller than for any subsequent year. This fact is probably due to a lack of completeness in the early methods of collecting statistics rather than to natural causes.

The average number of persons killed annually by lightning in the United States, as shown by the figures of Table I, is 312, a number probably under rather than above the true figure. Undoubtedly a greater or less number of persons are killed by lightning each year of which there is no knowledge outside of the immediate communities in which the casualties occur. The uncertainty which attaches to the figures of the table as a result, can not easily be determined. Another cause of uncertainty, which operates, however, in a direction contrary to the one just mentioned, is the tendency to exaggeration sometimes manifest in newspaper reports. An example of gross exaggeration is afforded in the following item, clipped from the Troy (New York) Budget of September 4, 1898:

> During thunderstorms last week in Vermont two men became victims of the lightning's fury—Samuel Swan, of New Bedford, Mass., a guest at Rutland, and Dr. Royal T. Sawyer, of Worcester. These deaths make a total of twenty-nine from lightning during the past year (1898) in Vermont.

As the figures given in the above article were so much at variance with those derived from other sources, special effort was made to prove their correctness or falsity. The chief local paper of Vermont and all other available sources of information were carefully consulted, and it was found that but *five* persons were positively known to have been killed in Vermont during the year. It is but fair to The Budget to say that the item was copied from an exchange. Anyone who has had experience in newspaper work will recognize at once the utter futility of attempting to trace a paragraph of this nature to a responsible head.

In the beginning of this investigation it was thought possible to obtain an idea as to the correctness of the statistics collected as hereinbefore described by comparing them with the returns of vital statistics made in a few States in compliance with local laws and usages. Subsequent inquiry proved that for one reason or another this could not be done except for a very few years in Minnesota, Michigan, and Massachusetts. In the first-named State returns made to the State Board of Health for the years 1896, 1897, and 1898 show a total of 33 deaths by lightning as against 24 according to the figures of the Weather Bureau. In Massachusetts the State Board of Health returns for 1896 and 1897, the only years for which comparisons could be made, showed a slightly greater number of deaths by lightning than were given by the Weather Bureau. In Michigan the State returns and those of the Weather Bureau agreed very closely.

TABLE I.—*Deaths by lightning in the United States,* 1890–1898.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1890	0	0	2	6	8	37	55	12	0	0	0	0	*120
1891	0	0	0	13	23	73	52	34	9	0	0	0	204
1892	0	0	0	5	27	74	67	54	15	6	1	2	251
1893	0	0	5	19	17	66	73	18	8	2	0	1	209
1894	0	2	6	14	45	96	60	78	29	6	0	0	336
1895	0	0	5	29	66	109	123	78	16	0	0	0	426
1896	0	1	6	26	71	45	89	75	21	6	1	0	341
1897	0	1	11	8	44	107	109	61	14	3	4	0	362
1898	0	0	1	2	44	71	110	86	41	12	0	0	367
Sums	0	4	36	122	345	678	738	496	153	35	6	3	2,496
Mean	.....	.....	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	312

* Not used in computing the mean.

These data are not sufficient, of course, to establish the general accuracy of the results obtained by Weather Bureau methods. It is quite probable, however, that the accuracy and completeness of the figures vary for different portions of the country, and, as before stated, that the number of deaths given in the table is under rather than above the true figure.

The number of deaths by lightning that occurred in the several States and Territories during the three years 1896, 1897, and 1898, is shown in Table II. It is not possible to give the distribution by States for earlier years.

When we attempt to analyze the figures in the first column of Table II we are met by a number of difficulties. Evidently the number of deaths by lightning in any community depends largely upon the number of persons exposed to thunderstorm action, and, in a less degree, upon the number of thunderstorms. It has been satisfactorily shown by Flammarion and Lawson, whose reports will be referred to in a subsequent portion of this paper, that danger from lightning stroke is reduced to a minimum in large cities and very thickly populated districts. If, therefore, the relative frequency of fatal lightning strokes be determined by the proportion of deaths therefrom to the total population, those districts in which the urban element largely predominates will show an immunity scarcely in accordance with the facts.

As a first rough approximation to the relative frequency by States, the number of fatal cases per unit of 100,000 agricultural laborers, a class of persons fully exposed to the vicissitudes of thunderstorm action, was calculated. The results for the farming States of the central valleys and the middle west, while consistent in some cases, were not so in others. Thus, for Ohio, the average annual death rate by lightning per unit of 100,000 agricultural laborers was 24; Indiana, 28; Illinois, 11; Iowa, 23; Michigan, 19; Wisconsin, 13. There is no reason known for the apparent immunity of agricultural laborers in Illinois from lightning stroke. In other States, especially those in which stock raising and mining interests predominate, the results were not satisfactory.

The unit of comparison next selected was 1,000,000 persons engaged mainly in outdoor pursuits, classed as follows: Agricultural laborers, apiarists, dairymen, dairywomen, farmers, planters, overseers, fishermen, oystermen, gardeners, florists, nurserymen, vine growers, lumbermen, raftsmen, quarrymen, stock raisers, herders, drovers, wood choppers, and others.

The enumeration of persons engaged in those pursuits was made in 1890 (Eleventh Census, Population of the United States, Part II, Table 79), and, therefore, the absolute values of death rate are a little greater than they would be for the population of the years

1896–98, but for comparative purposes this does not greatly matter. The ratio of fatalities per 1,000,000 persons engaged in outdoor pursuits is shown in the table below, both by States and geographic districts. We have added, for the sake of comparison, the ratio per million of rural population, defining as that element persons living in the country or in cities containing less than 8,000 inhabitants.

The statistics do not extend over a period long enough to enable us to draw definite conclusions as to the relative frequency of deaths by lightning stroke in the several States and Territories, but if we group them by larger geographic divisions having about the same thunderstorm frequency, we obtain what may be considered a first approximation to the true distribution. Such a grouping has been made, the results appearing in Table II.

We may observe in regard to the results shown in this table, first, that in the older and more densely populated districts, New England and the Middle Atlantic States, the proportion of fatal cases is more uniform than might be expected, and, second, that the number of fatal cases is generally large in regions of relatively great thunderstorm frequency, as shown by Plate I.

In the South Atlantic and Gulf States several incongruous results appear. Thus, the ratio of deaths in North Carolina, Georgia, Louisiana, and Alabama would appear at first sight to be considerably below the true figure and out of all proportion to the average number of thunderstorms. This may be due to a failure to report all deaths, particularly those of the colored race.

In Tennessee and the States of the Ohio Valley the figures seem to indicate as great a frequency as was observed in the Middle States, although the frequency of thunderstorms is somewhat greater.

The States of the central Mississippi Valley, except Iowa, show a smaller proportion of deaths than was to be expected.

The districts showing the greatest proportion of fatal cases are the Missouri Valley, the Plains, and the Rocky Mountain and Plateau regions. We should not fail to point out, however, that while the States of Montana, Wyoming, and Colorado contain a relatively small agricultural population, the proportion of fatal cases to the total population is twenty-one in a million, an unusually high rate.

The ratios obtained for Oklahoma and North Dakota were not used in computing the district averages. It is quite probable that the rate of increase in the population of Oklahoma subsequent to the organization of that Territory in 1890, has been considerably greater than in the older neighboring States. In the case of North Dakota, however, there has been, so far as known, no extraordinary increase in population. If we assume that the population has doubled within the last eight or nine years, the ratio of deaths to the total population is still very high, viz, sixteen in a million.

It should be remembered that the correctness of the ratios of the table depends in a measure upon the size of the numbers whence they were derived. In general, the larger the figures the greater is the probability that the corresponding ratios are correct. The smaller the numbers the greater is the possible error in the ratios derived from them.

TABLE II.—*Number of deaths by lightning in the United States during the three years,* 1896, 1897, *and* 1898, *also the ratio of deaths in a million living, classed as follows: Persons engaged in outdoor pursuits, rural population, and total population.*

State and district.	Total population. [1890.]	Total in 3 years.	Rate per million.		
			Outdoor pursuits.	Rural population.	Total population.
(1)	(2)	(3)	(4)	(5)	(6)
New England.					
Maine	661,086	2	8	1	1
New Hampshire	376,530	3	23	4	3
Vermont	332,422	5	30	5	5
Massachusetts	2,238,943	11	45	5	2
Rhode Island	345,506	1	27	5	1
Connecticut	746,258	6	41	6	3
Average		4 7	29	4	2
Middle Atlantic States.					
New York	5,997,853	63	53	9	4
New Jersey	1,444,933	16	73	8	4
Pennsylvania	5,258,014	71	70	8	5
Delaware	168,493	3	54	9	6
Maryland	1,042,390	9	30	5	3
Virginia	1,655,980	35	44	8	7
Average		32.8	54	8	5
South Atlantic States.					
North Carolina	1,617,947	14	12	3	3
South Carolina	1,151,149	46	47	14	13
Georgia	1,837,353	31	25	6	6
Florida	391,422	18	91	17	15
Average		27.2	44	10	9
Gulf States.					
Alabama	1,513,017	35	31	8	8
Mississippi	1,289,600	13	12	3	3
Louisiana	1,118,587	13	18	5	4
Texas	2,235,523	62	48	10	9
Average		30.8	27	6	6
Central Mississippi Valley.					
Arkansas	1,128,179	23	30	7	7
Oklahoma	61,834	8	192	43*	43*
Missouri	2,679,184	43	37	7	5
Iowa	1,911,896	50	52	10	9
Illinois	3,826,351	41	31	6	4
Average		33.0	68	7	6
Upper Mississippi Valley.					
Minnesota	1,301,826	24	41	9	6
Wisconsin	1,686,880	25	35	7	6
Michigan	2,093,889	41	47	8	7
Average		30.0	41	8	6
Upper Missouri Valley and Plains.					
North Dakota	182,719	18	137	33*	33*
South Dakota	328,808	8	39	8	8
Nebraska	1,058,910	24	47	10	8
Kansas	1,427,096	28	37	7	7
Average		19.5	65	8	8

*Not included in averages.

TABLE II.—*Number of deaths by lightning in the United States*—Continued.

State and district.	Total population. [1890.]	Total in 3 years	Rate per million.		
			Outdoor pursuits.	Rural population.	Total population.
(1)	(2)	(3)	(4)	(5)	(6)
Ohio Valley and Tennessee.					
Indiana	2,192,404	72	75	13	11
Ohio	3,672,316	78	64	10	7
Kentucky	1,858,635	36	37	8	6
Tennessee	1,767,518	38	38	8	7
West Virginia	762,794	6	17	3	3
Average	....	46.0	46	8	7
Rocky Mountain and Plateau Region.					
Montana	132,159	11	240	34	28
Wyoming	60,705	6	245	41	33
Colorado	412,198	22	187	28	18
New Mexico	153,593	1	14	2	2
Arizona	59,620	4	191	22	22
Utah	207,905	2	33	5	3
Nevada	45,761	0	0	0	0
Idaho	84,385	0	0	0	0
Average	....	5.8	114	16	13
Pacific Coast.					
California	1,208,130	2	5	1	1
Oregon	313,767	1	7	1	1
Washington	349,390	0	0	0	0
Average	... .	1.0	4	1	1

In comparing the relative frequency of fatal lightning strokes in the United States with that of European countries it is most convenient to consider the ratio of deaths to each million of the total population. The ratio of deaths by lightning in the United States during the nine years, 1890–1898, for which period we may assume the average population to have been, in round numbers, 65,000,000, was 5 persons in a million living. This rate is somewhat larger than generally obtains in Europe, if we except the region of the Austrian Alps and perhaps Prussia. The ratio of deaths by lightning in the provinces of Styria (Steirmark) and Carinthia (Kärnthen) for a nine-year period, is about 10 persons in a million living.[1] According to the earlier statistics for Prussia[2] for the fifteen years 1869–1883 the ratio was 4.4 in a million. A more recent publication gives the average number of persons killed by lightning in Prussia from 1882–1891 as 167.[3] On the basis of a total population of 28.5 millions during this period the ratio would be 6 in a million.

Information respecting the loss of life by lightning in Europe is not so comprehensive as might be expected. We give in the following paragraphs a brief résumé of the more important writings on the subject.

The deaths from lightning in England and Wales from 1852 to 1880,

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[1] Mittheilungen des naturw. Vereines für Steirmark. 1897.

[2] Beiträge zur Statistik der Blitzschläge in Deutschland. Hellman. Berlin, 1886.

[3] Die Zunahme der Blitzgefähr und die Einwirkung des Blitzes auf den Menschlichen Korper. Blenck. E. Berlin, 1894.

both inclusive, are given by Dr. Robert Lawson, Inspector General of Hospitals, in a paper communicated to the Royal Meteorological Society of London, January 22, 1889. (Quarterly Journal, Royal Met. Soc., Vol. XV, p. 140.) Dr. Lawson calls attention to the fact that deaths from lightning fluctuated considerably in different years; thus in 1863 there were 3 only, in 1864, 6, and in 1869, 7, while in 1852 there were 45, and in 1872, 46. Grouping them by periods it appears that the deaths in the country generally in 1852–1860, were 1.5 in one million persons; in 1861–1870, 0.65; and in 1871–1880, 0.95, the average for the whole period being 0.88, less than one person in a million.

The ratio of deaths was least in metropolitan and coast districts and greatest in the midland districts.

The published information for France is exceedingly brief. The only statistics we have been able to find are those given by M. Flammarion in Révue Mensuelle d'Astronomie populaire et de Météorologie. M. Flammarion finds that during the period 1835–1859 there were, on an average, 75 deaths annually, and that during the period 1860–1883 this number was increased to 114. The difference is explained on the ground that the statistics for the earlier years were incomplete, and that there were fewer omissions in the second series of years.

He assumes that, on an average, 114 persons are killed annually by lightning in France, or 3 for each million of living persons.

M. Flammarion points out the fact that in twenty years there was not a single death from lightning in the Department of the Seine, the metropolitan district.

Statistics of loss of life by lightning stroke in Belgium have been collected by Messrs. Evrard and Lambotte, directors of telegraph service, but only the years 1884–1889 are available. The number of persons killed during the six years was 74, or an average of 12.3 per annum. Assuming the population of the country to have been 5,800,000 during the above-named period, we have for the annual mortality by lightning a little over 2 persons in a million. The statistics for 1889, which we have drawn from Ciel et Terre, Vol. XII, p. 160, show that of the 18 persons killed 1 was within a building, 11 were without, and 6 were under trees. Forty-three persons were injured during the year, of which 20 were within buildings, 19 without, and 4 were under trees.

In Sweden the average number of persons killed annually by lightning during the period—

1816–1825 was 9.7 in 2.6 million inhabitants.
1826–1835 was 10.0 in 2.9 " "
1836–1845 was 8.7 in 3.1 " "
1846–1855 was 11.8 in 3.4 " "
1856–1865 was 10.8 in 3.8 " "
1866–1875 was 13.2 in 4.2 " "
1876–1883 was 14.2 in 4.6 " "

The increase in population from 1820 to 1880 was 77 per cent, while the increase in deaths by lightning in the same period was but 46 per cent, thus showing a relative decrease in the number of strokes. In the first period there were 3.7 deaths in a million inhabitants; in the last fifteen years of the record, 1869–1883, there were but 3.0 deaths in a million inhabitants.

In Prussia, as before stated, the ratio of deaths for the period 1869–1883 was 4.4 per unit of one million living persons, but for the ten years 1882–1891 the ratio was 6 in a million. In Baden, 1867–1883, the ratio was less, viz, 3.8. In Bavaria, 1882–1890, on a basis of a total population of 5.5 millions, the ratio was 4.4. In Saxony, 1882–1889, on a basis of a total population of 3.2 millions, the ratio was 5 in a million.

For the great Russian Empire we have been unable to obtain definite statistics. Klossovsky gives the average number of deaths in southwestern Russia for a period of seven years as 11[1]. The extent of territory included within that designation is not known; hence it is not possible to reduce the figures to a comparable basis.

Loss of property by lightning.—We have already seen that it is a difficult matter to obtain accurate returns of loss of life by lightning. In the case of property the difficulties are much greater. It would seem easy enough to deal with all property that is either directly or indirectly insured against loss by lightning; many companies, however, do not differentiate the causes of loss with sufficient minuteness to include loss due to lightning, being satisfied to include such loss under the general caption "loss by fire." In the large number of cases not covered by insurance we can form an approximate estimate of the loss or damage it is true, but we have no assurance that all of the cases of loss which occur come to our notice.

In many States of the middle west a large number of farmers' mutual fire insurance associations have been organized within recent years. These associations insure farm property, including live stock and growing crops, against loss by lightning, hail, and, in some cases, tornado. The farmers' mutuals, as they are called, operate mainly in the States of Illinois, Iowa, Minnesota, Wisconsin, Michigan, Nebraska, Missouri, Indiana, and Ohio, and it is to them we are mainly indebted for the statistics upon which this report is based.

The nature of the information sought to be collected by the Weather Bureau is shown by the following blank:

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[1] Review Meteorologique, Odessa, Vol. III, 1890–1894.

Form No. 4039—Mis.

U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

LOSS BY LIGHTNING.

Date of storm.............................., 189 ; hour of day,..............................M.
Where loss occurred, ... Township, ... Co., ...
State ....
On whose premises? ....
Kind of building struck? ....
Of what constructed (wood, brick, or stone)? ....
Kind of roof (shingle, slate, or metal)? ....
If building burned, how much loss? .... $...................
Value of contents burned .... $...................
If struck and not burned, how much damage? .... $...................
Was it provided with lightning rods? ....
If so, what metal was used? ....
What were the dimensions of buildings? Height, ...; length, ...
width, ...
How many points on the roof? ....

LIVE STOCK KILLED IN THE FIELD.

Kind of stock, ...; number, ...
Amount of loss, ...$.....................
Was the stock near a wire fence? ....
If near fence were ground wires used? ....

Please add details as to character of soil where lightning stroke occurred, whether moist or dry, whether upland or lowland, and whether timber or trees were near. Note special features of the storm, its direction of movement, etc.

(Name)...

(Post Office address)..

To be filled up and returned to Director Climate and Crop Service, Weather Bureau............

During the calendar year 1898 reports were received of 1,866 cases of buildings being damaged or destroyed by lightning, nineteen of which, however, were destroyed by reason of being exposed to other buildings that were set on fire by lightning stroke. The loss to buildings and their contents was $1,441,880. Column two of the table below shows the number of buildings damaged or destroyed in each State and Territory; columns three to six show the kind of building damaged or destroyed; columns seven to ten the character of the roof; columns eleven to fourteen whether or not the buildings were equipped with lightning rods; and, finally, columns fourteen to sixteen show the number of known and unknown cases of injury or destruction and the amount of loss in the known cases.

The average loss was $1,276. If we omit, however, six isolated cases of very heavy loss, aggregating $648,000, the average loss would be reduced to $700, an amount more in consonance with the real figures, it is true, but yet seemingly too high.

TABLE III.—*Buildings struck and damaged by lightning in the United States in* 1898.

States.	Total number.*	Kind.				Character of roof.				Rods.			Loss.		
		Barns, sheds, warehouses, etc.	Churches and schools.	Dwellings, stores, and office buildings.	All others.	Wood.	Slate.	Metal.	Unknown.	Yes.	No.	Unknown.	Known cases of.	Unknown cases of.	Amount on buildings and contents.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Alabama	20	5	2	11	2	15	......	......	5	1	15	4	14	6	$806 00
Arizona	1	......	1	......	......	......	......	......	1	......	......	1	......	1	......
Arkansas	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
California	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Colorado	25	8	......	16	1	20	......	4	1	......	25	......	23	2	2,382 00
Connecticut	52	24	3	25	......	2	2	......	48	1	......	51	7	45	8,750 00
Delaware	7	1	2	4	......	3	......	......	4	1	3	3	3	4	505 00
District of Columbia	2	2	......	......	......	......	......	......	2	......	......	2	1	1	1.000 00
Florida	3	......	......	3	......	2	......	......	1	......	1	2	1	2	3 00
Georgia	10	4	......	6	......	8	......	......	2	......	10	......	5	5	400 00
Idaho	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Illinois	171	95	10	63	3	120	2	3	44	7	76	86	128	43	348,097 00
Indiana	82	43	4	33	2	37	1	1	43	2	30	50	41	41	102,768 00
Iowa	58	42	......	16	......	33	1	......	23	2	26	29	37	21	17,361 00
Kansas	46	26	1	17	2	28	......	1	17	......	24	22	29	17	42,821 00
Kentucky	10	3	2	5	......	7	......	2	1	1	6	3	9	1	1,134 00
Louisiana	5	......	......	5	......	1	......	......	4	......	1	4	3	2	225 00
Maine	15	5	......	9	1	......	......	......	15	......	......	15	1	14	3,000 00
Maryland	22	11	......	9	2	15	1	......	6	4	13	5	16	6	10,785 00
Massachusetts	117	36	8	54	19	15	......	......	98	1	6	106	32	85	55,699 00
Michigan	77	52	1	24	......	46	2	1	25	......	42	32	56	21	30,840 00
Minnesota	64	32	4	27	1	30	......	1	33	1	27	36	45	19	81,252 00
Mississippi	7	2	......	4	1	5	......	......	2	......	4	3	5	2	570 00
Missouri	58	28	4	25	1	33	......	2	23	1	36	21	41	17	10,622 00
Montana	6	1	......	5	......	4	1	......	1	......	5	1	2	4	91 00
Nebraska	28	9	3	15	1	18	......	1	9	2	17	9	17	11	10,918 00
Nevada	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

New Hampshire	18	5	2	11	....	5	....	....	13	....	5	13	10	8	13,650 00
New Jersey	105	48	9	47	1	10	7	....	88	1	9	95	28	77	36,646 00
New Mexico	1	1	....	....	....	....	....	....	1	....	....	1	1	....	5,000 00
New York	395	256	17	109	13	249	8	8	121	5	243	138	281	114	439,882 00
North Carolina	41	18	1	17	5	23	....	3	15	3	18	20	26	15	10,015 00
North Dakota	12	7	3	2	....	11	....	....	1	....	8	4	11	1	1,745 00
Ohio	84	38	5	37	4	33	7	1	43	....	38	46	55	29	32,349 00
Oklahoma and Indian Territory	5	2	....	3	....	2	....	....	3	....	2	3	4	1	230 00
Oregon	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Pennsylvania	72	29	2	35	6	16	2	1	53	....	16	56	26	46	82,004 00
Rhode Island	5	1	2	1	1	....	....	....	5	....	....	5	1	4	10,000 00
South Carolina	34	17	1	16	....	24	1	2	7	....	23	11	23	11	17,006 00
South Dakota	57	28	4	25	....	47	....	1	9	....	40	17	44	13	8,932 00
Tennessee	4	1	....	2	1	2	....	....	2	1	0	3	2	2	725 00
Texas	14	4	1	8	1	9	....	1	4	2	8	4	9	5	1,615 00
Utah	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Vermont	7	3	....	4	....	1	....	....	6	....	....	7	1	6	2,000 00
Virginia	21	9	2	9	1	8	1	....	12	....	7	14	9	12	11,705 00
Washington	2	1	....	....	1	....	....	....	2	....	....	2	....	2	....
West Virginia	27	17	....	10	....	17	3	1	6	3	19	5	17	10	14,847 00
Wisconsin	75	52	1	22	....	59	....	....	16	1	52	22	66	9	23,500 00
Wyoming	1	....	....	1	....	....	....	....	1	....	....	1	....	1	....
Totals	1,866	966	95	735	70	958	39	34	816	40	855	952	1,130	736	1,441,880 00

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*The total number of strokes was 1,847; the figures given in this column include buildings set on fire by exposure to fires caused by lightning.

TABLE IV.—*Number of fires in the United States by lightning, insured buildings only.*

[From Chronicle Fire Tables.]

States.	Number of fires caused by lightning.								Kind of buildings.					Total.	Insurance in force per square mile.
	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	Barns.	Dwellings.	Churches.	Factories.	All other fires.		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Alabama	3	4	....	8	1	6	5	9	14	20	1	1	....	36	$587 00
Arizona	....	....	....	....	....	....	....	2	1	....	....	....	1	2	....
Arkansas	3	2	....	1	....	....	5	....	5	3	3	....	....	11	13 00
California	1	....	....	1	....	....	2	1	2	3	....	....	....	5	2,379 00
Colorado	3	....	....	....	....	....	5	10	7	10	1	....	....	18	46 00
Connecticut	32	17	45	23	14	37	58	19	129	95	10	8	3	245	289,366 00
Delaware	9	7	6	3	3	6	6	5	34	5	....	1	5	45	14,087 00
District of Columbia	0	....	....	1	2	1	2	....	2	3	1	....	....	6	735,286 00
Florida	2	2	3	7	3	7	3	6	8	24	1	....	....	33	....
Georgia	11	5	2	13	10	6	20	19	42	36	4	1	3	86	847 00
Idaho	....	....	....	....	....	....	1	....	....	1	....	....	....	1	....
Illinois	25	30	25	38	58	66	104	72	236	139	22	6	15	418	8,683 00
Indiana	42	41	58	48	46	26	144	96	347	98	32	10	14	501	1,239 00
Iowa	27	21	12	14	37	45	67	82	211	51	20	9	14	305	4,752 00
Kansas	1	5	3	7	10	14	40	22	57	36	5	3	1	102	97 00
Kentucky	16	7	7	9	4	5	28	23	55	34	6	2	2	99	1,961 00
Louisiana	9	4	5	3	4	1	5	6	5	27	4	....	1	37	2,817 00
Maine	19	29	40	20	50	22	32	25	157	73	5	1	1	237	340 00
Maryland	8	14	19	16	33	22	41	40	143	41	1	2	6	193	16,105 00
Massachusetts	25	24	40	35	40	54	42	43	144	123	20	14	2	303	123,296 00
Michigan	31	33	86	55	69	35	162	74	396	114	21	7	7	545	3,918 00
Minnesota	15	19	18	6	13	21	46	34	89	57	5	5	16	172	1,848 00
Mississippi	2	1	2	3	2	2	2	6	8	8	2	1	1	20	108 00
Missouri	17	9	7	32	40	9	51	47	117	72	9	10	4	212	1,979 00
Montana	0	....	0	0	0	0	3	2	4	1	....	....	....	5	....
Nebraska	6	6	3	17	10	15	37	16	63	34	8	3	2	110	677 00
Nevada	0	0	0	....	0	....	2	....	....	2	....	....	....	2	....
New Hampshire	9	4	4	9	13	6	11	20	50	23	2	1	....	76	20,029 00
New Jersey	34	19	46	24	39	54	97	38	233	101	11	3	3	351	44,846 00
New York	88	41	171	97	95	154	175	191	733	223	25	21	10	1,012	106 424 00

North Carolina	9	3	7	6	8	6	13	7	31	18	5	5	......	59	533 00
North Dakota	1	1	2	2	......	1	6	6	17	1	......	1	......	19	5 00
Ohio	60	36	43	36	28	15	134	238	448	100	23	13	6	590	9,764 00
Oklahoma and Indian Territory	......	......	0	......	3	2	......	3	1	6	......	......	1	8	......
Oregon	......	2	0	......	......	......	1	......	2	1	......	......	......	3	231 00
Pennsylvania	75	39	119	32	104	93	182	214	613	187	34	12	12	858	51,699 00
Rhode Island	4	1	6	13	9	7	19	15	23	43	1	3	4	74	36,861 00
South Carolina	2	4	0	1	6	3	9	4	15	12	2	......	......	29	145 00
South Dakota	......	5	7	......	6	9	17	12	31	18	1	2	4	56	223 00
Tennessee	1	......	1	3	6	8	28	16	36	22	4	1	......	63	7,657 00
Texas	5	9	11	15	16	10	13	17	49	39	5	......	3	96	33 00
Utah	......	......	2	......	......	......	......	3	3	2	......	......	......	5	......
Vermont	......	......	5	6	7	10	16	19	45	15	2	......	1	63	5,520 00
Virginia	5	......	9	12	9	4	16	19	43	22	4	......	5	74	1,566 00
Washington	......	2	0	......	1	1	1	3	2	3	2	......	1	8	30 00
West Virginia	3	1	4	2	3	4	14	13	34	9	1	......	......	44	633 00
Wisconsin	22	10	21	42	49	52	73	49	205	79	24	7	3	318	5,996 00
Wyoming	......	......	......	......	1	......	......	2	1	1	1	......	......	3	......
Total	625	457	839	660	852	839	1,738	1,548	4,891	2,035	328	153	151	7,558	......

The average amount paid by insurance associations of Michigan on 4,612 claims for indemnification of loss by lightning was only $111. We should remember, however, that the amount of the average loss in the different sections of the country will vary according to the character of the buildings and improvements. Thus, in Massachusetts, according to Table III, there were thirty-two cases of buildings struck by lightning in 1898, causing damage to the amount of $55,698, or an average of $1,740 per building. On the other hand, forty-four cases of damage to buildings in South Dakota gave an average loss of but $203 per building.

The great property loss in the States of Illinois, New York, Pennsylvania, Indiana, and Minnesota, shown by Table III, is partly due to single cases of heavy loss. Thus, in Illinois the total destruction of a brewery set on fire by lightning involved a loss of $300,000. In the State of New York there was a single loss of $150,000 and a large number of losses exceeding $2,000 each.

The total property loss during the year due to lightning, on the assumption that an average loss of $700 was maintained in the 736 unknown cases, would be about $2,000,000. It is reasonable to suppose, however, that the loss in a great majority of the unkown cases was trifling, and that the total loss in the 1,866 cases was not much over $1,500,000.

The figures in column 2, Table III, showing the number of damaging lightning strokes in the several States and Territories are incomplete in a number of cases. No returns, whatever, were received from Arkansas, a State in which the damage by lightning stroke is believed to be rather above than below the average.

The fidelity with which the figures in column 2 represent the actual number of damaging lightning strokes in any State must depend, among other things, upon the proportion of insured to uninsured buildings, the density of inhabited buildings, and the frequency of thunderstorms. The returns from Iowa, Illinois, Minnesota, Wisconsin, Michigan, Indiana, Nebraska, Ohio, New York, and Missouri, are probably more accurate than those from other States and Territories. If present conditions as to collecting statistics remain unchanged for a term of years it will be possible to detect any considerable increase or diminution in the number of damaging lightning strokes, and thus satisfy one of the objects of this inquiry. It will not be possible, however, to determine with reasonable approach to accuracy the regions of greatest danger from lightning. Such a desideratum can not be accomplished until the number of buildings per unit area and the ratio of insured to uninsured are better known than at present.

Table IV shows the number of fires by lightning and the money value of property destroyed during the period 1890–1897 as reported in the Chronicle Fire Tables. (The Chronicle Company, Limited, New York.)

Loss by lightning in 1890	$ 1,618,539 00
1891	1,487,322 00
1892	3,251,494 00
1893	1,843,872 00
1894	2,507,061 00
1895	1,839,786 00
1896	2,936,985 00
1897	2,187,710 00
Total in eight years	$17,672,772 00

We see in Table IV the need of information relative to the proportion of insured to uninsured buildings in the various sections of the country, and this is our reason for adding column 16 to the table as originally prepared. The figures in that column show the total fire risks in force per square mile in each State and Territory on December 31, 1889, (Eleventh Census, Report on Insurance Business, Part I, p. 1004). The small number of fires from lightning in a number of States wherein the frequency of thunderstorms is above the average for the whole country is explained by the relatively small number of insured buildings in those States.

LIVE STOCK IN THE FIELDS KILLED BY LIGHTNING.

Table V shows the number of cattle, horses, mules, and other domestic animals that were killed by lightning in the fields during 1898. The money value of the stock so killed, and the number of lightning strokes are shown in columns 7 and 8, respectively. In this table, more than in any of those which have preceded it, the completeness of the statistics is dependent upon the number and distribution of farmers' mutual insurance agents and adjusters. As we have already remarked, these associations are most numerous in Iowa, Illinois, Minnesota, Wisconsin, Michigan, Indiana, Nebraska, New York, Ohio, and Missouri, for which States the returns are generally more complete than for others, with the exception of Colorado and South Dakota. Both of the last-named States come well within the area of frequent thunderstorm action, and the fatalities from lightning appear to have been faithfully reported. Unfortunately we were unable to secure returns from Wyoming and New Mexico, in both of which regions the conditions are much similar to those which obtain in Colorado.

The remarks made on a previous page regarding the lack of information as to the proportion of insured to uninsured buildings apply with even greater force to live stock. It is quite evident from an examination of the figures in the table that we can not draw any conclusions as to the comparative danger from lightning in different parts of the country.

The total number of damaging strokes that fell upon live stock in the field in the whole country was 700, or 27 per cent of the whole number of damaging strokes observed. While this percentage generally holds good there is one notable exception, viz, in Iowa, where 73 per cent of the total number of damaging strokes fell upon live stock. The reason for the reversal of the general rule in that State is not known. We suspect, however, that it is partly due to the completeness of the record, the cases of damaging lightning stroke upon live stock in that State apparently having been reported with great faithfulness. The Director of the Iowa Weather and Crop Service, commenting upon the loss of live stock by lightning during the past year, says in his September, 1898, Monthly Review:

> These reports show the interesting fact that of the 266 head of live stock killed by lightning, 118 were found in close contact with wire fences; and also that these wire fences were not provided with ground wires. That is to say, over 44 per cent of the losses of live stock may have been caused by contact with wires charged with electric force.
>
> Unquestionably wire fences, as now constructed, serve as death traps to live stock, causing a vast amount of loss every year. And it is also quite evident that a considerable percentage of danger may be avoided by the use of ground wires at frequent intervals, in the construction of wire fences. In some of the reports it was stated that there were evidences that the lightning struck the fence at a considerable distance from the point where the stock was killed.

The wire fence has come into extensive use in the west and southwest and is destined to come into far greater use in the future. The lesson taught by the statistics collected in Iowa and other States is that precautions should always be taken to minimize the probable loss by lightning in all cases where stock is exposed to wire fences during thunderstorms. The use of ground wires, as suggested above, is calculated to lessen the danger from lightning. The subject should receive immediate attention. Nearly one-third of all the cases of damaging lightning strokes in the fields occurred in the immediate vicinity of wire fences.

The returns from California and Colorado afford two cases of very heavy mortality in as many flocks of sheep. In the first case, lightning struck a tall pine tree, under which a flock of nearly 200 sheep were huddled in the manner characteristic of that animal. The flash was quite severe. The two herders, who were a short distance away, being rendered unconscious for a few moments. Fifty-two of the sheep were killed outright, and others were stunned but not seriously injured. The accident occurred at Poison Lake, near Butte Creek, Lassen County, California. The second accident occurred on the farm of Mr. David Laybourn, near Cope, Colorado, 91 sheep being killed by a single stroke. The details are at present lacking.

Owing to the widely varying conditions which obtain in different sections of the country the statistics are worthless for comparative purposes. It is to be hoped, however, that their publication will awaken a lively interest in the matter, and greatly increase the number and completeness of the reports for the present year.

TABLE V.—*Live stock in the fields killed by lightning during* 1898.

States.	Cattle.	Horses.	Mules.	Pigs.	Sheep.	Value.	No. of strokes.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Alabama			1			$35	1
Arizona	9					201	4
Arkansas			2			100	1
California					52	104	1
Colorado	54	19	1		91	2,595	34
Connecticut	7					175	3
Delaware				3		30	1
District of Columbia							
Florida							
Georgia	3	3	2			490	6
Idaho							
Illinois	164	33		44		6,733	98
Indiana	40	8		4	8	1,541	17
Iowa	162	40	1	7	32	6,897	153
Kansas	67	12				1,418	28
Kentucky	7		1			325	3
Louisiana			1			70	1
Maine							
Maryland	5	3				470	6
Massachusetts	2	2				100	2
Michigan	22	15		9	77	1,695	34
Minnesota	18	20				1,717	21
Mississippi			1			150	1
Missouri	74	15	2	1		3,138	37
Montana	3	1				235	3
Nebraska	36	26	1			2,447	29
Nevada							
New Hampshire	2					50	1
New Jersey	18	1		3		575	12
New Mexico							
New York	74	17		10	55	3,587	41
North Carolina	7	4	2	10		606	8
North Dakota	7	6		1		620	8
Ohio	21	18	1	5	28	1,824	25
Oklahoma and Indian Territory	10					280	1
Oregon							
Pennsylvania	2	8	1			1,465	7
Rhode Island							
South Carolina	5	5	8	10		1,045	13
South Dakota	26	23		1	8	2,086	25
Tennessee							
Texas	2	3	5			480	4
Utah							
Vermont							
Virginia	8	3		4		480	7
Washington		1				60	1
West Virginia	3	1			6	228	2
Wisconsin	106	19		4	69	4,205	71
Wyoming							
Totals	964	306	30	116	426	48,257	710

THE CHARACTER OF THE SOIL.

In the great majority of reports no mention was made as regards the character of the soil at points struck by lightning, perhaps for a lack of information on soil nomenclature.

In very general terms we may say that all soils consist of more or less finely powdered and decomposed rock, sand, clay and vegetable matter, changed to a greater or less extent toward the condition of vegetable mold or humus. The relative proportions of these three principal constituents determine, in a general way, the classification of soils according to their nature. Accordingly we have those in which sand predominates, known as light or sandy soils; those in which clay is the principal element, known as heavy or clayey soils, and, finally, soils containing at least 5 per cent of humus, known as vegetable soils. These latter may be further subdivided into clayey humus, loamy humus, and sandy humus.

In addition to the above general classification we should include what is commonly known in the middle west as *prairie* soil, viz, a soil of very fine, close texture and of great fertility. This soil is found in Indiana, Illinois, Iowa, Kansas, Nebraska, and other States. It is a drift soil or diluvial deposit, and of a different formation from the alluvial soil of the river bottoms. There is also the fine clay-like soil "loess," found principally along the Missouri and Mississippi river bottoms.

Practical men are apt to classify soils in various ways, as for example, according to their weight or agricultural value. In an investigation of this character a very broad and general classification answers best. The classification we would recommend is as follows: sandy soils, clayey soils, and loamy soils (the latter such as have their grains intermediate between those of the sandy and heavy clayey types), prairie soils, swamp and loess soils. The term "prairie" should be applied to upland soils to distinguish them from the alluvial soils of river bottoms in the same neighborhood.

The order of frequency of lightning stroke on the various soils in percentages, deduced from 380 reports is as follows: loam, 26 per cent; sand, 24 per cent, clay, 19 per cent; prairie, 19 per cent; scattering, 12 per cent.

We fail to see wherein the character of the soil should have a marked influence upon the frequency of lightning stroke. We may observe, however, that the order of frequency as given above, is about the same as found by Dr. G. Hellmann for North Germany, although the percentage of strokes upon loam in the last-named country was much greater than in this country. The figures given by Dr. Hellman are as follows:

> If we call the liability (to lightning stroke) for chalk formation 1, then it is 2 for marl, 7 for clay, 9 for sand, and 22 for loam. (Beiträge zur Statistik der Blitzschläge in Deutschland, Berlin, 1886).

KIND OF TREES STRUCK BY LIGHTNING.

Aside from the interest that belongs to this question from a scientific point of view, there is a practical consideration of much importance, viz, if certain trees are found to be good lightning conductors, such trees only should be planted around the home and outbuildings as a natural and inexpensive form of lightning rod, and these trees should be avoided as a temporary refuge in time of thunderstorm.

As long ago as 1787 Mr. Hugh Maxwell, of Massachusetts, called attention to the fact that lightning often strikes the elm, the chestnut, every species of the oak and pine, but rarely, if ever, the beech, birch or the maple. (Memoirs American Academy of Arts and Sciences, Vol. II, p. 143.)

Professor Dennison Olmstead of Yale College remarked in 1850 in a paper read before the American Association for the Advancement of Science, that there is a popular impression in the southern part of the United States that the pine is more apt to be struck by lightning than other trees. This impression, he further observed, could not be due to the fact that in certain districts pine forests are the most extensive of any, since even when mixed with other trees of the forest the pine seems most frequently assailed, notwithstanding its resinous character which would lead us to expect for it an exemption from attacks of lightning. Professor Elias Loomis, commenting upon Professor Olmstead's paper, stated that in Ohio there is a common belief that the beech is never struck, although he had knowledge of one such being struck.

A correspondent of the St. Louis Globe-Democrat (1898) contributes the following in regard to the immunity of the beech from lightning:

> In your issue of the 11th instant, page 42, under the heading "News of Electricity," the question is asked: What tree is safest for shelter in a thunderstorm? The answer is the beech. It is not the first time this tree has been mentioned as a protector from lightning in your paper. Some years ago a contributor recommended the planting of beech trees around the farm to protect man and beast from lightning, with the statement that lightning had never been known to strike one.
>
> I will give you the result of my investigation on the subject. The woodland on the home of my youth in the State of Florida was beech hummock. At that time (from 1850 to 1855) we subscribed for the Southern Cultivator. An article in that paper recommended the planting of beeches about the farm as a protection from lightning stating they were never struck by it. After reading the article I went at once to the hummock in search of a beech struck by it. I soon found two, not more than 20 feet apart, struck apparently by the same discharge, and only a short time prior to the discovery as the fresh mark on the bark indicated. But instead of ripping off a strip of bark and wood 2 or 3 inches wide, as it would have done on an oak or a pine, it simply ploughed a narrow groove through the bark about the eighth of an inch wide. It looked like the channel cut with a woodcarver's paring tool. I watched them afterward to see if they would wither and die from the shock, like other kinds of timber, but they did not. The rents soon began to heal by new bark growing over them, and in a few months formed a ridge or vein along the side of the stroke about 1½ inch wide and protruding above the level of the trunk about half its width ⅝ of an inch. Such veins on beeches always result from a stroke of lightning. In regard to trees rent and torn asunder when the bark is dry and only scorched when it is wet, it is probable the bark of the beech, being so smooth, will, when covered with a film of water in a rain, conduct electrical discharges to the ground without injury to the tree.

In Germany, as in perhaps no other country, matters affecting the welfare and preservation of the forest receive very great consideration. We are, therefore, not surprised that the comprehensive plan of observation and experiment in German forests, instituted by the government in 1875, should yield among other things a striking confirmation of the opinion expressed by Hugh Maxwell, as before stated. The observations to which we particularly refer are those conducted by the overseers of nine forestry stations scattered throughout an area of about 45,000 acres in the dukedom of Lippe.

The results of these observations have already been published, but we doubt if they are familiar or generally accessible to American readers, and we, therefore, insert them here. We should first observe that the percentage of the various species of trees of which the forest is composed is, approximately, as follows: beech, 70 per cent; oak, 11; pines, 13; firs, 6.

Number of trees struck by lightning.

Variety.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1890.	Total.
Oak	17	45	11	9	4	40	27	6	159
Beech	7	4	1	1	....	6	2	....	21
Pine	6	3	1	....	....	4	3	3	20
Fir*	9	11	....	....	....	23	11	5	59
Birch	....	1	....	....	....	2	1	....	4
Larch	....	2	....	....	....	1	4	.....	7
Ash	1	1	....	....	....	2	1	....	5

*Pinus Silvestris.

If the liability of the beech to lightning stroke be considered as 1, we obtain for the remaining principal varieties the values shown in the following table:

Liability to lightning stroke of the oak, pine, and fir. (*Beech* = 1.)

Variety.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1890.
Beech	1.0	1.0	1.0	1.0	....	1.0	1.0	†
Oak	15.5	71.6	70.0	57.3	*	42.4	85.9	....
Pine	4.6	4.0	5.4	....	....	3.6	8.1	....
Fir	15.0	32.1	....	....	....	44.7	64.2	....

*Only oaks struck. †No beeches struck.

The above figures seem to show that the liability of the oak is always many times greater than that of the beech and that it varies considerably from year to year.

A very elaborate and rather ingenious investigation of the underlying causes of the seeming preference of lightning for certain trees was made by Mr. Dimitrie Jonesco, in Stuttgart, 1890, 1891, and 1892.[1] Jonesco laid aside, as having little or no influence, such physical conditions as the character of the soil, whether dry or moist, and the depth to which the roots of trees penetrate. He began his experiments by determinating the conductivity of the wood of different species of

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[1] Ursachen der Blitzschläge in Bäume. Stuttgart, 1892.

trees, a line of research previously followed by Du Moncel,[1] who failed, however, to reach definite conclusions.

Experiments with oak and beech indicated that the former was a much better conductor than the latter, thus confirming observations in the forests of Lippe, if we assume that conductivity plays the most important part. The cause of the better conductivity of one species of trees as compared with another was next sought, and as a first experiment it was looked for in the moisture contents of fresh wood—wood fresh cut from living trees—of different species. The percentage of moisture according to Schubler and Hartig is: for black poplar 51.8 per cent, beech 39.7, and oak 35.4. It was found, however, that the conductivity of wood was independent of its moisture contents.

Extending the range of the experiments so as to include a microscopic examination of the different woods, Jonesco found that the fresh wood of trees, rich in fatty materials, (Fettbäume), was in all cases a poor conductor of electricity, and the greater the proportion of fatty materials in the wood the poorer the conductor. The fresh wood of trees rich in starchy materials (Starkebäume) but poor in fatty materials, on the other hand, conducted electricity very well, although no important differences were noted for the various kinds of wood.

The distribution of fatty materials and starch in the wood of trees has been investigated by Fisher[2] and Suroz,[3] who have shown that the quantity of oil and starch varies with the time of year. It is possible to distinguish, therefore, (1) trees whose wood is always rich in fatty material, for example, walnut and beech; (2) trees whose wood in summer is deficient in fatty materials, as the pine, and finally (3) trees whose fatty contents are intermediate between those of classes 1 and 2, their fatty contents in winter falling below those of No. 1, and in summer rising considerably above those of class No. 2. Trees rich in fatty materials in summer appear to possess a high degree of immunity from lightning stroke, those richest in oil having the greatest immunity. On the other hand, trees deficient in fatty materials during the thunderstorm season, as also the trees rich in starch, are preferred by the lightning. The fact that lightning in winter thunderstorms is rarely observed to strike trees is explained on the ground that the wood of most of our cultivated trees is rich in oil during winter.

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[1] Recherches sur la conductibilitée électrique des corps médiocrement conducteurs et les phénomènes qui l'accompagnent. (Annales de chimie et de physique. 5 serie. T. X. S. 471 ff.)

[2] Beitrage zur Physiologie der Holzgewachse. (Pringsheim's Jahrb. für wissensch. Botanik. Bd. VII.)

[3] Öl als Reservestoff der Bäume. (VIII Kongress russicher Naturforscher und Ärtzte; Botanik s. 24–28; russisch.)

As a check upon his work Jonesco took the wood of typical trees rich in fatty materials, beech and walnut, and found, after depriving them of their oil by means of ether, that the conductivity was increased and became practically the same as that of typical trees rich in starchy material (Starkebäume).

In general, the effect of lightning stroke on trees is to plow one or more furrows down the side as shown in Plate II. The tree in this illustration is a black walnut (*Juglans nigra, L.*) a little over 2 feet in diameter, situated on the edge of a forest and about 100 paces from a barn, which together with a dwelling house, the latter surrounded by locust trees (*G. triacanthos, L.*) stands on the knob of a slight eminence. The tree was struck in January, 1899. A much more destructive effect is shown in Plate III. The tree in this case is an oak (*Q. rubra, L.*) 16 inches in diameter and about 50 feet high. It was struck in the summer of 1898, and the photograph from which the illustration was made was taken in March, 1899. The trunk of the tree lies on the right side of the stump as it fell. It is not very clearly outlined in the photograph on account of the dead leaves that still cling to the branches. The remarkable feature in this case is the fact that there is not a single vestige of the effect of the lightning stroke on the prostrate trunk above the point of fracture or splintering. It would seem as if the entire force of the discharge was felt only at the point of fracture. The ground at the root of the tree was not disturbed, and save for a slight crack, the stump is intact at the surface of the ground. Another, and somewhat similar case of complete fracture of the trunk of a tree by lightning, was observed in the same neighborhood. In the latter case there was less splintering, probably owing to the toughness of the wood, red cedar, (*J. Virginiana L.*) and the stump showed no injury below the point of fracture. Unfortunately, the top of this tree had been cut up for fuel and carried away before we could examine it. The features above described are not new, a correspondent of Symons's Monthly Magazine, Vol. VII, p. 184, having described somewhat similar ones in 1872.

The suggestion that the effects as above described were caused by horizontal strokes is scarcely admissible. While photographs of lightning show that occasionally a discharge takes place in a horizontal plane it is not seen how such a discharge could strike a single tree in a relatively dense forest without injuring others in its path.

The behavior of lightning in the matter of striking terrestrial objects presents many, at present, inexplicable features. That there is some process of selection whereby one species of tree is preferred to another seems to be an established fact, but the reason for such preference does not seem to be definitely known.

It is difficult to conceive that the difference in the conductivity of one species of tree as compared with another, or in the same species at different seasons, is great enough to have a marked influence upon an electrical discharge from cloud to earth or *vice versa.*

We have noticed, and our observation has been confirmed by the experience of others, that in some localities lightning seems to exercise a decided preference for small apparently isolated areas which thus acquire a local reputation as being dangerous resorts in time of thunderstorm. Such local danger spots do not possess, so far as our observation goes, any common characteristic, whether we consider the character of the soil or the topographic features; although they are more generally found on ridges and points slightly elevated above the general surface of the country than in the valleys. Elevation, however, does not seem to have a decided influence in determining the point of discharge.

The foregoing details are brought to the attention of our readers in the hope of arousing a lively interest in, and a close observation of, the results of lightning strokes on trees.

IS THE DANGER OF LIGHTNING STROKE INCREASING?

The above question is frequently asked. Such an interrogatory is naturally suggested by real though temporary increases in one region or another, such as occurred in the Lake region in 1896. In Michigan the number of cases of damage by lightning stroke reported to the Commissioner of Insurance in 1895 was 316, covering damages amounting to $37,563. In the following year the number of cases rose to 1,509, and the damages to $143,841. There was an increase in the number of thunderstorms also, but not in so great a proportion. Unfortunately it is not possible, on account of the fragmentary and incomplete nature of the data now available for the United States, to delimit, in all cases, the regions in which such temporary increases have occurred. The writer gives it as his opinion, in the absence of specific data, that electric disturbances vary from year to year more in intensity than in frequency, although there is undoubtedly a noticeable variation in frequency also.

Statistics of thunderstorm frequency are much more complete than those of damaging lightning stroke, but since it does not appear that the one is a simple function of the other, we have not attempted to draw any conclusions respecting the alleged increase of lightning strokes from the record of thunderstorm frequency. Thunderstorm activity often begins almost simultaneously over a rather large region and it may continue intermittently for a day or so, when, without any apparent reason, there is a decided increase in the violence of the storms. Again, violent thunderstorms may occur in the same district on two successive afternoons, but this is the exception rather than the general rule. A single outburst of electrical energy, such as occurred in the State of New York, August 23 and 24, 1898, is very often sufficient to turn what would otherwise have been a normal season into one of increased destructiveness.

We have no means of determining the cause or causes of these violent manifestations of electrical phenomena. So far as we have observed they occur in connection with the movement of sluggish cyclonic areas across the country during the warmer months, May to September, inclusive. The regions liable to visitation by these manifestations are in general the Lake region, the upper and middle Mississippi Valley, and from Missouri eastward to the Atlantic. What little progressive motion they have is generally to the eastward. Not infrequently the development of unusually severe conditions takes place, as before stated, in the afternoon almost simultaneously over a considerable area. Some years are almost free from violent electrical storms, while in others they occur with considerable frequency. Rarely is there an excess of them in all parts of the country in one and the same year.

The most comprehensive statistics for the study of secular variation in damaging lightning strokes that we know of are those of the German Empire. Dr. Wm. von Bezold, as early as 1869, in a study of the statistics collected by insurance associations of Bavaria,[1] expressed the opinion that in that kingdom to the right of the Rhine there was a steady increase in danger from damaging lightning stroke. He again took up the subject in 1874[2] and in 1884,[3] finding in both cases a continuation of the increase first noted in 1869.

Dr. G. Hellmann, discussing the same subject in 1886, with particular reference to Schleswig-Holstein, Baden, and Hesse, showed that the increase already noted for other parts of Germany did not obtain in all parts of these provinces, there being localities where the danger was apparently decreasing.

The subject, as viewed from an insurance standpoint, was investigated in 1889, 1892, and 1898, by Mr. Kassner, Director Fire Insurance Associations of Middle Germany.[4]

From Mr. Kassner's compilations we learn that from 1876 to 1883, in a million insured buildings in the German Empire, 164.2 were struck by lightning; from 1884 to 1891 the number rose to 258.4. For middle Germany alone the increase was greater but the period covered by the statistics was different. From 1864 to 1876 the average num-

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[1] Poggendorff's Ann. Bd. 136. S. 513 ff. 1869.

[2] Sitzungsber. d. k. b. Akad. d. Wiss. II Cl., S. 284 ff. 1874.

[3] Abhandl. d. k. b. Akad. d. Wiss. II Cl. XIV. Bd. 1, Abth. S. 172 ff. 1884.

[4] (*a*) Ueber zündende und nichtzündende Blitze. Merseburg, 1889. (*b*) Ueber Blitzschläge in Deutschland während der Jahr 1876 bis 1891. Merseburg, 1892. (*c*) Ueber Blitzschläge in der Province Sachsen und dem Herzogthum Anhalt. 1887–1897. Merseburg, 1898.

ber of buildings struck and damaged by lightning was 110.8; for the period, 1877 to 1889, the number was 223.1.

Mr. Kassner's most recent work, from which we extract the following, refers exclusively to the province of Saxony and the duchy of Anhalt: "In the flat country there were 804 cases of damaging lightning stroke for the five years, 1887 to 1891, as against 1,088 in the five years 1893 to 1897, an increase of 35.3 per cent. On buildings in cities the increase for the corresponding period was only 27.3 per cent."

The total number of insured buildings in the open country and city, respectively, struck by lightning in the eleven years, 1887–1897, was 2,091 and 524, thus showing the danger from lightning in the country to be nearly four times as great as in the city.

A table is also given showing the number of cases both of fire-causing (zündenden) and those which do not cause fire, (kalten) strokes for each year from 1887 to 1897. In regard to the conclusions to be drawn from this table the author says: "Finally, it follows (and certainly contrary to the early observations, according to which the increase of lightning strokes not causing fire was the greatest) that the strokes causing fire have increased more than those not causing fire."

"It is particularly shown:

(*a*) In the flat country the number of strokes causing fire rose from 164 in the first five years to 239 in the last, an increase of 45.7 per cent; the number of strokes not causing fire, from 649 in the first five years to 849 in the last, an increase of but 32.7 per cent.

(*b*) In the cities, during the same time, the number of strokes causing fire rose from 21 to 30, and increase of 42.9 per cent; those not causing fire from 188 to 236, an increase of 25.5 per cent."

We note in this connection that statistics for Bavaria, quoted on page 73, show an increase of strokes which do not cause fire, a result directly opposite to the one above mentioned.

Dr. von Bezold's most recent contribution to the subject[1] is largely a continuation of his earliest studies of fire insurance statistics for Bavaria supplemented by the data of quite recent years. The statistics for Bavaria are especially well adapted to the study of either annual or long period variations since the yearly values have been reduced in all cases to a constant unit, viz, one million insured buildings. We reproduce from Dr. von Bezold's work the table given below:

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[1] Uber die Zunahme der Blitzgefahr Während der letzten sechzig Jahre, sitzungsberichte der k. p. Akademie der Wissenschafften zu Berlin. Berlin, 1899.

TABLE VII.—*Damaging lightning strokes in the Kingdom of Bavaria for the insurance year, October of one year to September of the next, except columns* 6 *and* 7, *which are for the calendar year.*

Year.	Insured buildings in thousands.	No. of lightning strokes damaging buildings.	Number of cases per million insured buildings.		Wolf's relative sun spot numbers.	
			Actual values.	Smoothed values.	Actual values.	Smoothed values.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1833	1,021	17	16.6	....	8.5	....
1834	1,025	57	55.7	43.3	13.2	23.0
1835	1,061	48	45.3	40.0	56.9	62.2
1836	1,083	15	13.9	27.5	121.8	109.7
1837	1,085	40	36.9	27.9	138.2	125.3
1838	1,085	26	24.0	29.3	103.1	107.6
1839	1,088	35	32.2	31.7	85.8	84.5
1840	1,090	42	38.6	33.7	63.2	62.2
1841	1,095	28	25.6	27.7	36.8	40.2
1842	1,098	23	21.0	22.3	24.2	24.0
1843	1,102	24	21.8	21.6	10.7	15.2
1844	1,109	24	21.7	24.8	15.0	21.2
1845	1,115	38	34.1	34.7	40.1	39.2
1846	1,121	55	49.1	39.9	61.5	65.4
1847	1,128	31	27.5	32.4	98.4	95.6
1848	1,133	29	25.6	25.0	124.3	110.7
1849	1,136	25	22.0	24.0	95.9	95.6
1850	1,139	30	26.4	26.8	66.5	73.4
1851	1,142	37	32.4	34.1	64.5	62.4
1852	1,144	52	45.5	45.2	54.2	53.0
1853	1,144	60	57.7	47.8	39.0	38.2
1854	1,147	38	33.1	42.2	20.6	21.7
1855	1,152	52	45.1	47.5	6.7	9.6
1856	1,156	76	65.7	58.6	4.3	9.5
1857	1,159	67	57.8	58.4	22.8	26.2
1858	1,163	61	52.5	53.9	54.8	56.6
1859	1,171	62	52.9	51.2	93.8	84.5
1860	1,180	55	46.6	50.0	95.7	90.6
1861	1,183	64	54.1	51.9	77.2	77.3
1862	1,193	63	52.8	57.1	59.1	59.8
1863	1,206	83	68.8	61.3	44.0	48.5
1864	1,226	67	54.7	62.4	46.9	42.1
1865	1,244	89	71.5	59.3	30.5	31.0
1866	1,264	50	39.6	57.3	16.3	17.6
1867	1,278	99	77.5	76.7	7.3	17.0
1868	1,281	144	112.4	92.0	37.3	39.0
1869	1,292	85	65.8	76.2	73.9	81.0
1870	1,302	79	60.7	68.8	139.1	115.8
1871	1,307	115	88.0	79.3	111.2	115.8
1872	1,315	106	80.6	94.1	101.7	95.2
1873	1,328	169	127.2	105.3	66.3	69.7
1874	1,344	116	86.3	104.5	44.6	43.2
1875	1,358	161	118.6	98.3	17.1	22.5
1876	1,260	89	70.7	90.2	11.3	13.0
1877	1,279	129	100.9	89.8	12.3	9.8
1878	1,300	113	86.9	91.1	3.4	6.3
1879	1,320	119	90.2	87.5	6.0	11.9
1880	1,339	111	82.9	93.7	32.3	31.2
1881	1,357	162	119.4	103.5	54.3	50.1
1882	1,374	128	92.4	99.1	59.6	59.3
1883	1,408	130	92.3	96.6	63.7	62.6
1884	1,424	156	109.6	112.2	63.5	60.7
1885	1,440	198	137.5	143.4	52.2	48.3
1886	1,456	275	188.9	151.1	25.4	29.0
1887	1,471	131	89.1	127.9	13.1	14.6
1888	1,488	215	144.5	168.2	6.8	8.2
1889	1,503	443	294.8	221.6	6.3	6.6
1890	1,777	271	152.5	191.8	7.1	14.0
1891	1,795	300	167.2	169.3	35.6	38.0
1892	1,814	345	190.2	172.0	73.8	67.1
1893	1,835	258	140.6	154.4	85.2	79.2
1894	1,855	271	146.1	164.3	72.5	73.6
1895	1,875	421	224.5	199.0	64.0	60.2
1896	1,900	382	201.0	215.2	40.5	42.8
1897	1,926	451	234.2	....	26.3	....

The nature of the data in the several columns is generally indicated with sufficient clearness by the superscription. The smoothed values of column 5 and 7 were obtained by the formula $\frac{a+2b+c}{4}$ wherein b is the middle year and a and c the years immediately preceding and following.

We see here, as pointed out by the author, a steady increase in the danger from lightning from the first, the increase of the last ten years over the first being about sixfold. From 1833 to 1842 there were in 1,000,000 buildings 309.8 struck by lightning, an average of 31 per year; in the period 1888 to 1897, the number of buildings struck in the ten years rose to 1,895.6, an average of 190 per year, concerning which the author remarks:

> This is, at all events, a highly remarkable fact, especially in consideration of the circumstance that according to the compilations of Mr. Kassner during the period covered by his investigations, similar, and in some cases even greater increases were found for all except very inconsiderable portions of Germany. Unfortunately it is scarcely possible to express more than a conjecture as to the cause of this remarkable increase.

The compilations of the Bavarian fire insurance companies previous to 1883 did not differentiate between lightning strokes that caused fire and those which merely inflicted other damage upon the building, all cases of damage by lightning being given as loss by fire. This fact explains the substitution by von Bezold of the term *schadenblitze* (damaging lightning stroke) for *zündendeblitze* (fire-causing lightning) which it may be remembered was used in a former publication.

The following table gives the total number of strokes upon buildings, the number that caused fires, and the percentage of the latter to the whole number of strokes.

TABLE VII.—*Percentage of lightning strokes causing fire in Bavaria*, 1883–1897.

Year.	Lightning strokes.		*B* in per cent of *A*.	Year.	Lightning strokes.		*B* in per cent of A.
	A Altogether.	*B* Causing fires.			*A* Altogether.	*B* Causing fires.	
1883	130	67	51·6	1891	300	101	33.7
1884	156	64	41·1	1892	395	153	44.6
1885	198	82	41·4	1893	258	93	36.1
1886	275	97	35·3	1894	271	86	31.7
1887	131	54	41·2	1895	421	140	33.3
1888	215	78	36·3	1896	382	130	34.0
1889	443	138	31·2	1897	451	102	22.6
1890	271	92	33·9				

The figures of the above table reveal the important fact that for Bavaria, at least, while the total number of strokes has increased, the number of those which set fire to buildings has steadily diminished. We see this more clearly when we form them into 5-year means. Thus, the percentage of fire-causing strokes in the period—

1883–1887 was 42.7 per cent.
1888–1892 was 35.9 per cent.
1893–1897 was 31.5 per cent.

The author remarks that this can scarcely be considered surprising, since it is known from physical experiments that the severest discharges demolish and destroy, while the weaker and slower discharges cause fire. At any rate, it is of interest to note that with the increase in the severity of thunderstorms the so-called cold strokes increase in greater proportion than the fire-causing strokes. Of course, we should take into consideration, in connection with the last-given figures, the steady increase in the use of hard roofs; but this fact alone is not sufficient to explain the greater increase of cold strokes as compared with the strokes causing fire.

The questions here touched upon are of the greatest practical importance. Let us hope that each and everyone will contribute toward their final solution.

Plate I.

AVERAGE ANNUAL NUMBER OF THUNDERSTORM DAYS IN THE UNITED STATES.

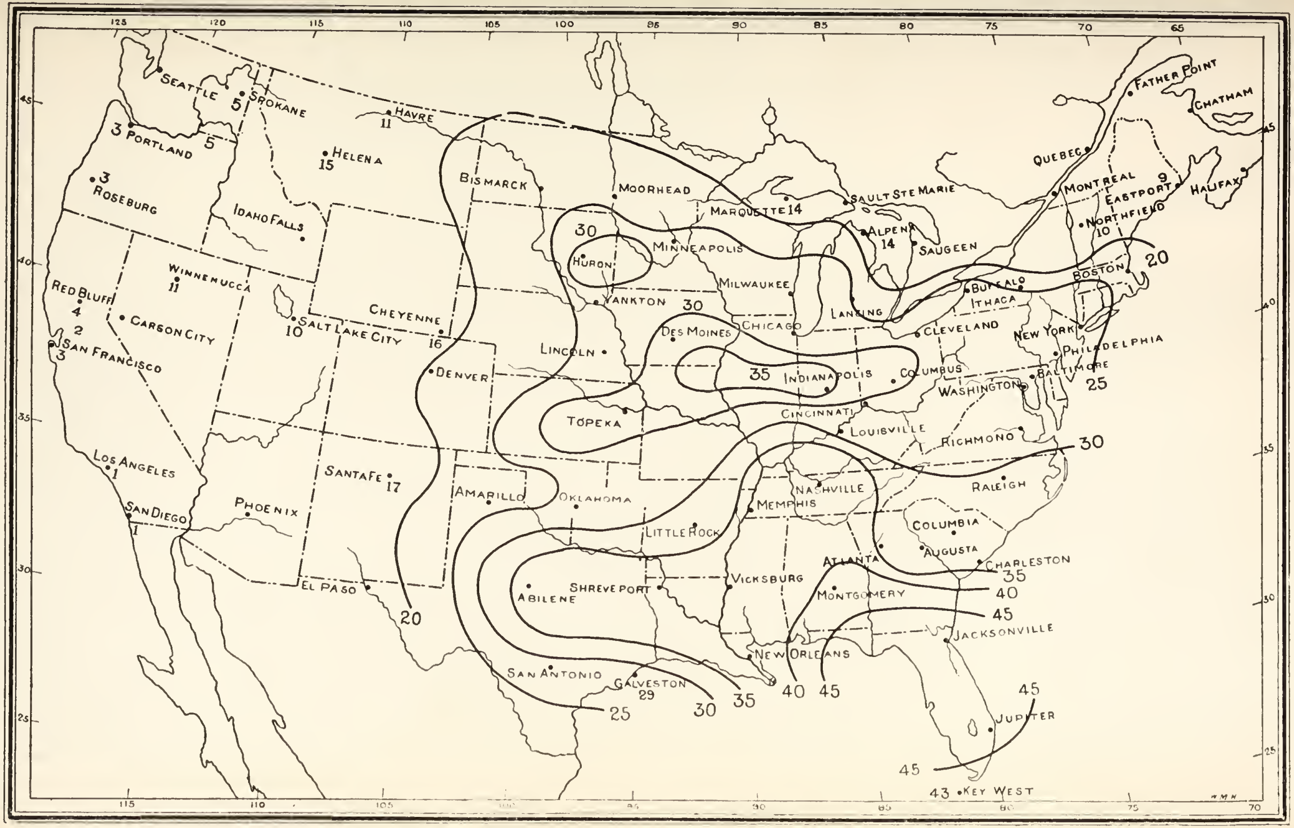

Plate II. EFFECT OF LIGHTNING STROKE ON A WALNUT TREE. Photographed by A. J. Henr

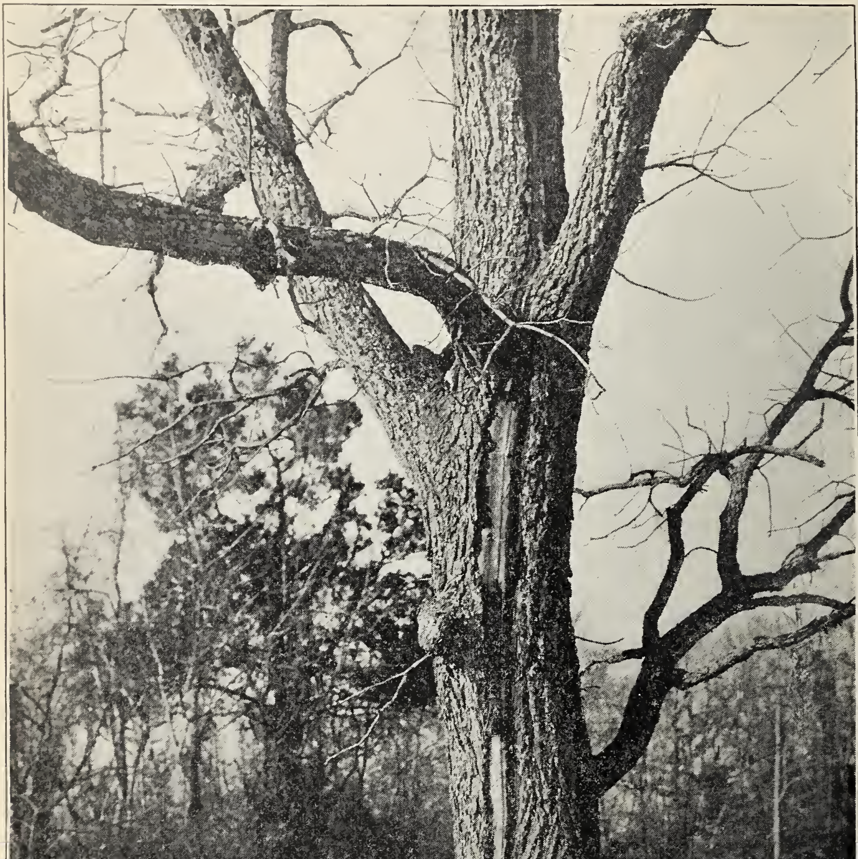

Plate III. EFFECT OF LIGHTNING STROKE ON AN OAK. Photographed by A. J. Henry.

Plate IV. BUR OAK SHATTERED BY LIGHTNING. Photographed by Frank Woodmancy.