Discharge of Electricity from the Leaves of Forest Trees

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A recent textbook on physics states that beech trees are seldom struck by lighting because of the large number of points on the leaves. This statement, made to illustrate the effect of points on the discharge of electricity, was challenged on the grounds that it was not based on proven facts. As a result of the challenge, it was suggested that I investigate the discharge of electricy from the leaves of forest trees. The subject "where lightning strikes" has been of interest to many people. It has been noted that forest trees are favorite targets for lightning and that certain kinds of trees are more often struck than others. A three-year census made by S. T. E. Dark, of the South London Botanical Institute, showed that the trees most often struck were, in order of frequency, oaks, elms, pines, poplar, willow, and ash.[1] He did not have record of a single beech, birch, horse chestnut, or holly tree that was struck.

In another survey, made by the government of Belgium, it was found that of eleven hundred trees struck 55% were poplar, 14% oak, 7% elm, and 7% conifers. In connection with the fact that isolated trees were most often injured it was stated: "In large forests of deciduous trees with fleshy leaves lightning strokes are prevented by a continuous interchange between the usually positive electricity of the air and the usually negative electricity of the earth. The stratum of air immediately over the trees is saturated with water vapor and is made conductive by evaporation from the leaves."[2]

These results are not in exact agreement, and this problem presented itself to me in the form of four questions:

1. Is the rate of discharge of electricity from leaves different for different trees?

2. Can these rates of discharge be compared by scientific methods?

3. Is there any relation between the rate of discharge and the structure of the leaf?

4. Can the resistance of the stems of different trees be compared by scientific methods?

The trees selected for experiment are representative Indiana species and may be divided into three groups: (1) trees with fleshy leaves, as the beech and the maple; (2) trees with dark green rather dry leaves, as the poplar and the oak; and (3) the conifers.

The plan of the experiment was to supply a high potential to an area of leaf surface equivalent to fifty beech leaves and measure the rate of discharge in milli-amperes. In like manner the high voltage was applied to a section of stem of given length and cross section and the current flow measured.

The high potential was supplied by a large type Wimhurst static machine, having four revolving mica plates each thirty inches in di-

[1]Dark, S. T. E., 1935. Where lightning strikes. Time, March 25.

[2]Anon., 1908. Liability of various trees to lightning stroke. Sci. Amer. Suppl. **66**:187-188.

ameter, separated by two stationary plates of hard rubber. The plates were rotated by a variable speed direct-current motor and were inclosed in a glass case to keep out dust and moisture. The charge was collected on insulated combs and stored in Leyden jars. This machine gave a six-inch spark between spheres, three-fourths of an inch in diameter.

The difference of potential was 180,000 volts. This was measured by an electrostatic voltmeter made by mounting a copper sheet electroscope in a five gallon oil container. A sheet ⅛x8 inches was hinged at the top to a copper plate 1x9 inches, and the whole insulated from the container with cake sulphur. The plate and the hinged strip, having a like charge, repelled each other, and the amount of deflection, observed through a window, measured the difference of potential. Readings were accurate to a tenth of a unit, and a mirror under the scale eliminated reading errors.

The current was measured by a 110-volt D. C. voltmeter in series. A large Leyden jar condenser was placed in parallel with the voltmeter to steady the current flow and to prevent change of polarity. A steel plate 36 inches square was used for a ground. The leaves were fastened to cross wires on a wooden frame 24 inches square and the distance between the frame and the ground was varied so that the tips of the different leaves were the same distance from the ground.

The resistance of the branches was compared by the same method. An air-gap resistance was placed in series with the branches to raise the resistance to a point where the static machine would build up the required potential.

Data derived from the experiment are based on averages taken from readings on five different days. The readings checked consistently on the different days, and the results give a good basis for comparison. The voltage applied to the leaves was determined from a voltmeter calibration graph, and the current was read in milli-amperes. The resistance was determined by applying Ohm's law, $R=E/I \times 1000$ ohms.

The tree having the least resistance was the jack pine. The applied voltage was 25,000 volts, the current 8.0, and the resistance 3,125,000 ohms. The trees arranged in order from the least to the highest resistance are: jack pine, sugar maple, beech, white ash, dogwood, white pine, white oak, tulip poplar, spruce, black willow, white elm, black walnut, shag-bark hickory, sycamore, Carolina poplar, honey locust, and hemlock. The readings for the hemlock were: applied voltage, 35,500; current, 5.8 milli-amperes; and resistance, 6,125,000 ohms. This resistance is practically twice that of the jack pine. The other trees were distributed rather evenly between these two limits.

The resistance of the stems was compared in a similar manner. The shag-bark hickory had the least resistance, 1,460,000 ohms, and the Carolina poplar the greatest, 2,250,000 ohms. The trees arranged in order are: shag-bark hickory, jack pine, sugar maple, hemlock, spruce, black walnut, white pine, white elm, sycamore, honey locust, white ash, tulip poplar, beech, dogwood, black willow, white oak, and Carolina poplar.

There is probably some relation between the rate of discharge and the number of points on the leaf, but this is not proven by this experiment. For example, the jack pine and the beech have many points and discharge well, while the spruce and the white elm have many points and discharge poorly. Also the sugar maple discharges as well as the beech but has only one-third as many points. The rate of discharge depends more upon the amount of moisture in the leaf than upon the shape. For example, the resistance of the sycamore leaves as given in the table was 4,810,000 but the resistance of the same leaves after drying on the frame over night was 6,040,000.

In the data found for the resistance of the branches, the amount of moisture again seems to be the controlling factor, because the size of the branch did not affect the resistance very much. The experiment does not show a definite relation between the specific gravity and the resistance.

The ideal condition for the tree to escape lightning strokes is for it to have a high stem resistance and a low leaf resistance. This prevents the charge from going to the leaves, and allows any charge that reaches the leaves to leak off. Considering these factors, the following trees are most likely to be struck: white elm, black walnut, shag-bark hickory, sycamore, Carolina poplar, honey locust, and hemlock. The following trees are least likely to be struck by lightning: beech, maple, white ash, dogwood, white pine, white oak, and tulip poplar.

My findings do not agree exactly with the results of the above mentioned surveys of lightning-struck trees, but there is a close correlation. It is an observed fact that the beech, maple, ash, and pine are seldom struck, while the walnut, sycamore, poplar, locust, and oak are the most likely to be struck. The observed facts are influenced by whether or not the tree stands in an isolated position.