How Does A Lightning Rod Work?

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It is a common misconception that 1ightning rods discharge clouds and thus prevent lightning. Actually lightning rods only serve to route the 1ightning harmlessly to ground. In doing so they divert the lightning when it is 10 to 100 yards away.

In 1749 Benjamin Franklin wrote a letter which was published in *Gentlemen's Magazine*, May 1750. It read, in part,

> There is something however in the experiments of points, sending off or drawing on the electrical fire, which has not been fully explained, and which I intend to supply in my text . . . from what I have observed on experiments, I am of opinion that houses, ships, and even towers and churches may be eventually secured from the strokes of lightning by

> their means; for if instead of the round balls of wood or metal which are commonly placed on the tops of weather-cocks, vanes, or spindles of churches, spires, or masts, there should be a rod of iron eight or ten feet in length, sharpened gradually to a point like a needle, and gilt to prevent rusting, or divided into a number of points, which would be better, the electrical fire would, I think, be drawn out of a cloud silently, before it could come near enough to strike.

This is Franklin's earliest recorded suggestion of the lightning rod. In the "experiments of points" he placed electrical charge on isolated conductors and then showed that the charge could be drained away (discharged) slowly and silently if a pointed and grounded (attached to ground) conductor were introduced into the vicinity. When the pointed conductor was brought too close to the charged conductor, the discharge occurred violently via an electric spark.

In the discussion in which he proposed the original experiment to determine if lightning were electrical (July 1750—see Chapter 1), Franklin repeated his suggestion for protective lightning rods, adding that they should be grounded (i.e., that a wire should connect the lightning rod to the ground or, in the case of a ship, to the water).

Lightning rods were apparently first used for protective purposes in 1752 in France and later the same year in the United States (Refs. 2.1, 2.2).

Franklin originally thought — erroneously — that the lightning rod silently discharged the electric charge in a thundercloud and thereby prevented lightning. However, in 1755 he stated:

> I have mentioned in several of my letters, and except once, always in the alternative, viz., that pointed rods erected on buildings, and communicating with the moist earth, would either prevent a stroke, or, if not prevented, would conduct it, so that the building should suffer no damage. (Ref. 2.3)

It is in the latter manner that lightning rods actually work. The charge flowing between a lightning rod and a thunder cloud

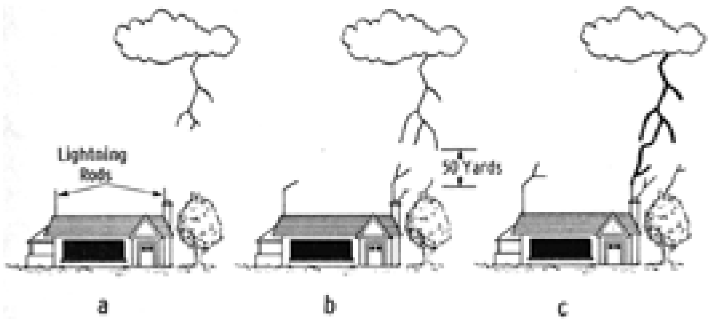

Figure 2.1: Final stages of a strike to a lightning rod. The time interval between B and A and between C and B is about 1/5000 second. The lightning channel becomes very bright (view C) immediately after the upward-traveling spark connects with the downward-moving lightning. Drawings are not to scale.

is much too small to discharge the thundercloud (Ref. 2.4). The rod diverts to itself a stroke on its way to earth but can do so only in the final part of the stroke's earthward trajectory. Diversion is achieved by the initiation of an electrical discharge (Fig. 2.1), a sort of traveling spark, which propagates from the rod, intercepts the downward-moving lightning, and provides a conducting path to the rod. Before the traveling spark is initiated, the downward-moving lightning is essentially uninfluenced by objects on the ground beneath it. The traveling spark is generally 10 to 100 yards long when it meets the lightning.

Any high object may initiate an upward-moving spark which attempts to reach the downward-moving lightning. It is therefore important that the lightning rod be the tallest object near the structure it protects, so that its traveling spark catches the lightning rather than a spark initiated by the chimney or a nearby tree.

Franklin refused to patent the lightning rod or otherwise to profit by its invention.

No lightning rod, however tall, can offer absolute protection; lightning has struck the Empire State Building 50 ft. below the top (see Chapter 6). Nevertheless, lightning rod systems are effective if used properly, and many codes have been written to describe their use (Ref. 2.5). A single vertical rod will almost always protect objects within an imaginary cone (the "cone of protection") formed by all lines connecting the top of the rod at height H with a circle on the ground, beneath the rod, of radius between H and 2H. In Fig. 2.2a, the house has a single lightning rod with a cone of protection assumed to have a base radius H in accord with the British lightning code. To protect a large house it is more practical to use multiple lightning rods: in Fig. 2.2b, three cones of protection overlap to provide a large volume of protection without excessive height. The house in Fig. 2.1 is protected according to the U.S. lightning code which specifies a base radius of 2H for the cone of protection. The smaller the base radius, the greater the probability that no lightning strokes will violate the cone. Thus, a structure containing explosives or highly flammable materials is often protected by a cone with a base radius as small as H/2.

A lightning rod system has three main parts: the rods on the roof, the wires which connect the rods together and those which run down the sides of the house or building to the grounding arrangement, and the grounding arrangement. Although the rods are the most visible, each of the three parts is equally important since the system may fail if any part is inadequate. Any metal rod or pipe may be an effective lightning rod, but to ensure a long lifetime for the rod, corrosion-resistant metal such as copper, aluminum, or galvanized iron should be used. There is no evidence that a pointed rod is better than one with a ball on the top. A wide variety of lightning rod shapes can be seen on urban and rural structures.

The primary function of the wires which link the lightning rods and those connecting the rods to the grounding arrangement is to carry the lightning current from the rods to the ground. The wires on the roof have the secondary function of intercepting lightning discharges which may have missed the rods. In fact, grids of wires alone have been used on roofs in place of lightning rods. The lightning codes recommend aluminum or copper wires. The U.S. lightning code suggests approximately 1/4 in. diameter copper wire or 3/8 in. diameter aluminum wire, while the British code recommends 3/8 in. diameter for both. In addition to round solid wire conductors, tubular, strip, or stranded aluminum or copper conductors of an appropriate cross-section may be used. The wire sizes speci-

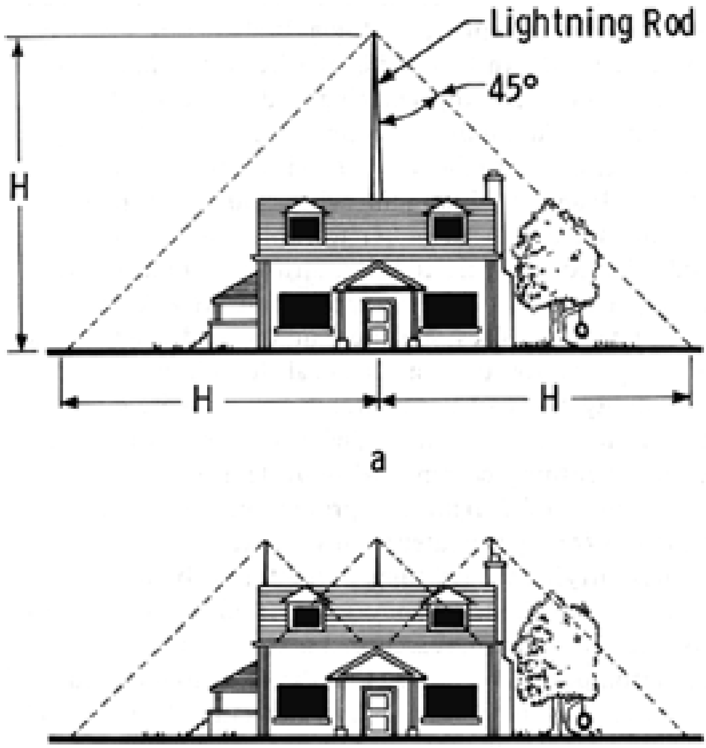

Figure 2.2: (a) A house protected by a single lightning rod having an assumed 45°-angle cone of protection - that is, the height of the rod is H and the base area assumed to be safe from a lightning strike has a radius H. (b) The same house protected by a lightning rod system consisting of three smaller rods, each assumed to provide a 45°-angle cone of protection.

fied in the codes appear to be chosen partly for their mechanical durability as well as for their ability to carry the lightning current. Wire several times thinner than that recommended will carry all but the most extreme lightning currents without damage (Refs. 2.7, 2.8). An example of a lightning protection system using small diameter wire is given later in this chapter.

Wires carrying the lightning current must be well grounded, otherwise the lightning may jump from the wires into the protected structure in search of a better ground. Grounding is best accomplished by connecting the wires to long rods which are driven into the ground or by connecting the wires to large buried metallic conductors. The rods or buried conductors should in turn be connected to all nearby gas pipes, water pipes, or other buried metallic pipes or cables.

It is sometimes imperative to keep the lightning current and possible attendant sparks from contacting any part of a protected structure - a typical case being a liquid-fuel storage vat in which flammable vapors are present. Here, the roof rods and wire conductors are often replaced by a system of wires suspended between tall towers arranged around the structure. A similar scheme is used to protect high voltage transmission lines from lightning strikes. A grounded wire (or wires) is strung above the high voltage lines to intercept strokes that would otherwise hit the power lines (Fig. 2.3).

The same principle has been adopted successfully in Poland for the protection of small farmhouses (Ref. 2.8). These buildings are usually made of wood and frequently have thatched roofs, thus making them very susceptible to lightning-caused fires. Since their inhabitants can rarely afford the expense (several hundred dollars) of a protective system satisfying the formal codes, Stanislas Szpor suggested a simpler, inexpensive system which the residents can install themselves. Basically, it consists of a 1/8 in. diameter galvanized iron wire suspended above the roof ridge from two small wooden towers installed at the ends of the roof ridge. From each tower the wire slopes downward and is buried in the ground. Over a five-year period, structures so protected had only about 10% of lightning-caused fires that unprotected structures suffered. Since about 2000 rural structures are ignited each year by lightning in the U.S. and since probably most are not protected because of the expense of the system specified by the U.S. code, it appears that Szpor's lightning protection system or some system similar to it could be advantageous to U.S. farmers.

Information about the number of lightning strikes per year to structures of various heights as well as to flat ground is given in Chapters 3, 6, and 7.

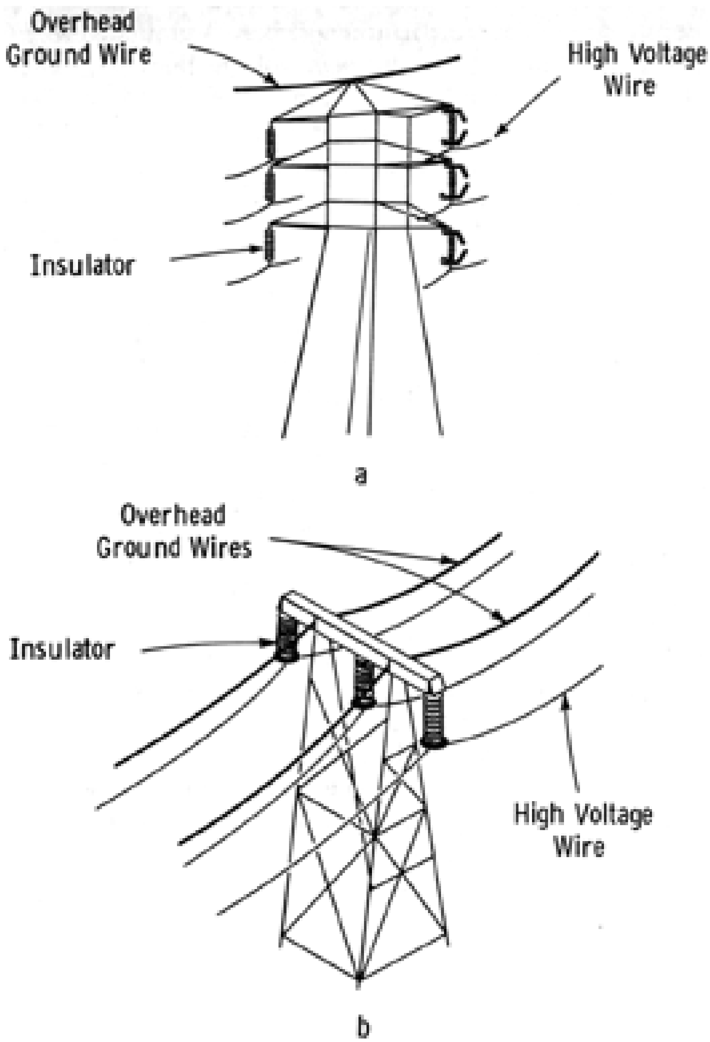

Figure 2.3: Use of overhead ground wires to protect high voltage transmission lines from lightning. Each of the high voltage wires is supported by the bottom of an insulator. Ground wires are attached to the metal transmission line towers which are well grounded. Drawings are not to scale. (a) A typical 132,000 volt line. (b) A typical 220,000 volt line.

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