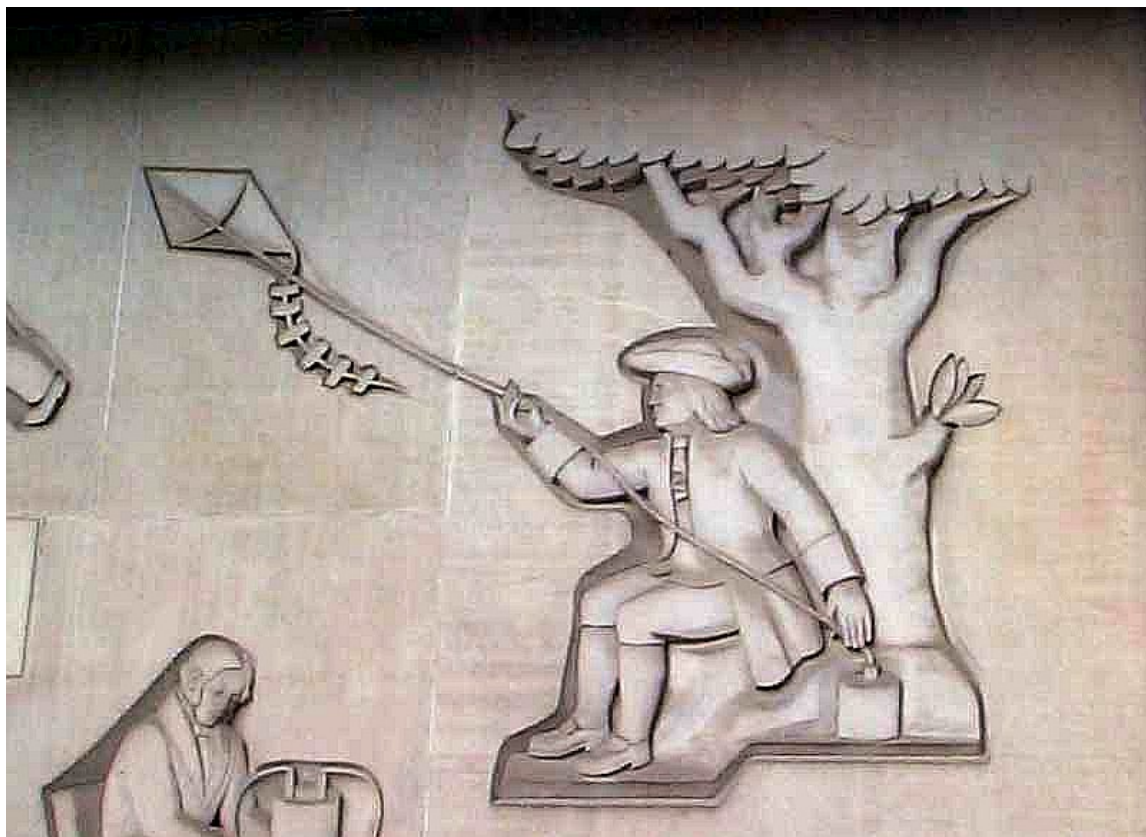


BENJAMIN FRANKLIN  
KITES AND RODS

In 1746 one Dr. Spence from Scotland demonstrated electrical apparatus in America. Franklin saw the demonstrations in Boston; he wrote "...being on a subject quite new to me, they equally surprized and pleased me." He acquired some electrical equipment and began his own experiments. Indeed Franklin was very successful in these electrical studies. He developed the "one fluid model" of electricity, and coined the terms *positive* and *negative* (he also used *plus* and *minus*) to describe an excess or shortage of the "fluid." Conservation of charge was an important part of his model: he showed that the charges on the conductors of a Leyden jar (a primitive capacitor) are equal but opposite because the fluid flows from one conductor to the other.

Now, the sparks that could be produced by the static electricity machines would have been less than an inch long. But somehow Franklin formed the idea that *lightning* is a similar phenomenon with much larger dimensions—up to miles in length. Further, Franklin proposed a way to test the idea. He had noticed that a grounded conductor with a sharp pointed end could discharge a charged object to ground without producing a spark. So he planned to erect a high pointed rod into a thunderstorm, collect charge from the cloud in a Leyden jar, and verify that all the phenomena that could be produced in a laboratory could be reproduced in the thunderstorm. The designed experiment was described in a book published by Franklin in London.

There was no tower in Philadelphia high enough for the lightning-rod experiment. (Franklin was waiting for a new church spire to be built.) Therefore the experiment was performed first in France, successfully, by D'Alibard and DeLor in May, 1752. However, communications were slow in those days, and before Franklin had heard of the French experiments he found another method—the famous kite experiment.

The Figure shows a *bas relief* sculpture over the front door of the Physics-Astronomy Building at Michigan State University. (Artist: Carl L Schmitz, 1947) There is some artist's license here. Franklin flew the kite from the protection of a shed, necessarily to keep his end of the string dry so that he would be isolated from the charge. And where is the key attached to the kite string, which was so important in Franklin's account of the experiment?

The kite experiment was made in June, 1752. He kept the trial secret in advance (except from his 21 year old son who assisted with the experiment) for fear of ridicule if it were unsuccessful. There is no need to recount the observations made in the thunderstorm. Just read Franklin's own account, in a letter of October, 1752, to Peter Townsend (Fellow of the Royal Society in London):

“Make a small cross of two light strips 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 accommodated with a tail, loop, and string, will rise in the air, like those made of paper; but this being of silk is fitter 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 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 any of 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 the loose filaments of the twine, will stand out every way, and be attracted by an approaching finger. And when the rain has wetted the kite and twine, so that it can conduct the electric fire freely, you will find it stream out plentifully from the key on the approach of your knuckle. At this key the phial may be charged: and from electric fire thus obtained, spirits may be kindled, and all the other electric experiments be performed, which are usually done by the help of a rubbed glass globe or tube, and thereby the sameness of the electric matter with that of lightning completely demonstrated. ”

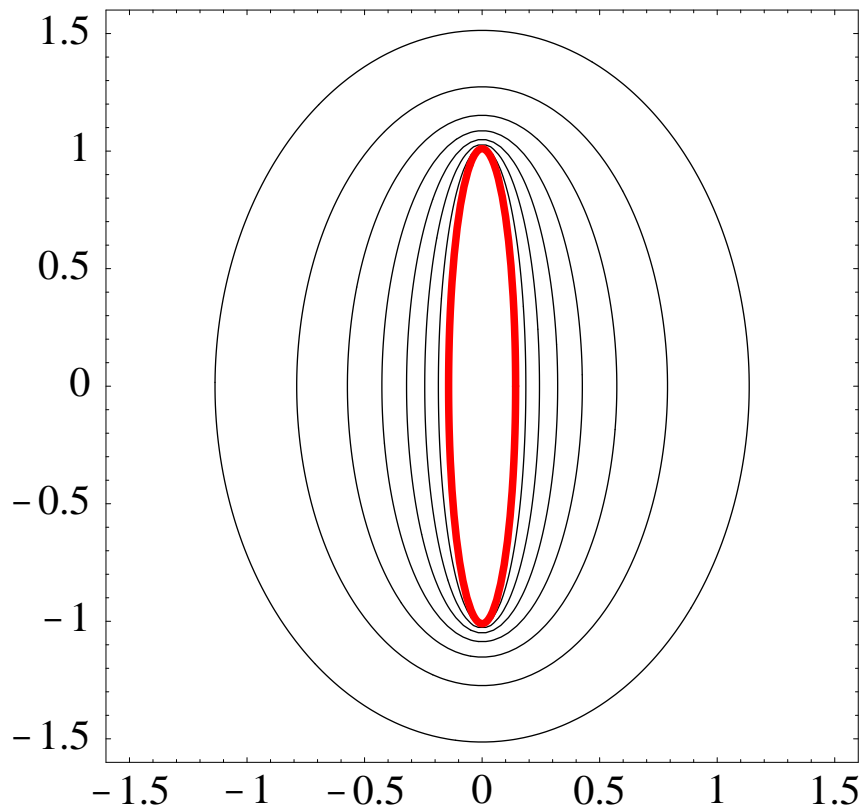
(The “phial” was the Leyden jar.)

The fundamental scientific discovery was to show that lightning—a mystery to humankind since prehistory—is an electrical phenomenon related to laboratory demonstrations of static electricity. The practical invention that followed was the lightning rod. Even today one can see pointed rods over the rooftops of high buildings. Franklin's concept that a pointed conductor would discharge the static electricity in a thunderstorm is not quite right, because the discharge rate would be too slow. But the building is protected because a lightning strike will hit the rod, and the charge be conducted safely to ground by the conductor.

The electric field around a pointed conductor is greatest at the sharp point. Mathematically, we can take this observation from solutions of Laplace's equation. [The field and potential of an ellipsoidal needle can be solved analytically; see Example 10 in Sec. 3.6 and Exercise 4.25. See also Fig. 4.10.] But empirically it goes back to the era of Benjamin Franklin.

The figure below shows equipotentials for an ellipsoidal conductor with eccentricity 0.99. The length of the needle is  $L = 2.02$  and the diameter at the midplane is

Figure 1: Equipotentials of a conducting needle.



0.28, in arbitrary length units. Note that the contours are close together near the tips, and farther apart on the midplane. Therefore the gradient is largest in magnitude at the tips. The electric field magnitude  $E = |\nabla V|$  is  $E_{\text{tip}} = 37V_0/L$  at the tip and  $E_{\text{mid}} = 5.3V_0/L$  on the surface at the midplane, where  $V_0$  is the potential of the needle.

The potential function for points outside the conductor is (see Sec. 3.6)

$$V(x, y, z) = K \log \left[ \frac{z + m + \sqrt{x^2 + y^2 + (z + m)^2}}{z - m + \sqrt{x^2 + y^2 + (z - m)^2}} \right]$$

where  $K$  and  $m$  are constants related to the geometry and potential of the needle. Please verify that  $V(x, y, z)$  satisfies Laplace's equation and is constant on the ellipsoidal conductor. (Hint: The parameter  $m$  is  $L\varepsilon/2$  where  $\varepsilon$  is the eccentricity of the ellipse.) Also, show

$$V_0 = K \log \frac{L + 2m}{L - 2m} \quad \text{and} \quad Q = 8\pi\epsilon_0 K m,$$

and so determine the capacitance of the needle as a function of eccentricity. How is this related to the discharge by a sharp pointed conductor?