1. Benjamin Franklin and the First Lightning Conductors

E. Philip Krider

Institute of Atmospheric Physics
The University of Arizona
Tucson, AZ 85721-0081, U.S.A.

Introduction

The Philadelphia experiments and observations on electricity, as led and communicated by Benjamin Franklin,[1] were important in the history of science because some were new and novel and because their interpretations helped to stimulate the development of electricity as a science and the beginnings of modern physics.[2-4] This work also led to the sentry box and kite experiments[5] that proved once and for all that thunderclouds are electrified and that lightning is an electrical discharge. The latter discoveries, in turn, validated the key assumptions that lay behind Franklin's supposition that tall, grounded rods would protect structures from lightning damage. Here, we will trace how Franklin's ideas evolved and the design of the first protective rods, and then we will describe some key improvements that Franklin made to his design, after experience was gained through practice in the years from 1752 to 1762.

Experiments and Observations in Philadelphia

Benjamin Franklin and his colleagues[6] began experimenting with static electricity in about 1746, after they saw some electrical demonstrations and parlor tricks that were then popular in Europe. They received apparatus from Peter Collinson, a Fellow of the Royal Society of London, and instructions on how to use it came from an article in *The Gentleman's Magazine* published in London.[7] This article was actually an imperfect translation of some German work[8] that had been reviewed by a Swiss working in Göttingen, and was published by professors in Holland.[9] It is interesting to note that even in the 18th century, experiments in Leipzig and Berlin could influence work in England and North America.

The initial Philadelphia experiments were described in a series of five formal letters that Franklin sent to Collinson in the years from 1747 to 1750. Lightning is mentioned in most of them in one way or another. In April 1751, Collinson published these letters in a small (86-page) pamphlet entitled *Experiments and Observations on Electricity, made at Philadelphia in America, by Mr. Benjamin Franklin, and Communicated in several letters to Mr. P. Collinson, of London, F.R.S.*; this was soon translated into French and later into German and other languages. [1]

In the first paragraph of the first letter,[10] Franklin described "the wonderful effect of pointed bodies, both in *drawing* off and *throwing* off the electrical fire." He showed that discharges to and from points work quickly and at considerable distances, that sharp points work better than blunt points, that metal points work better than dry wood, and that the pointed object should be touched (*i.e.*, grounded) in order to obtain a maximum draw effect. Next, Franklin introduced the idea that rubbing glass in a friction machine does not actually create electricity; rather, at the instant of friction, the glass simply takes "the thing" out of the rubbing material. Whatever is added to the glass, an equal amount is now missing from the rubber. The terms *plus* and *minus* were used to describe these electrical states, and the glass was assumed to be electrified *positively* and the rubbing material *negatively*. The letter concludes with a comparison of lightning to electrical flashes on a gilded china plate or on the gold trim of a leather book.

In the second letter,[11] Franklin combined the concept of equal positive and negative charges with an assumption that glass is a perfect insulator and described the electrical behavior of a Leyden jar, the first electrical capacitor. He noted the importance of grounding in both charging and discharging the jar, and he made an analogy between electricity and lightning when he described a discharge through the gold gilding on the cover of a book that produced "a vivid flame, like the sharpest lightning."

In his third letter,[12] Franklin began to use terms like *charge* and *discharge* in describing the Leyden jar and showed that the electrification of such a device resides entirely in the glass. Next, he described an *electrical battery* wherein several capacitors were charged in series "with the same effort as charging one" and then discharged in parallel to provide the force of all at once "through the body of any animal forming the circle with them." Later, Franklin used such a battery to simulate the effects of lightning in a variety of materials.

In the fourth letter,[13] Franklin introduced the concept of the *sparking* or *striking distance*. If two gun barrels that are electrified "will strike at two inches distance, and make a loud snap; to what great a distance may 10,000 acres of electrified cloud strike and give its fire, and how loud must be that crack!" Based on his previous experience with the power of points, Franklin then speculated that when an electrified cloud passes over a region, it will draw electricity from and discharge to high hills and trees, lofty towers, spires, masts of ships, chimneys, etc. This supposition led to some practical advice that is still valid today; namely, that it is dangerous to take shelter under a single, isolated tree during a thunderstorm; it is safer to remain in an open field. Franklin also suggested that it might be safer to stay in the open because there one's clothing will tend to be wet, and wet clothes will provide a conducting path to ground that is outside the body. His laboratory analogy was "a wet rat cannot be kill'd by the exploding electrical bottle, when a dry rat may."

In the fifth letter,[14] Franklin attempted to explain the power of points. He described how discharges between smooth or blunt conductors occur with a "stroke and crack," whereas sharp points discharge silently and produce large effects at greater distances. He then described what he viewed to be a "Law of Electricity;" namely, that points will tend to "draw on and throw off the electrical fluid with more or less power, and at greater or less distances, and in larger or smaller quantities in the same time" as the angle of the point is more or less acute. Given Franklin's obvious interest in lightning and the power of points, it was a short step to the lightning rod:

> "I say, if these things are so, may not the knowledge of this power of points be of use to mankind; in preserving houses, churches, ships, etc. from the stroke of lightning; by directing us to fix on the highest parts of those edifices upright rods of iron, made sharp as a needle and gilt to prevent rusting, and from the foot of those rods a wire down the outside of the building into the ground; or down round one of the shrouds of a ship and down her side, till it reaches the water? Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike, and thereby secure us from that most sudden and terrible mischief!"[15]

Clearly, Franklin's initial supposition was that the silent discharges from one or more sharp, metallic points might reduce or eliminate the effects of any electricity in the cloud aloft and thereby reduce or eliminate the chances of being struck by lightning. From his earlier experiments, Franklin knew that point discharges worked best when the conductor is grounded, and he also knew that tall objects were preferred places for lightning to strike. Therefore, even if the point discharges did not neutralize the cloud, a tall, grounded conductor would provide a safe path for the lightning to go to ground.

In the very next paragraphs, Franklin made the following proposal:

> "To determine the question, whether the clouds that contain lightning are electrified or not, I would propose an experiment to be try'd where it may be done conveniently.
>
> On the top of some high tower or steeple, place a kind of a sentry box (see Figure 1) big enough to contain a man and an electrical stand. From the middle of the stand let an iron rod rise, and pass bending out of the door, and then upright 20 or 30 feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when such clouds are passing low, might be electrified, and afford sparks, the rod drawing fire to him from the cloud. If any danger to the man be apprehended (tho' I think there would be none) let him stand on the floor of his box, and now and then bring near to the rod, the loop of a wire, that has one end fastened to the leads; he holding it by a wax-handle. So the sparks, if the rod is electrified, will strike from the rod to the wire and not affect him."[16]

It should be noted that the purpose of the sentry box (and also the kite) experiment was to determine if thunderclouds are electrified; for this, the rod (or the conducting kite string) must be carefully *insulated* from ground. For lightning protection, the rod should be *grounded*.

People in London were amused when Franklin's suggestions about electrical rods were read to the Royal Society, and they did not publish them in their *Philosophical Transactions*. Unbeknownst to Franklin or Collinson at the time, on May 10, 1752, a retired French dragoon acting on instructions from Thomas-François Dalibard, the translator of Franklin's book from English into French, succeeded in drawing sparks from a tall iron rod that was carefully insulated from ground (see Figure 1) at the village of Marly-la-Ville near Paris.

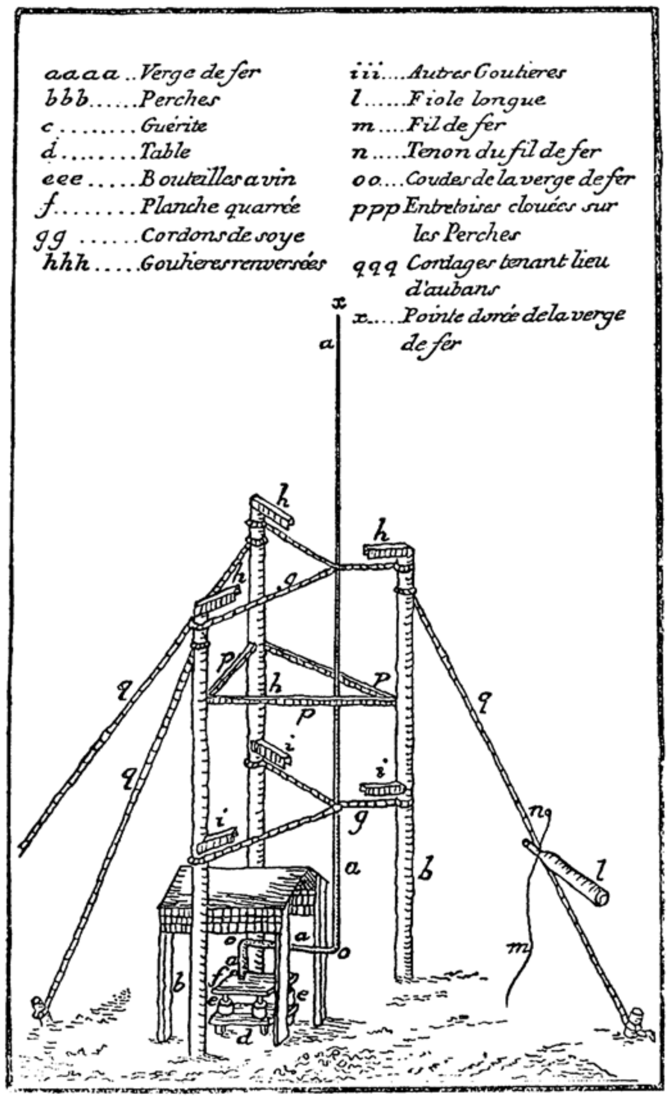

Fig. 1. The apparatus used in the sentry box experiment at Marly-la-Ville, France. The rod was about 13 m (40 ft) tall and was insulated from ground by the wine bottles, *e.* (From *Expériences et Observations sur L'Électricité....* Trad. de l'Anglais par M. Dalibard, Seconde Édition, Paris, Vol. II, 1756, p.128.)

The sparks drawn at Marly-la-Ville proved, for the first time, that thunderclouds are electrified and that lightning is an electrical discharge. This experiment was sensational and was verified within days by Delor in Paris and soon by many others throughout Europe. When Dalibard and Delor reported their results to the French Academy of Sciences, they acknowledged that in doing these experiments, they had followed the path that Franklin had traced for them "…En suivant la route qu'il nous a tracée, j'ai obtenu une satisfaction complette."[17] Meanwhile in Philadelphia, Franklin drew sparks from the conducting string of his famous kite (insulated from ground by silk ribbon) in June or July, 1752, after the success at Marly-la-Ville but before he knew about it.[5] People in London were surprised by the experiment at Marly-la-Ville, and the following year the Royal Society of London awarded Franklin its Copley gold medal.

Several authors have noted that Franklin was not the first to compare sparks with lightning nor to hypothesize that lightning might be an electrical discharge.[18-21] In fact, almost every experimenter who had described electrical discharges before Franklin had, at one time or another, mentioned the analogy with lightning. Franklin's unique contributions were the suggestions (a) that tall, insulated rods could be used to determine if thunderclouds are electrified and (b) that tall, grounded rods could be used to protect against lightning damage.

After Franklin heard about the success at Marly-la-Ville, he installed a tall, insulted rod on the roof of his house to study the characteristics of thunderstorm electricity. The conductor ran down a stairwell to ground but had a gap in the middle, as shown on the left of Figure 2. A small ball was suspended between chimes mounted on each end of the gap, and the ball was placed so that the chimes would ring whenever an electrified cloud passed overhead. Franklin used this apparatus to measure the polarity of thunderclouds and to compare the properties of atmospheric electricity with the electricity that was generated by friction. He found that the two electricities were the same and "…that the clouds of a thundergust are *most commonly* in a negative state of electricity, but *sometimes* in a positive state,"[22] a result that was regarded as definitive for the next 170 years. At this time, Franklin thought that all discharges went from positive to negative so he concluded "that for the most part in thunder strokes, *'tis the earth that strikes into the clouds*, and not the clouds that strike into the earth."[22] Judging by his later correspondence, Franklin was fascinated by this discovery, and he postulated that the effects of a lightning discharge would be very nearly the same whether the current flowed up from the ground or down from the cloud.

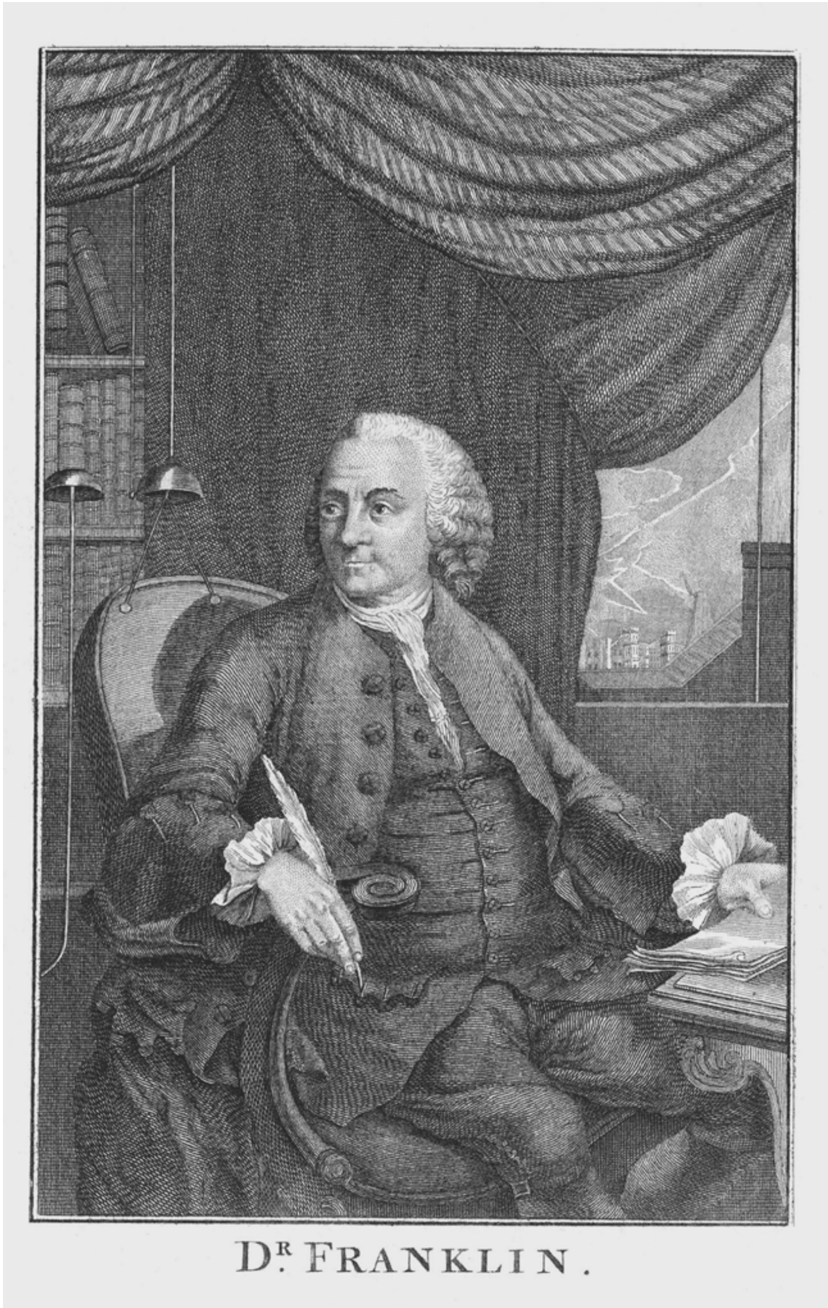

Fig. 2. Benjamin Franklin shown next to the apparatus that he used to study thunderstorm electricity. A grounded rod of the 1762 design is shown in the background on the right. (An 18th century engraving after a painting by Mason Chamberlain, 1762.)

From 1749 to 1753, Rev. Ebenezer Kinnersley, a leading electrical experimenter and friend of Franklin, traveled the east coast of North America giving lectures and demonstrations on electricity.[23] He told people that lightning is an electrical discharge, and he showed them how grounded rods would protect model houses from sparks that simulated lightning. These lectures were advertised widely and represent the first public disclosure that grounded rods will protect buildings from lightning damage.

First Lightning Protection System

In the late fall of 1752, Franklin published the following in *Poor Richard's Almanack* for 1753:

> "How to secure houses, etc. from Lightning
>
> It has pleased God in his goodness to mankind, at length to discover to them the means of securing their habitations and other buildings from mischief by thunder and lightning. The method is this: Provide a small iron rod (it may be made of the rod-iron used by the nailers) but of such a length, that one end being three or four feet in the moist ground, the other may be six or eight feet above the highest part of the building. To the upper end of the rod fasten about a foot of brass wire, the size of a common knitting-needle, sharpened to a fine point; the rod may be secured to the house by a few small staples. If the house or barn be long, there may be a rod and point at each end, and a middling wire along the ridge from one to the other. A house thus furnished will not be damaged by lightning, it being attracted by the points, and passing thro the metal into the ground without hurting any thing. Vessels also, having a sharp pointed rod fix'd on the top of their masts, with a wire from the foot of the rod reaching down, round one of the shrouds, to the water, will not be hurt by lightning."[24]

His opening phrase anticipated a religious objection to protective rods that would later appear among the populace. In the late summer or fall of 1752, protective rods were installed on the spires of the Academy of Philadelphia (later the University of Pennsylvania) and the Pennsylvania State House (later Independence Hall).

The modern terminology[25] for the three key elements in Franklin's design of a protective rod are: (1) one or more *air terminals* that are mounted on the roof. (2) Horizontal *roof conductors* and vertical *down conductors* connect the air terminals to (3) a *grounding system* that provides an electrical connection to earth. Because Franklin thought that point discharges might aid in providing protection, the first air terminals were thin, sharp needles mounted on an iron rod. The first down conductors were chains of nail rods, each several feet long, mechanically linked or hooked together as shown in Figure 3. (Figure 3 also shows that the first down conductors could be attached to the inside walls of a tall tower.) The first grounding system was simply a nail rod driven 3 to 4 feet into moist earth.

Fig. 3. Fragments of a down conductor, found under paneling and plaster on the inside wall of the northwest corner of the tower stairwell, on Independence Hall, Philadelphia. The inset on the right shows the hook connection in greater detail [Independence National Historical Park Collection].

In June of 1753, Franklin published a "Request for Information on Lightning" in *The Pennsylvania Gazette* and newspapers in New York and Boston:

> "Those of our readers in this and the neighboring provinces, who may have an opportunity of observing, during the present summer, any of the effects of lightning on houses, ships, trees, etc. are requested to take particular notice of its course, and deviation from a strait line, in the walls or other matter effected by it, its different operations or effects on wood, stone, bricks, glass, metals, animal bodies, etc. and every other circumstance that may tend to discover the nature, and compleat the history of that terrible meteor. Such observations being put in writing, and communicated to Benjamin Franklin, in Philadelphia, will be very thankfully accepted and gratefully acknowledged."[26]

In 1753, Dr. John Lining repeated Franklin's kite experiment in South Carolina, but when he tried to install a rod on his house, the local populace objected. They thought that the rod was presumptuous, i.e., that it would interfere with the will of God, and that it would attract lightning.[27] Similar fears would be repeated in most countries of Europe.[28] In April of that year, Franklin commented on presumption in a letter about the Abbé Nollet, the leading electrical experimenter in France and a strong opponent of protective rods:

> "…He speaks as if he thought it presumption in man to propose guarding himself against *Thunders of Heaven*! Surely the thunder of heaven is no more supernatural than the rain, hail, or sunshine of heaven, against the inconvenience of which we guard by roofs and shades without scruple.
>
> But I can now ease the gentleman of this apprehension; for by some late experiments I find, that it is not lightning from the clouds that strikes the earth, but lightning from the earth that strikes the clouds."[29]

Improvements

In the next years, Franklin continued to gather information and study reports about lightning and lightning damage, and in 1757 he went to London as an agent of the Pennsylvania Assembly. In March of 1761, Kinnersley sent Franklin a detailed description of a lightning flash that struck the house of William West in Philadelphia.[30] The West house had been equipped with a protective rod that was very similar to the installation described in *Poor Richard's Almanack*. At the time of the strike, an observer reported that "the lightning diffused over the pavement, which was then very wet with rain, the distance of two or three yards from the foot of the conductor." An investigation showed that the top of the brass needle had been melted, as shown in Figure 4, but otherwise, there was no damage to the house. Kinnersley concluded that "surely now it will be thought expedient to provide conductors for the lightning as for the rain."

Fig. 4. Kinnersley's sketch of how lightning melted the top of a sharp, brass wire that terminated an early air terminal. Initially, the length of the wire was 10 inches; after the lightning, it was about 7.5 inches. (From [1], Plate II, p. 353)

Prior to receiving Kinnersley's letter, Franklin had received descriptions of two similar strikes to houses that had been protected in South Carolina.[31] In one case, the lightning had evaporated the points and a length of the brass down conductor. In the other, three brass points mounted on top of an iron rod, each about seven inches long, had evaporated, and the iron down conductor, about half an inch in diameter and in several sections with links hooked together, had its links and joints unhooked by the discharge. Almost all the staples that held this conductor to the outside of the house had also been loosened or started. "Considerable cavities" been made in the earth near the ground rod (sunk about three feet into the earth), and the lightning had also produced several furrows in the ground "some yards in length." Franklin was pleased by these reports because, even though the conductor "when too small, may be destroyed in executing its office," the grounded rods had indeed saved the houses from substantial damage. In his reply to Kinnersley,[32] Franklin transcribed the reports from South Carolina and then recommended larger, more substantial conductors and a deeper, more extensive grounding system to reduce surface arcs and keep any explosions in the soil away from the foundation of the house. Kinnersley's letter was read to the Royal Society and subsequently published in the *Philosophical Transactions*.[33]

Since all reports from North America showed that grounded rods did protect houses and their occupants from lightning-caused damage, Franklin sent improved specifications for "the shortest and simplest method of securing buildings, etc. from the mischiefs of lightning"[34] to the Scottish philosopher, David Hume, in January of 1762, together with excerpts from Kinnersley's letter and the reports from South Carolina. This letter was subsequently read to the Philosophical Society in Edinburgh and published by that society (in 1771)[35] together with a comment by Prof. James Russell.

In the letter to Hume, Franklin recommended much more substantial, steel air terminals, 5 to 6 feet long and tapered to a sharp point. If the building has any dimension greater that about 100 feet, Franklin stated that a pointed rod should be mounted at each end and that there should be a conductor between them. All roof and down conductors should be at least half an inch in diameter, continuous, and stapled to the outside of the building. If any links or joints must be made in these conductors, these should be filled with lead solder. The ground connection should be a one-inch diameter iron rod driven 10 to 12 feet into the earth, and if possible, this rod should be at least 10 feet from the foundation. Franklin also recommended that the ground rod be painted, in order to minimize rust, and stated that a connection to the water of a well is best, if a well is nearby. An illustration of the upper portion of a 1762 protective rod is shown on the right side of the background in Figure 2.

Franklin published his reply to Kinnersley and the reports from South Carolina in the 1769 edition of *Experiments and Observations* together with some "Remarks"[36] on the construction and use of protective rods. He began the remarks with an acknowledgement that "Like other new instruments, this appears to have been at first in some respects imperfect; and we find that we are, in this as in others, to expect improvement from experience chiefly…" He then repeated his recommendations to mount pointed air terminals 5 or 6 feet above the highest part of the building, that "a rod in one continued piece is preferable to one composed of links or parts hooked together," and that ground rods should be deep and kept away from the foundation of the building.

Conclusion

Today most authorities agree that the main functions of lightning rods and the associated conductors are to define and control the points where lightning will attach to a structure and then to provide safe paths for the current to flow to ground.[25] In his reply to Kinnersley in 1762, Franklin noted that "Indeed, in the construction of an instrument so new, and of which we could have so little experience, it is rather lucky that we should at first be so near the truth as we seem to be, and commit so few errors."[37] Lucky indeed - today virtually every lightning protection code in the world still recommends Franklin rods for protecting ordinary structures, and the basic elements of their design and installation are, in essence, the same as Franklin's specifications of 1762.[38-42]

Acknowledgement

The author is grateful to Penepole H. Batchelor of the Independence National Historical Park for calling his attention to Figure 3.

Endnotes

1. I. Bernard Cohen, *Benjamin Franklin's Experiments: A New Edition of Franklin's Experiments and Observations on Electricity*, Harvard Univ. Press, Cambridge, MA, 1941.

2. I. Bernard Cohen, *Franklin and Newton: An Inquiry into Speculative Newtonian Experimental Science and Franklin's Work in Electricity as an Example Thereof*, Am. Philos. Soc., Philadelphia, PA, 1956, Part Four.

3. J. L. Heilbron, *Electricity in the 17th and 18th Centuries: A Study of Early Modern Physics*, Univ. California Press, Berkeley, CA, 1979, Part Four.

4. J. L. Heilbron, *Elements of Early Modern Physics*, Univ. California Press, Berkeley, CA, 1982, Chapter III.

5. I. Bernard Cohen, *Benjamin Franklin's Science*, Harvard Univ. Press, Cambridge, MA, 1990, Chapter 6.

6. Principally Ebenezer Kinnersley, Philip Syng, and Thomas Hopkinson.

7. J. A. Leo Lemay, *Ebenezer Kinnersley: Franklin's Friend*, U. Pennsylvania Press, Philadelphia, 1964, 54–59.

8. Principally by Georg Mathias Bose, Christian August Hansen, and Johann Heinrich Winkler.

9. J. L. Heilbron, "Franklin, Haller, and Franklinist History", *Isis*, *68*, 1977, 539–549.

10. Franklin documents have been taken from *The Papers of Benjamin Franklin*, Ed. By L. W. Labaree, W. B. Wilcox, C. A. Lopez, B. B. Oberg, E. R. Cohn *et al.*, Yale University Press, New Haven, CT, Vol. I, 1959 to Vol. 35, 1999 with some capital letters suppressed to conform with modern usage. In the following notes, these volumes will be referred to as *BF Papers*; the volume number will be in italics, and the page numbers will be inclusive. The text of the first letter is in *BF Papers*, *3*, 126-135.

11. Ibid., *3*, 156-164.

12. Ibid., *3*, 352-365.

13. Ibid., *3*, 365-376.

14. Ibid., *4*, 9-34

15. Ibid., *4*, 19.

16. Ibid., *4*, 19-20.

17. Ibid., *4*, 303.

18. Cohen, 1941, op. cit., 21-56.

19. Cohen, 1956, op. cit., Chapter 11.

20. Heilbron, 1979, op. cit., Chapter 13.

21. Cohen, 1992, op. cit., Chapter 6.

22. *BF Papers*, *5*, 71.

23. Lemay, op. cit., 62-81.

24. *BF Papers*, *4*, 408-409.

25. E. Philip Krider and Martin A. Uman, "Cloud to ground lightning, lightning protection, and lightning test standards", *Encyclopedia of Electrical and Electronics Engineering*, John Wiley & Sons, New York, 1999, *11*, 350-357.

26. *BF Papers*, *4*, 510.

27. Lemay, op. cit., 78.

28. Cohen, 1990, Chapter 8.

29. *BF Papers*, *4*, 463.

30. *BF Papers, 9*, 282-293.

31. These reports came from John Raven and William Maine who lived near Charleston.

32. *BF Papers, 10*, 37-59.

33. *Phil. Trans. (London)*, *53*, 84-97, 1764.

34. *BF Papers, 10*, 17-23.

35. *Essays & Obs. (Edinburgh), 3*, 129-41, 1771.

36. *BF Papers, 10*, 55-59.

37. Ibid., 50-51.

38. R. H. Golde, *Lightning Protection*, Chemical Publ. Co., New York, 1975.

39. National Fire Protection Assn., *Lightning Protection Code*, NFPA 780, Quincy, MA, 1997.

40. Norme Française, *Installations de Paratonnerres*, NF C 17–100, Paris, Fevrier, 1987.

41. British Standards Institution, *Code of practice for protection of structures against lightning,* BS 6651:1999, London, UK, 1999.

42. National Standard of the People's Republic of China, *Design Code for Lightning Protection of Structures*, GB 50057-94, Beijing, 1994.