Benjamin Franklin and Lightning Rods

Franklin's work on electricity and lightning earned him worldwide fame and respect—ideal assets for brokering aid from France during the American Revolution.

E. Philip Krider

On 10 May 1752, as a thunderstorm passed over the village of Marly-la-Ville, a retired French dragoon, acting on instructions from naturalist Thomas-François Dalibard, drew sparks from a tall iron rod that had been carefully insulated from ground (see figure 1). The sparks showed that thunderclouds are electrified and that lightning is an electrical discharge. In the mid-18th century, such an observation was sensational and was soon verified by Delor, Dalibard's collaborator in Paris. Within weeks of hearing the news, many others throughout Europe had successfully repeated the experiment.[1,2]

When Dalibard and Delor reported their results to the Académie des Sciences in Paris three days later, they acknowledged that they had merely followed a path that Benjamin Franklin had traced for them. In June 1752, shortly after the experiment at Marly-la-Ville but before he knew about it, Franklin drew sparks himself from a key attached to the conducting string of his famous electrical kite that was insulated from ground by a silk ribbon.

The French results were important because they called attention to Franklin's small pamphlet, *Experiments and Observations on Electricity, Made at Philadelphia in America*,[3] that helped to stimulate other work in electricity and contributed to the beginning of modern physics.[4] The observations also validated the key assumptions that lay behind Franklin's supposition that tall, grounded rods can protect buildings from lightning damage.

A Philadelphia story

Franklin performed his initial experiments on electricity in collaboration with friends and neighbors, including Thomas Hopkinson, a lawyer and judge; Ebenezer Kinnersley, a clergyman and teacher; and Philip Syng Jr, a master silversmith. Franklin described the experiments and their results in five formal letters to Peter Collinson, a fellow of the Royal Society of London, during the years from 1747 to 1750. Collinson in turn communicated those letters to the Society and published them in April 1751.

In his first letter,[5] Franklin described "the wonderful Effect of Points, both in *drawing* off and *throwing* off the Electrical Fire." He showed that points work quickly at "a considerable Distance," that sharp points work better than blunt ones, that metal points work better than dry wood, and that the pointed object should be touched—that is, grounded—to obtain the maximum draw effect.

Next, Franklin introduced the idea that rubbing glass with wool or silk does not actually create electricity; rather, at the moment of friction, the glass simply takes "the Electrical Fire" out of the rubbing material. Whatever amount is added to the glass, an equal amount is lost by the wool or silk. The terms plus and minus were used to describe those electrical states; the glass was assumed to be electrified positively and the rubbing material negatively. The idea that electricity is a single fluid that is never created or destroyed, but simply transferred from one place to another, was profound, and it greatly simplified the interpretation of many observations.

In his second letter,[5] Franklin described the behavior of a Leiden jar capacitor by combining the concept of equal positive and negative states with an assumption that glass is a perfect insulator. "So wonderfully are these two States of Electricity, the *plus* and *minus* combined and ballanced in this miraculous Bottle!" He also made an analogy between electricity and lightning when he described a discharge through the gold trim on the cover of a book that produced "a vivid Flame, like the sharpest Lightning."

In his third letter,[5] Franklin began to use terms such as "charging" and "discharging" when describing how a Leiden jar works, and he noted the importance of grounding when charging and discharging the jar. He also showed that the electricity in such a device resides entirely in the glass and not on the conductors that are inside and outside the jar. Franklin described how several capacitors could be charged in series "with the same total Labour" as charging one, and he constructed an "Electrical Battery"—a capacitor bank in today's parlance—using panes of window glass sandwiched between thin lead plates, and then discharged them together so that they provided the "Force of all the Plates of Glass at once thro' the Body of any Animal forming the Circle with them." Later, Franklin used discharges from large batteries to simulate the effects of lightning in a variety of materials.

In the fourth letter,[5] he applied his knowledge of electricity to lightning by introducing the concept of the sparking or striking distance: If two electrified gun barrels "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 experiments with sharp points, Franklin then postulated that when an electrified cloud passes over a region, it might draw electricity from, or discharge electricity to, high hills and trees, lofty towers, spires, masts of ships, and chimneys. That supposition then led to some practical advice against taking shelter under a single, isolated tree during a thunderstorm; crouching in an open field is less dangerous. Franklin also noted that out in the open during a thunderstorm, cloth-

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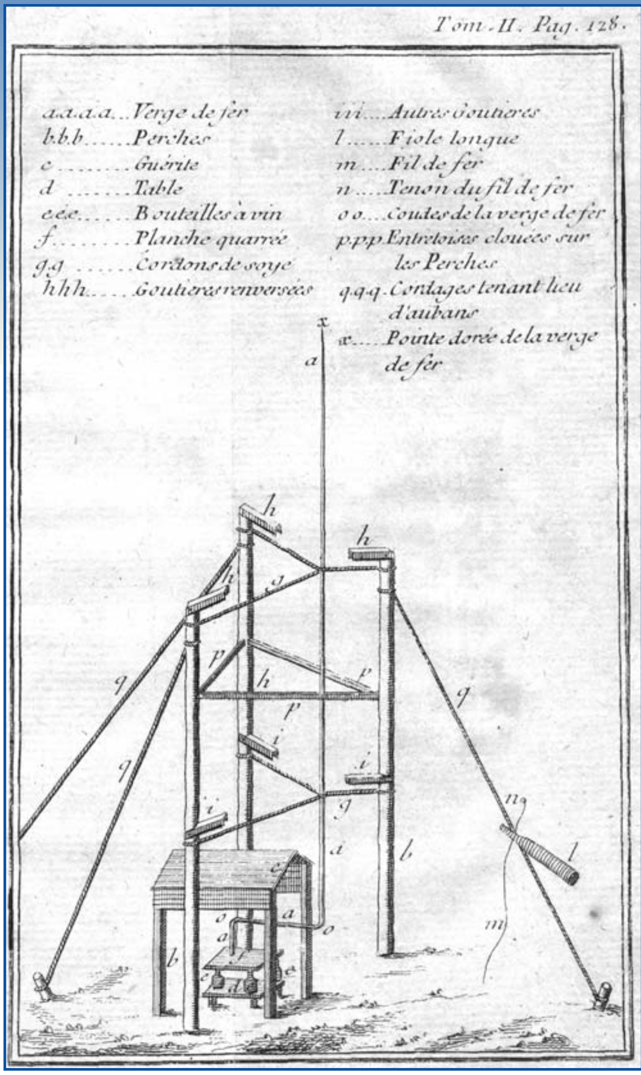

Figure 1. This sketch of the "sentry-box" experiment conducted at Marly-la-Ville, France, in 1752 was based on Benjamin Franklin's proposal to determine whether thunderclouds are electrified. Silk ropes (*g*) and wine bottles (*e*) insulated a 13-meter iron rod (*a*) from ground, and covers (*h*) sheltered the ropes from rain. A person standing on the ground could draw sparks from the rod or charge a Leiden jar when a storm was in the area. (From B. Franklin, *Expériences et Observations sur L'Électricité . . .*, 2nd ed., vol. 2, an extended translation from English by T. F. Dalibard, Chez Durand, Paris, 1756.)

ing tends to become wet, thereby providing a conducting path outside the body. His laboratory analogy was that "a wet Rat can not be kill'd by the exploding electrical Bottle, when a dry Rat may."

In the fifth letter,[5] Franklin 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 introduced what he viewed to be a "Law of Electricity, That Points as they are more or less acute, both 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." Given his interest in lightning and the effects of metallic 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!

Clearly, Franklin supposed that silent discharges from one or more sharp points might reduce or eliminate the electricity in the clouds above and thereby reduce or eliminate the chances of the structure being struck by lightning. From his earlier observations, he knew that point discharges work best when the conductor is grounded and that lightning tends to strike tall objects. Therefore, even if the point discharges did not neutralize the cloud, a tall conductor would provide a preferred place for the lightning to strike, and the grounded conductor would provide a safe path for the lightning current to flow into the ground. Franklin also stated in his fifth letter,[5]

> 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 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.

Franklin was not the first person to compare sparks with lightning or to hypothesize that lightning might be an electrical discharge. In fact, almost every experimenter who had previously described electric sparks had, at one time or another, mentioned an analogy to lightning. Franklin's seminal contributions were his suggestions that tall, insulated rods could be used to determine if thunderclouds are, in fact, electrified and that tall, grounded rods would protect against lightning damage.

The French connection

Shortly after Collinson published the first edition of *Experiments and Observations*, he sent a copy to the famous French naturalist, the Comte de Buffon, who asked Dalibard to translate it from English into French. While he did that, Dalibard asked Delor to help him repeat many of the Philadelphia experiments. In March 1752, Buffon arranged for the pair to show the experiments to King

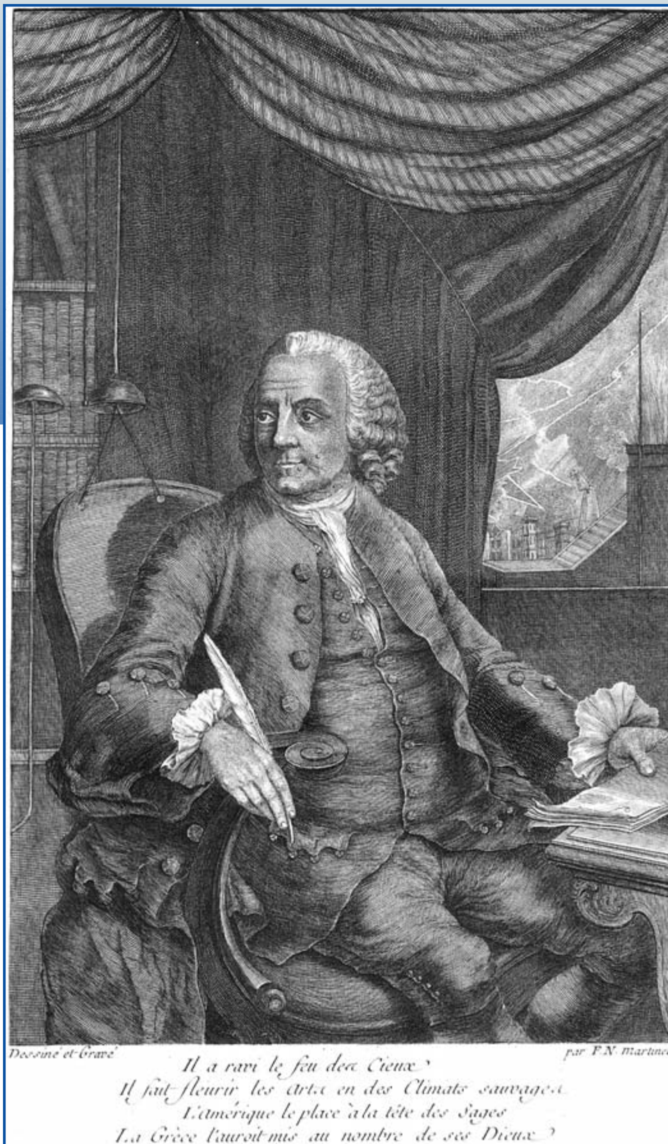

Figure 2. Modeled after a 1762 painting by Mason Chamberlain, this etching depicts Benjamin Franklin looking at electrostatic bells he used to study cloud electricity. Two chimes, separated from each other by a small gap, are connected to rods that go up through the roof and to ground. A thundercloud charges the right-hand bell, either by induction or point discharge; the bell then alternately attracts or repels a small ball suspended between the chimes on a silk thread. The ball rattles between the bells, ringing an alarm when a storm approaches. The electroscope hanging from the right-hand bell was used to measure the cloud's polarity. A grounded rod of Franklin's 1762 design can be seen through the window. (Frontispiece from *Oeuvres de M. Franklin*, translated by J. B. Dubourg, Chez Quillau, Paris, 1773.)

Louis XV. The king's delight inspired Dalibard to try the sentry-box experiment at Marly-la-Ville.

At the time of the sentry-box experiment, Abbé Jean-Antoine Nollet was the leading "electrician" in France and was known throughout Europe for his skill in making apparatus and in performing demonstrations. Unfortunately, because of personal rivalries, Buffon and Dalibard completely ignored Nollet's work in a short history that preceded their translation of Franklin's book. After Dalibard read an account of the sentry-box experiment to the Académie des Sciences on 13 May 1752, Nollet suppressed publication of the results.[6] News reached the Paris newspapers, however, and from there spread very rapidly. After Louis XV saw the experiment, he sent a personal message of congratulations to Franklin, Collinson, and the Royal Society of London for communicating "the useful Discoveries in Electricity, and Application of Pointed Rods to prevent the terrible Effects of Thunderstorms."[7]

Nollet was both surprised and chagrined by the experiment at Marly-la-Ville. He acknowledged that insulated rods or "electroscopes" did verify that thunderclouds are electrified, but for the rest of his life he steadfastly opposed the use of grounded rods as "preservatives." In 1753, he published a series of letters attacking Franklin's *Experiments and Observations* and suggested other methods of lightning protection. On 6 August 1753, the Swedish scientist Georg Wilhelm Richmann was electrocuted in St. Petersburg while trying to quantify the response of an insulated rod to a nearby storm. The incident, reported worldwide, underscored the dangers inherent in experimenting with insulated rods and in using protective rods with faulty ground connections. Nollet used Richmann's death to heighten the public's fears and to generate opposition to both types of rods.[8]

In London, members of the Royal Society were amused when Franklin's letter about lightning conductors was read to the Society, and they did not publish it in their *Philosophical Transactions*. In 1753, however, they awarded Franklin their highest scientific honor, the Copley Gold Medal. In his 1767 history of electricity, Joseph Priestley described the kite experiment as drawing "lightning from the heavens," and said it was "the greatest, perhaps, in the whole compass of philosophy since the time of Sir Isaac Newton."[9]

Experiments in colonial America

After Franklin learned about the success of the sentry-box experiment in France, he installed a tall, insulated 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 illustrated on the left side of figure 2. A small ball suspended between chimes mounted on each end of the gap would ring the chimes whenever an electrified cloud passed overhead. Franklin used this apparatus to compare the properties of atmospheric electricity with the electricity generated by friction and to measure the polarity of thunderclouds.

He found that both types of electricity were the same and "that the Clouds of a Thunder Gust are *most commonly* in a negative State of Electricity, but *sometimes* in a positive State,"[10] a result that was regarded as definitive for the next 170 years. At that 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." Judging by his later correspondence, Franklin was fascinated by this discovery, and he postulated that the effects of lightning would be very nearly the same regardless of the direction of the current flow.

First protection system

In the 1753 issue of *Poor Richard's Almanack*, Franklin published a method for protecting houses from lightning damage:

Figure 3. Independence Hall, Philadelphia. During a restoration in 1960, fragments of the original grounding conductor were found under paneling and plaster on the inside wall of the northwest corner of the tower stairwell. (From the Independence National Historical Park Collection.)

> 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.

The opening phrase of this description anticipated a religious objection to protective rods that would soon appear in America and Europe. In the late summer or fall of 1752, grounded conductors were installed on the Academy of Philadelphia (later the University of Pennsylvania) and the Pennsylvania State House (later Independence Hall). Figures 3 and 4 show fragments of the original grounding conductors that were installed inside the tower of Independence Hall and on the Gloria Dei (Old Swedes') Church in Philadelphia, respectively.

Three key elements made up Franklin's protection system. Metallic rods, or air terminals as they're now called, were mounted on the roof of a structure and connected by horizontal roof conductors and vertical down conductors to a ground connection. Because Franklin initially thought point discharges might provide protection, the first air terminals were thin, sharp needles mounted on top of an iron rod. The first down conductors were chains of iron rods, each several feet long, that were mechanically linked or hooked together as shown in figures 3 and 4. Because the current in point discharges is usually less than a few hundred microamperes, the roof and down conductors could be mechanically hooked together and attached to the inside walls of towers and steeples without creating a hazard.

Because Franklin wanted to verify that lightning would actually follow the path of a metallic conductor and determine what size that conductor should be, in June 1753 he published a "Request for Information on Lightning" in the *Pennsylvania Gazette* and other newspapers:

> 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 affected 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.

In the summer of 1753, Dr. John Lining, a physician with many scientific interests, verified Franklin's kite experiment in Charleston, South Carolina, but when he tried to install a rod on his house, the local populace objected. They thought that the rod was presumptuous—that it would interfere with the will of God—or that it might attract lightning and be dangerous.[11] In April of that year, Franklin commented on that issue,

> [Nollet] 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.
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> 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.[12]

Figure 4. David B. Rivers, pastor of the Gloria Dei (Old Swedes') Church in Philadelphia, holds a section of the original iron conductor that protected the church. The upper links in the chain were stapled to the inside of a wooden steeple. The inset shows how a mechanical link may have been ruptured, its hook forced open by an explosive arc during a lightning strike. (Courtesy of E. Philip Krider.)

Improvements

In the following years, Franklin continued to gather information about lightning, and in 1757 he traveled to London as an agent of the Pennsylvania Assembly. In March 1761, Kinnersley sent Franklin a detailed description of a lightning flash that struck a Philadelphia house equipped with a protective rod. An observer had reported at the time 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." Further investigation showed that the lightning had melted a few inches of the brass air terminal and Kinnersley concluded, "Surely it will now be thought as expedient to provide Conductors for the Lightning as for the Rain."[13]

Before Kinnersley's letter, Franklin had received reports of two similar strikes to protected houses in South Carolina. In one case, the points and a length of the brass down conductor had melted. In the other, three brass points, each about seven inches long and mounted on top of an iron rod, had evaporated. Moreover, several sections of the iron down conductor, each about a half-inch in diameter and hooked together, had become unhooked by the discharge (see figure 4). Nearly all the staples that held the conductor to the outside of the house had also been loosened. "Considerable cavities" had been made in the earth near the rod, sunk about three feet underground, and the lightning had produced several furrows in the ground "some yards in length." Franklin was pleased by these reports, and replied to Kinnersley that "a conductor formed of nail rods, not much above a quarter of an inch thick, served well to convey the lightning" but "when too small, may be destroyed in executing its office." Franklin sent the reports from South Carolina to Kinnersley with a recommendation to use larger, more substantial conductors and a deeper, more extensive grounding system to protect the foundation of the house against the effects of surface arcs and explosions in the soil.

Because all reports from North America showed that grounded rods did indeed protect houses from lightning damage, in January 1762 Franklin sent an improved design for "the shortest and simplest Method of securing Buildings, Etc. from the Mischiefs of Lightning," together with excerpts from Kinnersley's letter and the reports from South Carolina, to Scottish philosopher David Hume. That letter was subsequently read to Edinburgh's philosophical society, which published it in 1771.

In the letter to Hume, Franklin recommended large, steel air terminals, 5 to 6 feet long and tapered to a sharp point. He said that any building with a dimension greater than about 100 feet should have a pointed rod mounted on each end with a conductor between them. All roof and down conductors should be at least a half-inch in diameter, continuous, and routed outside the building—the earlier design allowed routing the conductors inside a building's walls. Any links or joints in these conductors should be filled with lead solder to ensure a good connection. The grounding conductor should be a one-inch-diameter iron bar driven 10 to 12 feet into the earth, and if possible, kept at least 10 feet away from the foundation. Franklin also recommended that the ground rods be painted to minimize rust and connected to a well, if one happened to be nearby. Figure 5 illustrates an implementation of Franklin's 1762 design.

In the 1769 edition of *Experiments and Observations*, Franklin published his reply to Kinnersley and the reports from South Carolina together with some "Remarks" on the construction and use of protective rods. After repeating his recommendations for an improved design, he also noted a psychological benefit of having protection against lightning:

> Those who calculate chances may perhaps find that not one death (or the destruction of one house) in a hundred thousand happens from that cause, and that therefore it is scarce worth while to be at any expense to guard against it. But in all countries there are particular situations of buildings more exposed than others to such accidents, and there are minds so strongly impressed with the apprehension of them, as to be very unhappy every time a little thunder is within their hearing; it may therefore be well to render this little piece of new knowledge as general and well understood as possible, since to make us *safe* is not all its advantage, it is some to make us *easy*. And as the stroke it secures us from might have chanced perhaps but once in our lives, while it may relieve us a hundred times from those painful apprehensions, the latter may possibly on the whole contribute more to the happiness of mankind than the former.[14]

Today, most authorities agree that lightning rods define and control the points where lightning will strike the structure and then guide the current safely into ground. As Franklin noted in 1761, "Indeed, in the construction of

Figure 5. An 18th-century house with a lightning rod of Franklin's 1762 design. The thick, continuous rod can carry tens of kiloamperes of current to ground without harming the house or its foundation.

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." Franklin was truly lucky: His original 1752 design was based on the low current levels of point discharges, but direct lightning strikes deliver tens of kiloamperes of current, enough to produce explosive arcs across any imperfect mechanical connections; and those arcs can produce momentary overpressures of several hundred atmospheres and enough heat to ignite flammable materials. The early applications of lightning rods could have been disastrous. Franklin's 1762 design, however, has stood the test of time and remains the basis for all modern lightning protection codes in the world today.

'Snatching lightning from the sky'

It is difficult for us living in an electrical age to appreciate how important lightning conductors were in the 18th century. The discovery that thunderclouds contain electricity and that lightning is an electrical discharge revolutionized human perceptions of the natural world, and the invention of protective rods was a clear example of how basic, curiosity-driven research can lead to significant practical benefits. In his later years, Franklin devoted most of his time to public service, but he did continue to follow the work of others and conduct occasional experiments. He also participated on scientific advisory boards and panels that reviewed methods of lightning protection, and made recommendations for protecting cathedrals and facilities for manufacturing and storing gunpowder.

Eventually, Franklin became a leader of the American Revolution. When he embarked for France in November 1776 to seek aid for the newly declared United States of America in the war against Great Britain, he took with him a unique asset—his worldwide fame. By then his work on lightning and electricity had called attention to his other writings in science, politics, and moral philosophy,[15] and the intellectuals of France and Europe viewed Franklin as one of their own.

In 1811, John Adams, the first vice president and second president of the US, who served with Franklin in France in the 1770s (and who actually hated him), summarized Franklin's reputation:

> Nothing, perhaps, that ever occurred upon this earth was so well calculated to give any man an extensive and universal celebrity as the discovery of the efficacy of iron points and the invention of lightning rods. The idea was one of the most sublime that ever entered a human imagination, that a mortal should disarm the clouds of heaven, and almost "snatch from his hand the sceptre and the rod!" The ancients would have enrolled him with Bacchus and Ceres, Hercules and Minerva. His *Paratonnerres* erected their heads in all parts of the world, on temples and palaces no less than on cottages of peasants and the habitations of ordinary citizens. These visible objects reminded all men of the name and character of their inventor; and, in the course of time, have not only tranquilized the minds and dissipated the fears of the tender sex and their timorous children, but have almost annihilated that panic terror and superstitious horror which was once almost universal in violent storms of thunder and lightning. . . .
>
> His reputation was more universal than that of Leibnitz or Newton, Frederick or Voltaire, and his character more beloved and esteemed than any or all of them. Newton had astonished perhaps forty or fifty men in Europe; for not more than that number, probably, at any one time had read him and understood him by his discoveries and demonstrations. And these being held in admiration in their respective countries as at the head of the philosophers, had spread among scientific people a mysterious wonder at the genius of this

perhaps the greatest man that ever lived. But this fame was confined to men of letters. The common people knew little and cared nothing about such a recluse philosopher. Leibnitz's name was more confined still. . . . But Franklin's fame was universal. His name was familiar to government and people, to kings, courtiers, nobility, clergy, and philosophers, as well as plebeians, to such a degree that there was scarcely a peasant or a citizen, a valet de chambre, coachman or footman, a lady's chambermaid or a scullion in a kitchen, who was not familiar with it, and who did not consider him as a friend to human kind. When they spoke of him, they seemed to think he was to restore the golden age.[16]

In June 1776, the celebrated economist and former comptroller-general of France, Anne-Robert Jacques Turgot, composed a prophetic epigram in Latin that captures Franklin's legacy in a single sentence: "Eripuit caelo fulmen, sceptrumque tyrannis" ("He snatched lightning from the sky and the scepter from tyrants").[17]

I am grateful to Penelope Hartshorne Batcheler for calling my attention to the photograph in figure 3.

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