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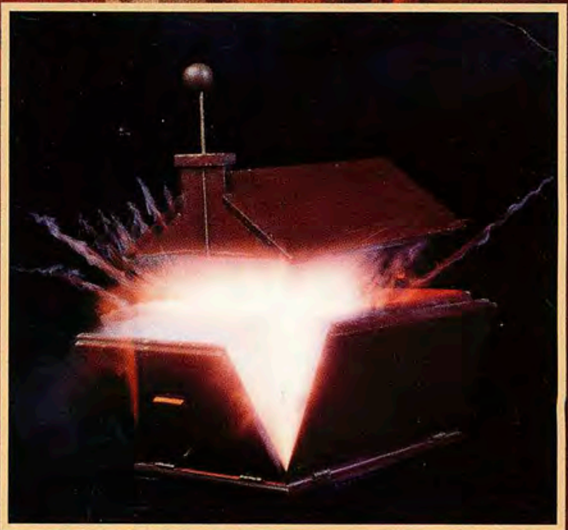
Franklin's "Scientific Amusements"

His exploding "thunder house" gives electrifying proof of the value of pure knowledge.



BEN FRANKLIN'S

"SCIENTIFIC AMUSEMENTS"

Although renowned for pragmatism, Franklin fathered a scientific revolution by indulging his insatiable curiosity.

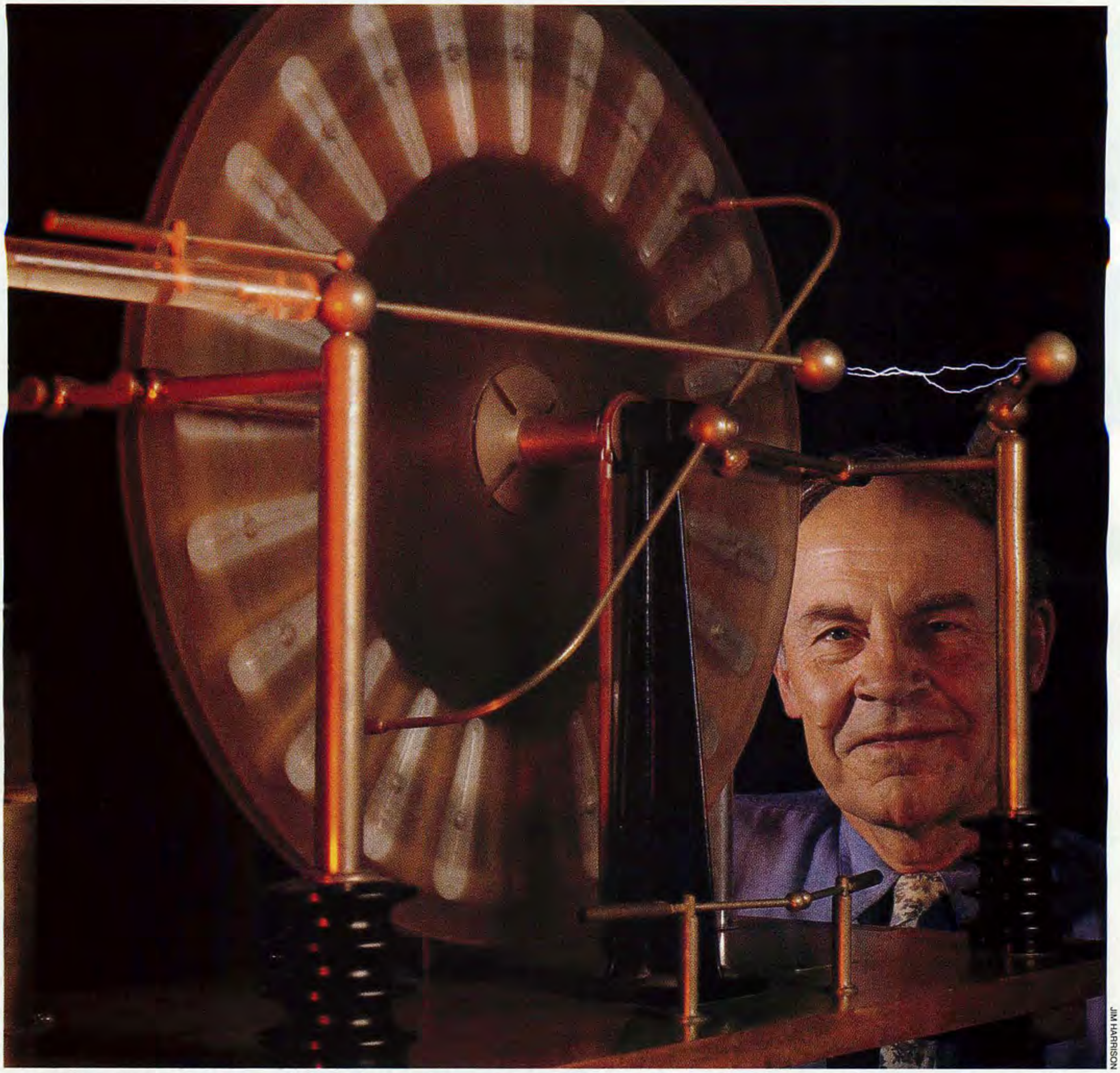
by DUDLEY R. HERSCHBACH

As an American icon, Benjamin Franklin is often portrayed as wise and canny in business and politics, earnestly pursuing and extolling diligence, sensible conduct, and good works. Also legendary are some of his inventions, such as the lightning rod, bifocals, and an efficient wood-burning stove. All of this is usually taken to exemplify the virtues of his down-to-earth, pragmatic outlook. Today, however, surprisingly few people appreciate that, in his own time, Franklin was greatly esteemed throughout Europe as an intellectual. His work on electricity was recognized as ushering in a scientific revolution comparable to those wrought by Newton in the previous century or by Watson and Crick in ours. Moreover, by his own account, Franklin's studies of electricity and many other phenomena were prompted not by practical aims, but by his playful curiosity—which often became obsessive, even antic.

My first inkling of this side of Ben Franklin came in 1956, when I was a graduate student. To commemorate the 250th anniversary of Franklin's birth and the 200th of Mozart's, the American Academy of Arts and Sciences put on a concert that featured a glass harmonica specially constructed for the occasion, and intended to do justice to music that Mozart had composed specifically for that instrument. Like the "armonica" invented by Franklin in 1762, it consisted of glass bowls of increasing diameter mounted on a rotating spindle. Unlike the original models, which were played by pressing wet

Above: The old engraving of a church being struck by lightning, and of a "thunder house" demonstration of the same phenomenon, is from Dominicus Beck, *Kurzer Entwurf der Lehre von der Elecktricität*, published in 1787. Opposite: Mason Chamberlin's 1762 portrait shows Franklin with his indoor lightning detector.

PHOTOGRAPH ABOVE: HARVARD COLLECTION OF HISTORICAL SCIENTIFIC INSTRUMENTS . RIGHT: PHILADELPHIA MUSEUM OF ART: GIFT OF MR. AND MRS. WHARTON SINKLER



Harvard bought a pair of beautifully crafted electrostatic machines for £40 in 1766, when Franklin was 60, from a well-known instrument maker, Benjamin Martin. Dudley Herschbach produces copious sparks from a machine similar to the eighteenth-century devices, which are now in the Harvard Collection of Historical Scientific Instruments.

fingers against the rims of the bowls, this was a very large contraption with 37 glass bowls and a keyboard enabling it to be played like a piano. I remember that E. Power Biggs, after performing beautifully with simple musical glasses, had some difficulty with the armonica because several of the bowls had shattered, and more did as he played.

The concert included a live performance of the famous string quartet attributed to Franklin. Experts are unsure whether Franklin really composed it, but there are typically impish hints. The quartet is in the key of F. It employs three violins and a cello, with scordatura tuning such that each musician has to play only four notes, one on each of the open strings. The result is 16-tone music, vastly simplified for the performers. Indeed, the string players had quizzical expressions on their faces; their left hands were used to fingering like mad but in this quartet had nothing to do. Certainly the piece, whether or not composed by Franklin, exhibits his yen for whimsical fun.

That concert left me intrigued with Franklin, and in the years since I have enjoyed looking into what he called his "scientific amusements." Like so much else he did, the scope of his work in science is amazing. (See "Chronology of Curiosity," opposite.) Fortunately, his experiments and observations are amply documented in his own writings, especially in letters to his friends and colleagues. While he was always alert for practical applications, in most of his scientific studies his style was that of an explorer, eager for adventure and insight rather than profit or utility. Many of his letters convey his zest for understanding and his joy in discovery; some ruefully admit an ad-

Chronology of Curiosity

When and where: Franklin was born in Boston on January 17, 1706, and died in Philadelphia on April 17, 1790. He lived in Boston until 1723, then in London (1724-26), Philadelphia (1726-57, 1762-64, 1775-76), London (1757-62, 1764-75), Paris (1776-85), and Philadelphia (1785-90).

Franklin's world was much larger than ours: crossing the Atlantic took not a few hours but four to six weeks, a voyage he made eight times. To his perceptive eye, the world bulged with challenging puzzles. His intellectual voyage extended more than 60 years, during which he recorded a host of fresh observations and interpretations and conducted many experiments. This sampling of his science includes annotations for a few choice items.

1726 Returning from his first trip to London, makes notes on ocean currents, temperature, weather—subjects that would continue to interest him all his life.

1729 While working hard to establish himself as a printer, performs his first recorded scientific experiments, on color and heat absorption, by laying squares of light- and dark-colored cloth on snow on a sunny day and noting how deep they sank.

1730 Begins publishing in his newspaper, *The Pennsylvania Gazette*, his own observations and those of others, indicating his wide range of interests. Writes about the effect of earthquakes on the color of rivers.

1732 Reports observations of the aurora borealis.

1739 Invents "Pennsylvania stove." (An amusing chapter of I. Bernard Cohen's *Benjamin Franklin's Science* points out that no genuine "Franklin stoves" exist today, for good reason: his clever design proved in practice to be a smoky fiasco. Ben was fallible!)

1742 Discusses behavior of comets.

1743 Reports observations on eclipse of the moon and motion of storms.

Attends electrical demonstrations by Archibald Spencer, becomes intrigued.

1745 Writes long critique of Cadwallader Colden's anatomical manuscript on perspiration and the bloodstream.

Receives from Peter Collinson an "electrical tube" apparatus and directions for its use; begins intensive series of electrical experiments.

1748 Retires from business at age 42, giving as a major reason his desire to concentrate on scientific experiments.

1750 Proposes use of lightning rods. Severely shocked while trying to electrocute a turkey.

1751 Collection of his letters to Collinson, read at the Royal Society, published in London as *Experiments and Observations on Electricity, made at Philadelphia in America*; additional work included in later editions of 1754, 1760, 1769, and 1774.

1752 Conducts kite experiment. Equips his house with a lightning rod. Invents flexible catheter (to aid brother John, who suffers from bladder stone).

1755 Writes *Observations Concerning the Increase of Mankind, Peopling of Countries, Etc.* Noting that the English population in North America was one million, but that only 80,000 had immigrated, Franklin calculated that population would double every 20 to 25 years, which it did until 1860, when immigration surged. This work also explicitly anticipated the limitations stressed by Thomas Malthus in his famous essay of 1798.

His major paper, *Physical and Meteorological Observations, Conjectures, and Suppositions*, read at the Royal Society.

1758 Performs experiments on evaporation at Cambridge University.

1773 Reports experiments on spreading of oil on water.

JIM HARRISON

Historical instruments curator William Andrewes with one of the eighteenth-century electrostatic generators.

1775 On voyage to America, measures temperature of air and water to begin mapping of Gulf Stream.

1782 Witnesses early manned balloon ascensions; when asked by dubious observer, "What use is it?", replies, "What use is a new-born baby?"

1784 Constructs bifocal eyeglasses.

1785 Serves as spokesman for a French royal committee that successfully discredits purported cures by "mesmeric fluid" generated from animal magnetism, which had become a craze in Paris. Appointed by Louis XVI, the committee included the famous chemist Lavoisier and the physician Guillotin. (A few years later the king and the chemist both lost their heads to another French craze via a means once publicly endorsed as humane by the physician.)

On last voyage home, at age 79, writes *Maritime Observations*, noting best form of rigging for swift vessels, proposing design of sea anchor, and reporting further data about the Gulf Stream.

diction to science akin to his indulgence in chess and magic squares.

Franklin's scientific work and engaging discussions of it are readily accessible to the general reader, but deserve to be better known. Much of this article draws on recent scholarship about him. The first part is based mostly on *Benjamin Franklin's Science*, by I. Bernard Cohen, Thomas professor of the history of science emeritus and surely the world's greatest authority on Franklin's science. The second part is drawn from *Ben Franklin Stilled the Waves*, by Charles Tanford, a distinguished biochemist and professor of physiology emeritus at Duke University. (For particulars about these and other pertinent books, see "A Shelf for Ben's Science," below.)

ELECTRICAL AMUSEMENTS: "HELP TO KEEP A VAIN MAN HUMBLE"

As Cohen emphasizes, in the early eighteenth century electricity was a greater mystery than was gravity a century earlier. Franklin, almost entirely self-educated and far from any center of learning, solved that mystery. He devised, executed, and correctly interpreted a series of simple, compelling experiments and formulated lucid explanations. Among his several major discoveries, foremost was his concept of electricity as a single fluid, manifest as a "positive or negative" charge, depending on whether the fluid was present in excess or deficit relative to the neutral condition.

Franklin's book *Experiments and Observations on Electricity, made at Philadelphia in America*, consisting of the letters he had sent to Peter Collinson (who had supplied him with an electrical tube apparatus) was a sensation in Europe: it went through five editions in English and was translated into French, German, and Italian. It was read not only by scholars but by the literate public, including the clergy and aristocracy. All were astonished that an amateur far off in America had been able to establish the nature of something as puzzling as electricity.

During the several years when he was chiefly occupied with his electrical studies, Franklin often confessed apologetically to friends that he had become obsessed with his experiments. He called them "philosophical amusements," which he pursued in hopes of gaining insight, despite what seemed then a total lack of prospects for practical applications. Three years before he conceived of the lightning rod, Franklin averred that electricity at least "may help to keep a vain man humble."

Franklin often confessed that he had become obsessed with his experiments, which he pursued despite what seemed a total lack of practical applications.

Much that he did was for the sheer fun of it. For example, one of his favorite toys was an electrical spider; when charged up, it moved around like a real spider. In letters he mentioned the crowds that came to his house to see such things and how he liked to play tricks on them. He had an iron fence and would wire it up to make sparks leap along the rails to excite the onlookers. We can reproduce the effect with electrostatic machines such as those in the Harvard Collection of Historical Scientific Instruments. The machines have a glass globe that is rotated by a gear mechanism to rub the glass against silk and generate an electrical charge. Since antiquity, sparks have been generated this way, by rubbing suitable materials together. Often we do it inadvertently by walking across a carpet. Today we speak of knocking some electrons off by friction. But before Franklin established the nature of electricity, it was thought that different substances gave rise to various kinds of mystical particles.

In Franklin's day, the public became intensely interested in

A Shelf for Ben's Science

The two essential books on the scientific Franklin, both sprightly and nontechnical, are I. Bernard Cohen's superb *Benjamin Franklin's Science* (Harvard University Press, 1990) and Charles Tanford's *Ben Franklin Stilled the Waves* (Duke University Press, 1989). Also of much interest is another superb book just published by Cohen, *Science and the Founding Fathers: Science in the Political Thought of Jefferson, Franklin, Adams, & Madison* (Norton, 1995; see "Endpapers," page 118).

Foremost among other books I particularly recommend is a fine anthology of Franklin's *Writings*, edited by J. A. Leo LeMay (Library of America, 1987). There are many biographies; my favorites are Catherine Drinker Bowen's *The Most Dangerous Man in America* (Little, Brown, 1974) and Ronald W. Clark's *Benjamin Franklin* (Random House, 1983). Both include some scientific episodes.

A rich lode of graphics is found in Louise Todd Ambler's *Benjamin Franklin: A Perspective* (Fogg Art Museum, 1975) and David P. Wheatland's *The Apparatus of Science at Harvard, 1765-1800* (Harvard University Press, 1968).

Striking material on lightning abounds; particularly vivid are accounts by James S. Trefil in *Meditations at Sunset* (Macmillan, 1987); by Ido Yaretz in "Lightning and the History of Science and Technology" (*News from the Burndy Library*, fall 1993); and by Dava Sobel in "Jove's Thunderbolts" (*Harvard Magazine*, July-August 1979).

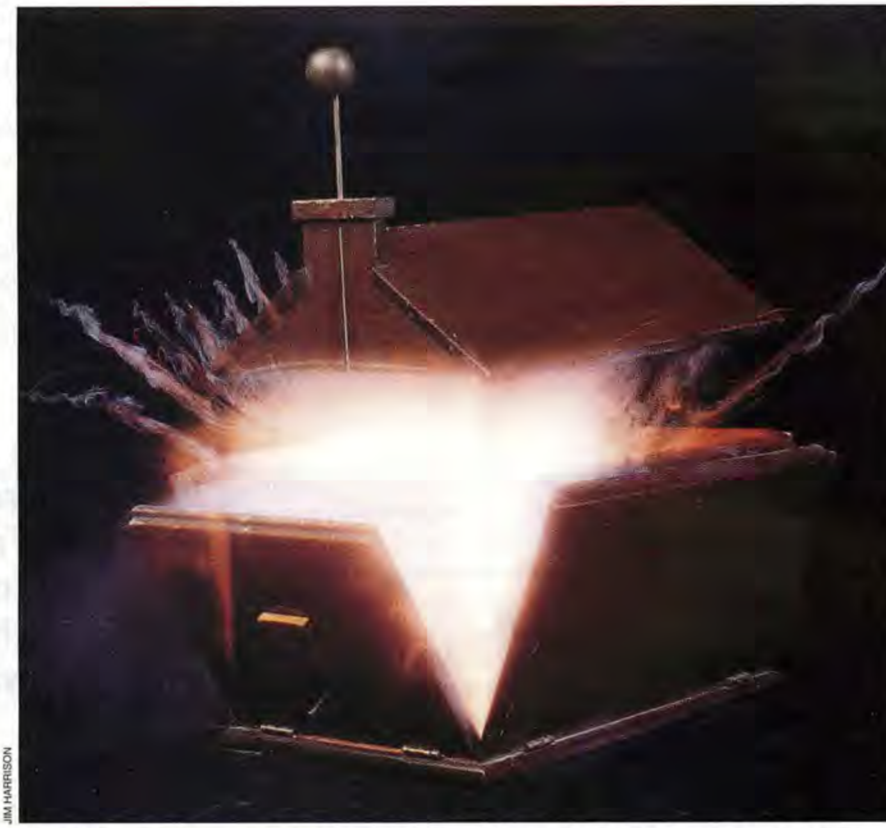
***Benjamin Franklin*, from the Fogg's 1975 exhibit**

electrical phenomena. A very popular book of 1759, titled *Young Gentleman and Lady's Philosophy*, illustrated a parlor game that Franklin himself might well have pursued. Evidently the conversation did not go, "Would you like to see some fine etchings?", but "Would you like to see a fine electrostatic generator?" As a kid, I was puzzled to hear my parents speak of "sparking"; now I wonder whether that quaint usage derives from a higher level of scientific literacy 200 years ago!

The Lightning Rod

The concepts that Franklin established in several years of playful experiments were essential prerequisites to his invention of the lightning rod. In a 1750 letter he wrote:

> ...may not the Knowledge of this Power of Points be of use to Mankind, in preserving Houses, Churches, Ships &c. from the Stroke of Lightning, by directing us to fix on the highest parts of those Edifices, upright Rods of Iron...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?


JIM HARRISON

This "thunder house," akin to models Franklin made to demonstrate the virtues of his lightning rod, is a replica of an instrument purchased by Harvard in 1789 from the Reverend John Prince of Salem. A three-dimensional mahogany model of a house (10 by 6 by 8 inches), built with removable roof and collapsible walls hinged to the base, it is equipped with a lightning rod that runs up the gable and ends in a detachable brass ball above the chimney. A wooden block can be inserted to break the circuit. Within the house is a cup containing gunpowder. When the circuit is complete, an electrical charge goes through the lightning rod, with no effect on the house. When the circuit is broken, the spark ignites the gunpowder with convincing—and entertaining—effects.

Professor I. Bernard Cohen had the replica made 45 years ago and often used it in his lectures; he recalls consulting his colleague, chemist George Kistiakowsky, about the gunpowder charge.

Nowadays this might be a grant proposal! It depends on his discovery that pointed conductors were very effective at drawing away the electrical fluid. We now say this happens because the "electrical field" is higher at a pointed conductor than at a rounded one, so some of the air is ionized and conducts better. Franklin's proposal further depends on his understanding that it is essential to ground the conductor (so the charge runs off into the vast reservoir of the earth or sea). Also fundamental, as revealed by his research, was the fact that the electricity would flow through a good metallic conductor instead of the poor conducting materials of the building or ship. Others had suspected that lightning is electrical, but an experimental test could not be devised until Franklin had created a sufficiently good intellectual conduit, connecting that conjecture to well-grounded concepts.

In the next paragraph of the letter, Franklin outlines his proposed experiment quite specifically:

> On the top of some high Tower or Steeple, place a kind of Sentry-box 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...

Cohen's book reproduces a diagram from Franklin's letter. In effect, the sentry would hold up the iron rod (or touch it with a wire) to draw off electrical current from the cloud, just as you might hold a key to a doorknob to discharge static electricity you've picked up in walking across the carpet. It was apt that Franklin specified a sentry, a disciplined person who doesn't flinch. Actually, as he correctly explained, if the sentry holds the rod via an insulated stick or wax bar, connected to a grounded conductor, he could do the experiment with perfect safety.

Franklin did not undertake this experiment because Philadelphia did not then have a suitably tall structure. Later he realized that by flying a kite he could accomplish his purpose much more simply. (That happens with research proposals in our day, too!) Meanwhile, his book, including the 1750 letter and others, caused particularly great excitement in France because Louis XV liked electrical parlor games. For instance, he would have 100 grenadiers line up holding hands, then connect them to electrical leads at each end, to see them all jump in unison. In one variant, the king had this done with 200 monks instead. The king requested that Franklin's experiments be performed for his edification. The proposed sentry-box experiment thus was first done in France, under direction of the translator of his book; it appears that Franklin heard of that only after his kite experiment.

We now know much more about lightning; *Meditations at Sun-*

set, by James S. Trefil, provides an excellent survey. In essence, Franklin's ideas hold up. Clouds contain some charged particles and, empirically, the positively charged particles tend to be somewhat lighter than negative ones. Thus, a cumulus cloud will often have excess negative charges along its bottom—say, at an altitude of 5,000 feet—and excess positive charges up above. As a result, a big potential difference can develop within the cloud. When the cloud floats over a tree or house, what matters is the charge near the earth. The negative bottom of the cloud repels some of the negative charges in the tree or house, pushing them into the ground. Things in the shadow of the cloud thus acquire a net positive charge, which drifts along the earth beneath the floating cloud. When the voltage difference between the negative cloud bottom and its positive shadow exceeds the capacity of the air to withstand it, lightning discharges *via* the most conductive available pathway.

High-speed photography has shown what Franklin couldn't see with his own eyes: the electrical breakdown usually ionizes the air for only a few hundred feet. Then there's another such breakdown, and another, until the cloud-ground gap is bridged when descending and ascending discharges meet. Franklin, simply by draining charge from a rod on his roof and finding it negative with respect to charge obtained from his electrostatic machine, did in fact infer that a lightning stroke typically goes up, not down.

Earthly Thunder

Soon after the kite and sentry-box experiments, Franklin installed lightning rods on the tallest public buildings in Philadelphia and placed an announcement in the 1753 edition of his best-selling book, *Poor Richard's Almanack*:

> 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 [full construction details follow]....A House thus furnished will not be damaged by Lightning, it being attracted to the Points, and passing thro the Metal into the Ground without hurting any Thing.

From enlightened quarters there soon rained down on Franklin high honors, sparked by his invention of the lightning rod. These included the first honorary degree awarded by Harvard and the Copley Medal of the Royal Society, both in 1753. Further honors followed from a host of scholarly societies. In particular, in 1772 he was elected a foreign associate of the French Academy of Sciences (only eight are allowed); he was the first American elected—and the only one for another century.

Perhaps even more telling were what we might term low honors. The immense popularity Franklin enjoyed during his ministry to France stemmed from his fame as the tamer of lightning as well as a revolutionary patriot. Although T-shirts were not yet fashionable, Franklin's image appeared everywhere in Paris on medallions, engravings, and banners, often with the Latin motto coined by Turgot: *Eripuit coelo fulmen sceptrumque tyrannis* ("He snatched lightning from the sky and the scepter from tyrants"). Indeed, Louis XVI became so annoyed by this veneration that he gave his favorite mistress a chamber pot with a Franklin medallion at the bottom of the bowl.

From enlightened quarters there soon rained down on Franklin high honors, including the first honorary degree awarded by Harvard.

The Harvard Collection of Historical Scientific Instruments includes several versions of persuasive devices used by Franklin and many other lecturers to demonstrate the virtues of his lightning rod, both in classrooms and for popular entertainments. A fine example is the exploding "thunder house" (see photograph on page 41).

It's appropriate that the thunder house has a little steeple.

The Local Connections

Crowns of lightning rods adorn most of the tallest buildings at Harvard, including William James Hall, the Science Center, Memorial Hall, and Holyoke Center, as well as the towers of several of the Houses. These crowns consist of short rods, 12 to 18 inches tall, spaced about 20 feet apart around the periphery of the highest portion of the roof. The rods are linked by half-inch-thick braided cables of copper wire, connected to a grounded bus bar. Some spires, such as the steeple of Memorial Church, are clad in a heavy copper sheath, directly connected to a grounded conductor. In effect, this makes the entire spire serve as a lightning rod.

All told, Harvard's lightning protection employs several hundred rods and many thousands of feet of copper cable. This is in the care of the Boston Lightning Rod Company; the firm's service extends back more than a century, during which Harvard has suffered almost no significant damage from lightning strokes.

An instructive exception occurred in August 1986. The building involved, Byerly Hall in Radcliffe Yard, had not been protected by lightning rods because its roof is much lower than surrounding trees. A bolt struck one of eight unused chimneys that had been capped by an ungrounded copper plate. The copper cap, about 5 feet square, was blown more than 50 feet into the Yard, together with several dozen bricks.

JIM HARRISON

Lightning rods stand guard at William James Hall.

THE BURNDY LIBRARY, DIBNER INSTITUTE FOR THE HISTORY OF SCIENCE AND TECHNOLOGY

A Japanese example of Louis XV's electrical parlor game, from Sōkichi Hashimoto's *Oranda shisei erekiteru kyūrigen*, 1813.

Before Franklin's discoveries, lightning was generally seen as a supernatural phenomenon. If a house was struck by lightning, the fire company would douse the neighboring structures, but only pray over the struck one, not wanting to intrude on God's punishment. Such views also led to the custom of storing gunpowder in churches, where it might have divine protection. For example, in 1767 the authorities in Venice opted to store hundreds of tons of powder in a church vault. Lightning blew it up, killing 3,000 people and destroying a sizable portion of the city. After that, lightning rods became much more common in Italy.

Another long tradition, going back to the time of Charlemagne, was the ringing of consecrated church bells during thunderstorms to ward off lightning bolts hurled by diabolical spirits; church bells typically bore inscriptions extolling such powers. That made bell-ringing a hazardous occupation. A book published in Munich in 1784 recorded that in the previous 35 years, lightning had hit 386 churches in Germany and killed 103 bell-ringers. Cohen cites many other instances of lightning strikes on steeples and electrocutions of bell-ringers, some more than a century after Franklin had shown the down-to-earth efficacy of lightning rods.

Despite Franklin's astutely diplomatic assertion acknowledging divine beneficence ("It has pleased God..."), religious prejudice against his lightning rods was thunderous and sustained—understandably, perhaps, in the context of the times, since his science fundamentally challenged the supernatural. In 1756, when an earthquake hit Boston, ministers attacked Franklin for his audacity in stealing lightning from the Almighty. People feared that his rods would attract strikes that would not otherwise happen, and that draining electricity into the ground would cause earthquakes.

Political opposition also arose—particularly in England, from those angry with or suspicious of Franklin as the representative of rebel colonies. Some claimed the sharp-tipped rods he advocated were more likely than round knobs to attract strikes and thus become dangerous if the lightning did not meekly run down the rod to ground. (In fact, while this effect is marked in the lab, it is moot for lightning; to a cloud far aloft, any difference in the shape of a rod is imperceptible.)

For the most part, Franklin was unruffled by the opposition. But he was annoyed by the unsound attacks of the Abbé Nollet, a powerful French intellectual whose theorizing about electricity had been rendered void by Franklin's discoveries. Writing in 1753 to a friend, Franklin said:

> In one or two Places, [Nollet] seems to apply to the superstitious Prejudices of the Populace, which I think unworthy of a Philosopher. He speaks as if he thought it Presumption in man, to propose guarding himself against the Thunders of Heaven! Surely the Thunder of Heaven is no more supernatural than the Rain Hail or Sunshine of Heaven, against the Inconveniences of which we guard by Roofs & Shades without *Scruple*.

Gradually, of course, lightning rods became widely accepted,

JIM HARRISON

Franklin was fascinated by the interaction of oil and water. Lecture-demonstrator Daniel Rosenberg elucidates the phenomenon by sprinkling powder on the surface of an artificial "pond" to form a pollen-like coating. When he adds a very small drop of olive oil, it spreads in the blink of an eye, repelling the powder.

although that took roughly 40 years. A nineteenth-century illustration of a man with lightning-rod equipped umbrella offers a charming endorsement!

Franklin had a lightning detector of special design in his own house. The device had two parallel segments, one coming down from the roof beside his chimney, the other sunk in the ground and extending upward. Each segment led to a small bell; the two bells, a few inches apart, were connected by a silk thread carrying a little brass ball. When a cloud went over and induced some charge in the upper rod, the little ball would pick up the charge and rattle back and forth, ringing the bells. In the event of a lightning stroke, strong sparks would also leap between the bells. Franklin gleefully reported how the light from such sparks was sometimes strong enough that he could read a newspaper by it. (On the other hand, the rattling bedeviled his wife while he was away in London; he therefore suggested that she connect the balls by a metal wire, to conduct the current silently.)

OIL ON WATER: "THE LEARNED...ARE APT TO SLIGHT TOO MUCH THE KNOWLEDGE OF THE VULGAR"

Charles Tanford's *Ben Franklin Stilled the Waves* bears a subtitle in eighteenth-century style: *An Informal History of Pouring Oil on Water with Reflections on the Ups and Downs of Scientific Life in General.* He describes the context and consequences of a research odyssey that stems from one of Franklin's simplest experiments. It was done toward the end of his long sojourn in England as a trade representative, when ominous political waves were cresting. Here is Franklin's account, excerpted from a letter to William Brownrigg in 1773. It responds to Brownrigg's questions about the experiment, but begins by referring to an earlier experiment, of the culinary variety:

...I suppose Mrs. Brownrigg did not succeed in making the Parmesan Cheese, since we have heard nothing of it....

...I had when a Youth, read and smiled at Pliny's Account of a Practice...to still the Waves by pouring Oil into the Sea....it has been of late too much the Mode to slight the Learning of the Ancients. The Learned too, are apt to slight too much the Knowledge of the Vulgar....This art of smoothing the Waves with Oil, is an Instance of both.

...at Clapham I observed a large pond very rough with the Wind. I fetched out a Cryet of Oil, and dropt a little of it on the Water. I saw it spread itself with surprising Swiftness upon the Surface....the Oil tho' not more than a Tea Spoonful produced an instant Calm, over a Space several yards square, which spread amazingly, and extended itself gradually...making all that Quarter of the Pond, perhaps half an acre, as smooth as a Looking Glass.

...It seems as if a mutual Repulsion between its particles took Place....The Quantity of this Force and the Distance to which it will operate, I have not yet ascertained, but I think it a curious Enquiry, and I wish to understand whence it arises.

This is one of my favorites among Ben's letters. Clearly, his always lively curiosity was excited. He devoted many pages to conjectures, reluctant to take leave of such intriguing phenomena, regardless of their practical import. That's something Franklin did all his life.

Later in his letter, Franklin writes:

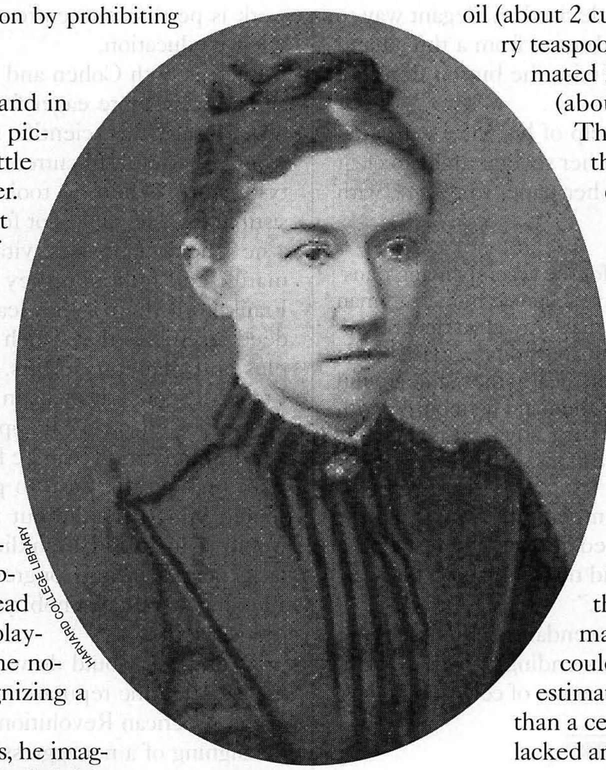
...this is not a Chamber Experiment; for it cannot very well be repeated in a Bowl or Dish of Water on a Table. A considerable Surface of Water is necessary to give Room for the Expansion of a small Quantity of Oil. In a Dish of Water if the smallest Drop of Oil be let fall in the Middle, the whole Surface is presently covered with a thin greasy Film proceeding from the drop; but as soon as that Film has reached the Sides of the Dish, no more will issue from the drop, but it remains in the Form of Oil, the Sides of the

Dish putting a Stop to its Dissipation by prohibiting the farther Expansion of the Film.

What Franklin could not understand in the eighteenth century is easy to picture today. Suppose you have a little *pile of oil molecules* on top of water. Oil and water molecules don't want to mix. So we imagine the pile of oil molecules tumbling down and spreading out, and continuing to spread until it's a monolayer.

Yet more must be said. Franklin knew that oil and water don't mix, and even considered matter to be composed of corpuscles. That was Newton's view in his *Opticks*, which exemplified for Franklin how to pursue experimental science. Why didn't Franklin suppose that oil corpuscles would spread out to form a cheek-by-jowl monolayer? Tanford suggests it's because the notion of corpuscles precluded recognizing a key property of molecules.

When Newton spoke of corpuscles, he imagined that they were the smallest indivisible units of matter, like the atoms of the ancient Greeks. But if corpuscles were indeed the smallest unit, they would all have exactly the same properties. That's why Franklin, who knew that like repels like, thought in terms of the mutual repulsion of oil corpuscles. The repulsion might spread them far apart, so there need be no relation between the corpuscules' size and their spacing in the oil film.


HARVARD COLLEGE LIBRARY

Agnes Pockels's kitchen science would have delighted Franklin.

Franklin could have obtained the first fairly good estimates of molecular size and mass, had he not lacked an elementary molecular concept.

Molecules, as we now know, can have parts with very different properties, especially if they are big molecules—just as in human chemistry, large organizations often have antagonistic parts. In this case, one end of the olive-oil molecule loves water, but the other end hates it. This produces a monomolecular film, since the oil spreads until the water-loving ends are all submerged, while the water-hating hydrocarbon ends snuggle together, cheek-by-jowl.

If the molecules in the film form a cheek-by-jowl layer, one molecule thick, Franklin's experiment provides an extremely simple way to determine the size of a molecule and even its mass. He tossed on the pond a volume of one teaspoonful of oil (about 2 cubic centimeters—eighteenth-century teaspoons were smaller than ours) and estimated it spread over an area of half an acre (about 20,000,000 square centimeters). The ratio of volume to area gives the thickness of the film (roughly a hundred billionths of a centimeter). How small is that? I like Victor Weisskopf's favorite comparison: the width of a typical molecule is about one ten-thousandth of the thickness of a human hair. Another vivid answer was favored by John Strutt, Lord Rayleigh: the size of a molecule compares with the width of your thumbnail about as one-third of a second compares to a year. From the molecule's size we can estimate its volume; then the known density of the oil allows us to determine approximately the molecular mass. Franklin could have obtained the first fairly good estimates of molecular size and mass more than a century before anyone else, had he not lacked an elementary molecular concept. Elementary it seems now, but not so in historical context.

In fact, in 1890, Lord Rayleigh got the first quantitative estimates of the size and mass of a molecule from a scaled-down version of Franklin's experiment. The story is an illuminating one about both the continuity and the personality of science honorably conducted.

Rayleigh used a tub of water about 6 feet long (perhaps his Victorian bathtub) and repeatedly added oil drops to find out what sized individual drop would spread to cover the whole tub surface. He used little bits of camphor to tell how much of the surface the oil covered. On a clean water surface, bits of camphor will scoot around because camphor molecules dissolve somewhat in water, thereby causing the camphor bits to recoil much like the exhaust spewing from a mini-rocket. When oil covers the water, the camphor doesn't dissolve anymore, so the mini-rocket sits still.

Among other intriguing episodes traced by Tanford, we come now to the one I suspect would have pleased Franklin most. Soon after Rayleigh's paper about molecular size came out, he received a letter from a lady in Braunschweig, Germany, named Agnes Pockels. She was a housewife with no formal scientific education. For the past 10 years, as a hobby, she had been doing experiments in her kitchen to study surface tension and wetting phenomena. On reading Rayleigh's paper, she realized that her experimental technique was much better than his, and her insight at least comparable. So she wrote to tell him about her work.

Essentially, her apparatus was a rectangular baking dish, with a glass ruler across it. The ruler could be slid along to scrape the water surface clean. Franklin had said that his experiment wouldn't work on a small scale because he found a little smudge of grease from his finger was enough to contaminate the whole surface. The scraper employed by Pockels swept away that crucial difficulty, making it easy to clean the surface quickly and repeatedly. She had also devised an elegant way to measure surface tension: she hung a button from a thread and measured the force needed to barely raise the button from the surface.

To his credit, Rayleigh, with the help of his wife, translated Pockels's letter into English, wrote to her several times to clear up some points, and then submitted her paper to *Nature*, with this benediction:

I shall be obliged if you can find space for the accompanying translation of an interesting letter which I have received from a German lady, who with very homely appliances has arrived at valuable results respecting the behavior of contaminated water surfaces. The earlier part of Miss Pockels' letter covers nearly the same ground as some of my own recent work, and in the main harmonizes with it. The later sections seem to me very suggestive, raising, if they do not fully answer, many important questions.

This letter was the first of a series of important papers by Pockels. Forty years later, the distinguished surface chemist Irving Langmuir would say that she had "laid the foundation for nearly all modern work with films on water."

I shall mention just one further descendant of Franklin's oil-on-water experiment. A line of work extending over 60 years finally established in the late 1960s the nature of cell membranes.

Bringing Franklin out from the shadow of his icon would at least add irony when confronting attacks now heard in Congress on "curiosity-driven" research as a luxury, as merely a hobby of professors, and even as an unpatriotic activity.

This showed that the membranes are chiefly constructed from lipid molecules. These are akin to olive oil; they have a water-loving end and a fatty, water-hating end. In all living things, cells are packaged in a double layer of lipid molecules, termed a bilayer. This has the fatty ends of pairs of lipid molecules snuggled together, while the water-loving ends interact with the aqueous environment inside and outside the cell.

In his last years, Franklin—ever enthusiastic about science—liked to show visitors a glass model in his study that demonstrated the circulation of blood in the human body. He would have been delighted to learn that the packaging of the red blood cells is so simply related to the oil film he spread on the pond at Clapham. And, as Tanford says, he "would have enjoyed the unity of science that could make so marvelous a connection."

BEYOND THE ICON

As an icon, Ben Franklin has long been represented as the supreme utilitarian: striving always for what is useful and sensible, both in human affairs and in science. But this shortchanges his major role in science. The historical Franklin is far more instructive than the icon. In at least three respects, Franklin's work is pertinent to current debates about science policy and science education.

First, as both Cohen and Trefil emphasize, Franklin lived in an age even more eager for practical results than ours. Yet he never limited his scientific studies to what he could anticipate would be useful. In current parlance, his research was "curiosity-driven." When he took up electricity, it was just an irresistible toy. He could not foresee that his work would establish a new field of physics, vital for understanding the nature of matter and radiation, key to myriad applications. The link Franklin made between leaping sparks and lightning bolts indeed resembles that which Newton made between falling apples and planetary orbits. Both exemplify the paradigm of Francis Bacon: advances in basic science inevitably create opportunities for practical applications. But neither the advances nor the applications can be foretold.

In making this case to public officials and the media, we should bring Franklin out from the shadow of his icon. That would at least add Franklinesque irony when confronting attacks now heard in Congress on "curiosity-driven" research as a luxury, as merely a hobby of professors, and even as an unpatriotic activity.

Second, we would do well to appreciate how Franklin's immense scientific reputation played a major role in the success of the American Revolution. His arrival in Paris coincided with the signing of a nonaggression pact between France and England, ending 20 years of conflict. Although the pact specified that France not aid any rebellion against the British, Franklin's stature helped him gain influence with the French court and thus obtain crucial arms and funds to aid the American colonies. Turgot's famous praise of Franklin might be recast as: "Snatching the lightning from the sky enabled him to take the scepter from tyrants."

A Franklinesque query: Now that America has become the leading debtor nation, might not respect for our science again be a significant factor in attracting vital foreign funds?

Finally, the historical Franklin can render unique service in our efforts to promote science education and literacy. In our society, science is regarded not as part of our general culture, but almost as the preserve of a distinct species. This attitude, which greatly handicaps all aspects of education, is reinforced by the fact that we confine science to separate courses. The multifaceted Ben Franklin ought to appear throughout the curriculum, breaking down those barriers. He is so accessible and such fun! Everyone should repeat and enjoy some of his simple experiments, admire his descriptions and logic, trace the reception and legacy of his work. Doing so would not only show the rewards of inquiry pursued for its own sake. It would also help students and citizens understand how science reshapes human culture—in his time, in ours, and beyond.

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