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Franklin, Benjamin

(*b.* Boston, Massachusetts, 17 January 1706; *d.* Philadelphia, Pennsylvania, 17 April 1790)

electricity, general physics, oceanography, meteorology, promotion and support of science and international scientific cooperation.

[Benjamin Franklin](#) was the first American to win an international reputation in pure science and the first man of science to gain fame for work done wholly in electricity. His principle achievement was the formulation of a widely used theory of general electrical “action” (explaining or predicting the outcome of manipulations in electrostatics: charge production charge transfer, charging by electrostatic induction). He advanced the concept of a single “fluid” of electricity, was responsible for the principle of conservation of charge, and analyzed the distribution of charges in the [Leyden jar](#), a capacitor. He introduced into the language of scientific discourse relating to electricity such technical words as “plus” and “minus,” “positive” and “negative,” “charges” and battery. By experiment he showed that the lightning discharge is an electrical phenomenon, and upon this demonstration (together with his experimental findings concerning the action of grounded and of pointed conductors) he based his invention of the lightning rod,

Franklin made contributions to knowledge of the [Gulf Stream](#), of atmospheric convection currents, and of the direction of motion of storms. His observations on population were of service to Malthus. He was the principal founder of the [American Philosophical Society](#), the New World’s first permanent scientific organization.

Early Life and Career

[Benjamin Franklin](#)’s father, Josiah, who was descended from a family of British artisans, immigrated to America, settling in Boston in October 1683. His mother, Josiah’s second wife, was Abiah (“Jane”) Folger, daughter of Peter Folger of Nantucket, a weaver, schoolmaster, miller, and writter of verses. On both sides of the family Franklin had forebears skilled in the use of their hands and with literary or intellectual gifts.

Franklin relates in his autobiography that he “was put to the [Grammar School](#) at eight years of Age,” but remained “not quite one Year.” His father then sent him “to a School for Writing and Arithmetic.” Although Franklin by his own admission failed arithmetic, he later repaired this deficiency. In midlife, he took up “making magic Squares, or Circles,” some of which were very complex and obviously required skill in computation. Published in England and in France from 1767 to 1773, they have attracted much attention and comment ever since.

At ten years of age, Franklin was taken home from school to assist his father, a tallow chandler and soap boiler. Since he was fond of reading and had in fact spent on books “all the little Money that came into . . . [his] Hands,” it was decided that Benjamin should become a printer. He was, accordingly, at age twelve indentured to “Brother James.” Within a few years he was able to break the indenture and secure his freedom. He left Boston to seek his fortune, first in [New York](#) (briefly and unsuccessfully) and then in Philadelphia

Franklin had immediate success in Philadelphia Before long he came to the attention of Governor Keith, who offered to subsidize him—although he was only eighteen—in the printing business. Franklin was sent to London to select types and presses and to make useful business contacts. Once at sea, Franklin discovered that the governor had sent him off without any letter of introduction and without funds for purchasing the printing equipment—indeed, that the governor had merely been “playing. . . . pitiful Tricks . . . on a poor ignorant Boy!” On arrival, Franklin found work in [Samuel Palmer](#)’s printing house, where he set type for William Wollaston’s *The Religion of Nature Delineated*.

After two years away from Philadelphia (from November 1724 to October 1726) Franklin returned to his adopted city, skilled in the various aspects of the printing craft. He soon had his own shop and before long became a major figure in the town and, eventually, in the colony. With a partner, he published the *pennsylvania Gazette*; when the partnership was dissolved in 1730, Franklin kept the newspaper and shortly began publication of poor Richard; *An Almanack* (1733). He was Clerk of the Assembly, postmaster of Philadelphia (1737–1753), and publisher (1741) of the *General Magazine*. He was an organizer of the Library Company (1731), and the Union Fire Company (1736), and was a promoter of the Academy of Philadelphia (later the College and Academy of Philadelphia and now the University of pennsylvania), of which he became president of the trustees (1749).

As he became more deeply concerned with civic affairs and public life, Franklin retired from active business (1748), setting up what would become an eighteen-year partnership with David Hall, his printing house foreman. He was elected a member of the Pennsylvania Assembly (1751) and alderman of Philadelphia and was appointed a deputy postmastergeneral for the British colonies in [North America](#) (1753–1774). He was sent to England in 1757 and remained until 1762 as the Assembly’s agent.

Preparation for Scientific Research

When, in 1757, Franklin sailed for England for the second time, he had already won a high place in world science. He had published articles in the world’s leading scientific journal, the *Philosophical Transactions of the* [Royal Society](#), and was a fellow of that society (elected 29 May 1756). For his research in electricity the Society had conferred upon him (on 30 November 1753) one of their highest awards-the Copley Medal. He had received honorary degrees from Harvard (1753), Yale (later in 1753), and William and Mary (1756). His book on electricity had already appeared in three editions in England and two in France, and one of his experiments—“proving the sameness of Lighting and Electricity”—was world-famous. Franklin was largely self-taught in science-as he was in other subjects-but this does not mean that he was uneducated. He had rigorously studied the science of his day in the writings of the best masters available.

In 1744 Franklin sponsored Adam Spencer’s lectures on experimental science in Philadelphia and purchased his apparatus; he had previously attended Spencer’s lectures in Boston. Also in 1744 Franklin published a pamphlet on the stove he had invented; in it he refers to, and quotes from, certain great masters of experimental science whose works he knew, including Boerhaave, Desaguliers, ’sGravesande, and Hales. He was also familiar with the writings of [Robert Boyle](#) and knew well the major treatise on experimental physics of the age, Newtork’s *Opticks*. He had also encountered expositions of the Newtonian natural philosophy in the published Boyle lectures, a series which included books by [Samuel Clarke](#) and William Derham . Having known Pemberton in London, he no doubt would have read Pemberton’s *View of* [Sir Isaac Newton’s Philosophy](#), of which peter Collinson had sent a copy to the Library Company in 1732. Thus, even though Franklin may have had no formal training, he was well educated in Newtonian experimental science.

Gadgets and Inventions

Benjamin Franklin’s reputation in science was made by his experiments and the theories he conceived or modified to explain his results. The experimental scientist of Franklin’s day had not only to be able to design but also to construct the devices he needed. Franklin the artisan had no aversion to manual labor and operations. A gifted gadgeteer and inventor, he was not only able to make the devices he conceived but he could also think in terms of the potential of gadgets and instruments in relation to the development of his ideas: a significant ability, since usually the conception of an experimental problem cannot be separated from the means of exploring or solving it.

Throughout his life Franklin found it (as he writes in his autobiography) a source of “Pleasure . . . to see good Workmen handle their Tools.” He was aware of the great advantage to his research in being able “to construct little Machines for my Experiments while the Intention of making the Experiment was fresh and warm in my Mind. “This aspect of Franklin’s research was especially noted by William Watson in his review of Franklin’s book on electricity (*Philosoprhical Transactions*, 1752); Franklin, the reviewer said, has both “a head to conceive” and “a hand to carry into execution” whatever he considers “may conduce to enlighten the subject-matter.”

Among Franklin’s notable inventions and gadgets are the rocking chair, bifocal glasses, and the pennsylvania fireplace, or Franklin stove. He also conceived the idea of “summer time,” or [daylight saving time](#). His most important invention, teh lightning conductor or lightning rod, is, however, in a different category altogether, an application to human needs (in the Baconian sense) of recent discoveries in pure science.

First Researches in Electricity

In the early 1740’s Franklin encountered the new electrical experiments in at least two ways. He saw some experiments performed by Adam Spencer in Boston in 1743 and again in Philadephia in 1744 Then, in 17459 (or possibly 1746) the Library Company of Philadelphia received “from Mr.Peter Collinson F.R.S; of Londn, a present of a Glass Tube, with some Account of the Use of it in making such electrical Experiments.” Franklin records that he “eagerly seized the Opportunity of repeating what I had seen in Boston, and by much practice acquir’d great Readiness in performing those also which we had an account of from England, adding a Number of new Ones.”

The first researches in electricity at Philadelphia were made by a group of four experimenters; Frankline Philip syng, Thomas Hopkinson, and Ebenezer Kinnersley, who was Franklin’s principal coexperimenter. One of Franklin’s first recorded discoveries was the action of pointed bodies. A grounded pointed conductor, he found, could cause a charged, insulated conducting body to lose its charge when the point was six to eight inches away; but a blunt conductor would not produce such a discharge until it was an inch or so away, and then there would be an accompanying spark. A companion discovery was made by Hopkinson: a needle placed on top of a suspended iron rod would prevent it from becoming, charged, the electrical fire “continually runing out silently at the point” as fast as it was accumulated; this discovery had been anticipated by William Watson.

Other discoveries led Franklin and his coexperimenters to the concept that “the electrical fire is a real element, or species of matter, not created by the frication. but *collected* only.” Thus all kinds of electrification, or changes in electrification, in electrification, were to be explained by the transfer of “electrical fire,” which was “really an element diffused among, and attracted by other matter, particularly by water and metals.” Each body has a “natural” quantity of “electrical fire” if it loses some, Franklin would call it electrically negative, or minus; if it gains some and therefore has a “superabundance” of “electrical fire,” it would be positive, or plus. “To electrise *plus or minus*,” Franklin wrote in a letter to Collinson of 25 May 1747, “no more needs to be known than this, that the parts of the tube or sphere that are rubbed, do, in the instant of the friction, attract the electrical fire, and therefore take it from the thing rubbing.” In short since one or more bodies must gain the “electrical fire” that a given body loses, plus and minus charges or states of electrification must occur in exactly equal amounts. This quantitative principle is known today as the law of conservation of charge. It is still fundamental to all science, from microphysics to the electrification of gross bodies.

The Analysis of the Leyden Jar

One of the earliest and most significant results of the new Franklinian theory was the successful analysis of the [Leyden jar](#), a topic introduced in a letter to Collinson, sent sometime prior to 28 July 1747. The Leyden jar, a from or condenser, or capacitor, was discovered or invented in the 1740’s and was named after one of the several claimants to the discovery, Musschenbroek of Leyden; Franklin knew the device as Musschenbroek’s “wonderful bottle.” Essentially the device was a nonconductor (glass) with a conductor on each side; before long it was used with the inside filled with water or metal shot, and the outside coated with metal. Electrical contact was made with the water or metal shot by means of a wire running through an insulating cork stuck into the neck of the bottle. When the outer coating was grounded, as by being held in the hands of an experimenter, and the wire was brought to charged body, the jar seemed capable of “accumulating” and “holding” a vast amount of “electricity.”

The first observation made by Franklin was that if the wire and water inside the bottle are “electrised *positively or plus*,” then the outer coating is simultaneously “*electrised negatively or minus* in exact proportion,” The equilibrium could not be restored through the glass of the bottle unless a conducting material simultaneously made contact with the outer coating and with the wire connected to the water or inner conducting material. He was astonished at the “wonderful” way in which “these two states of Electricity, the *plus and minus* are combined and balanced in this miraculous bottle.”

In a letter of 29 April 1748, containing “Farther Experiments and Observations in Electricity,” Franklin described some new experiments showing that a charged Leyden jar always has charges of opposite signs on the two conductors and that the charges are of the same magnitude. Clearly, he concluded, the “*terms of charging and discharging*” a Leyden jar are misleading, since “there is really no more electrical fire in the phial after what is called its *charging* than before nor less after its discharging.....”

Franklin then annouced the most astonishing discovery of all, that in the Leyden jar “the whole force of the bottle, and power of giving a shock, is in the GLASS ITSELF.” He reached this conclusion by a series of ingenious experiments, which are known today as the Franklin experiments on the dissectible condenser. A Leyden jar with a loosely fitting cork a glass insulator. The cork was carefully removed, together with the wire that hung down into the water; it was then found that the jar could be discharged as before by an experimenter’s putting one hand around the outside of the jar while bringing a finger of the other hand to the jar’s mouth so as to reach the water. Thus, the “force” was not “in the wire”. Next, a test was made to determine whether the force “resided in the water” and was “condensed in it.” A jar was charged as before, set on glass, and the cork and wire removed. The water was then carefully decanted into an empty, uncharged jar resting on glass; this second jar showed no evidence whatever of being charged. Either the “force” must have been lost during the decanting, or it must have remained behind in the glass. The latter was shown to be the case by refilling the first bottle with “unelectrified water,” whereupon it gave the shock as usual.

In the next stage Franklin looked into the question of whether this property of glass came from the nature of its substance, or whether it was related to shape—a relevant question, since Franklin had pioneered in studying the effect of shape in the action of pointed and blunt conductors. In this inquiry he constructed a parallel-plate condensers (or capacitor) consisting of two parallel lead plates separated by a flat pane of sash glass. This condenser produced the same electrical effects as a Leyden jar, thus demonstrating that the “force” is a property of the glass as glass and is not related to shape. Franklin ingeniously joined together a number of such parallel-plate condensers to make “what we called an *electrical-battery*” consisting of eleven panes of glass, each “armed” with lead plates pasted on both sides, hooked together in series by wire and chain; the battery could be discharged by a special contrivance.

Full Statement of the Mature Theory

On 29 July 1750, Franklin sent Collinson his “Opinions and conjectures concerning the Properties and Effects of the electrical matter, arising from Experiments and Observations, made at Philadelphia, 1749.” This paper began with the proposition that the electrical matter consists of “extremely subtle” particles since it can easily permeate all common matter, even metals, without “any perceptible resistance.” Here Franklin used the term “electrical natter” for the first time. Although he indicated a cause for belief in its “subtility,” he took its atomicity or particulate composition for granted. The difference between electrical matter and “common matter” lies in the mutual attraction of the particles of the latter and the mutual repulsion of the particles of the former (which cause “the appearing divrgency in a stream of electrified effluvia”) In eighteenth-century terms, such electrical matter constitutes a particulate, subtle, elastic fluid. The particles of electrical matter, although mutually repellent, are attracted strongly by “all other matter.” Therefore, if a quantity of electrical matter be applied to a mass of common matter it will be immediately and equally diffused through the whole. In other words, common matter’s is “a kind of sponge” to the electric fluid. Generally, in common matter there is as much electrical matter as it can contain; if more be added, it cannot enter the body but collects on its surface to form an “electrical atmosphere” in which case the body “is said to be electrified.” All bodies however do not “attract and retain” electriacal matter with equal strength and force” those called electrics per se (or non-conductors) “attract and retain it strongest, and contain the greatest quantity.” That common matter always contains electrical fluid is demonstrated by the fact of experience that a rubbed globe or tube enables us to pump some out.

The “electrical atmospheres” said to surround charged bodies are a means for explaining the observed repulsion between them, but this explanation takes cognizance only of the repulsion between positively charged bodies (that is, those which have gained an excess of fluid over their normal quantity). It offers no aid whatever in understanding the repulsion between negatively charged bodies—a phenomenon that had been observed by Franklin and his colleagues and reported by him in an earlier paper.

The concept of “electrical atmospheres” was not wholly novel with Franklin. Franklin’s original contribution lay in the particular use he gave to this concept in his theory of electrical action. For example, Franklin stated that it takes the “form . . . of the body it surrounds.” A sphere will thus have a spherical atmosphere and a cylinder a cylindrical one. Others had supposed that both would have a sphere of effluvia.

Franklin’s concept of “electrical atmospheres” was based on the idea that an uncharged body must have its “normal” quantity of electrical matter or fluid and that, therefore, any further electrical matter or fluid added to it will collect around the outside, like a cloud. If two such charged bodies came near one another these two clouds would produce repulsion, sincne the particles of which they are made tend to repel one another. Similarly, a body that has lost some of its normal quantity of electrical matter or fluid will attract the particles in the electric atmosphere of a positively charged body, until the two draw concept of “electrical atmospheres” to explain the unequal distribution of charge in bodies that were not completely symmetrical, such as those which might be pointed or pear-shaped. These explanations were qualitatively successful, but they do not always appear convincing and certainly constitute one of the weakest and least satisfactory parts of the theory. Even more important, the doctrine of “electric atmospheres” could not contribute to the solution of one outstanding unsolved problem in the Franklinian explanation of electrical phenomena: the “apparent” repulsion between negatively charged bodies. We shall see below that this major defect in the theory was remedied by the addition of a new and very radical postulate by Aepinus.

One of the major advantages of the Franklinian theory was that it enabled “electricians” to distinguish clearly between the concept of a “repelling force” which could act even through a sheet of glass, although the electric fluid itself does not penetrate through glass. This basic concept was used in the explanation of the action of the condenser, wherein Franklin explained clearly—for what was, so far as I know, the first time—the mechanism of induced charges, the phenomenon of a negative charge being induced on a grounded conductor when a positively charged conductor is brought near it, or when a nearby conductor acquires a positive charge.

In the Leyden jar, according to Franklin’s doctrine, the application of a positive charge to the conductor on one side of the glass will not cause the jar to be charged until or unless the conductor on the other side can lose some of its normal electric fluid, that is, until or unless it is grounded. Then and only then will electric fluid move away from that grounded conductor, leaving it negatively charged. Franklin thus naturally predicted, and proved by experiment, that the jar could be charged through its outer coating when the wire leading into the water is grounded, just as easily as in the normal manner—when a positive charge is applied to the inner conductor (water and wire) and the outside is grounded.

Later, in a famous series of experiments and explanations based upon some earlier ones made by [John Canton](#), Franklin developed more fully this explanation of what we call today induced charges, or the phenomenon of charging by

(electrostatic) induction. There is no doubt that it was Franklin’s clear understanding of this process that caused his theory to be so highly valued in the eighteenth century. The theory is still used, with slight modifications, in all laboratory circumstances when charged objects are moved in the neighborhood of conductors which may be grounded or insulated or which can undergo a change in their condition of grounding or insulation. Only Franklin, and those who accepted his doctrine, could easily explain such phenomena as this: A positively charged body is brought near a conducting metal object placed on an insulating base and temporarily grounded; then the grounding is interrupted before the charged body is removed; the effect will be to induce in that object a negative charge. Now let the second object be an insulated cylinder; it will plainly display an unequal charge distribution, the end near the first body becoming negative and the far end positive; when the first body is withdrawn, the cylinder returns to its normal state and no longer shows any indication of charge. In the eighteenth century many scientists adduced this feature of the Franklinian theory (its ability to predict exactly the outcome of such experiments) as its major asset. In our own time J. J. Thomson has explained that the service of the onefluid theory “to the science of electricity, by suggesting and co-ordinating researches, can hardly be overestimated.” We still use this theory in the laboratory, Thomson said: “If we move a piece of brass and want to know whether that will increase or decrease the effect we are observing, we do not fly to the higher mathematics, but use the simple conception of the electric fluid which would tell us as much as we wanted to know in a few seconds” (in *Recollections and Reflections* [London, 1936], p. 252).

Dissemination of Experiments and Theories

Franklin’s experiments on pointed conductors, grounding, the Leyden jar, and the conservation of charge, together with the statement of his theory of electrical action, based on the principle of conservation of charge, were all assembled by Collinson into a ninety-page book issued by E. Cave of London in 1751, with an unsigned preface written by [Dr. John Fothergill](#). Buffon, who had recently stated that in electrical phenomena there seemed to be on one law governing the outcome of experiments, and that indeed the subject was characterized more by “bizzareries” than by regularities, came upon the book and had it translated into French in the following year; the French version was done by the naturalist Dalibard.

Thus, within two years Franklin’s concepts and experiments were available to “electricians” on both sides of the Channel—and but for a number of minor revisions and extensions to new phenomena—all the main elements of Franklin’s contributions to electrical theory had appeared in print.

One of the most challenging parts of Franklin’s book was his discussion of thunder, lightning, and the formation of clouds. In a letter addressed to [John Mitchel](#) in London, dated 29 April 1749, Franklin wrote out some “Observations and Suppositions” that had led him to the hypothesis that clouds tend to become electrified through the vaporization effect on water of “common fire” (or ordinary heat) and “electrical fire.” Rain, dew, and flashes of lightning between land clouds and sea clouds formed part of Franklin’s suppositions, but six years later he freely admitted that he was “still at a loss” about the actual process by which clouds “become charged with electricity; no hypothesis I have yet formed perfectly satisfying me.” Nevertheless, before April 1749 Franklin had assumed that clouds are electrified and that the lightning discharge is a rapid release of electric fluid from clouds.

On 7 November 1749, Franklin drew up a list of twelve observable similarities between the lightning discharge and the ordinary spark discharges produced in the laboratory. Notably, he concluded that since the “electric fluid is attracted by points,” we might find out “whether this property is in lightning. . . . Let the experiment be made.” But even before this experiment could be performed, Franklin assumed a favorable outcome. Convinced that lightning must be an electrical phenomenon, he warned his readers that high hills, trees, towers, spires, masts, and chimneys will act “as so many prominencies and points” and so will “draw the electrical fire” as a “whole cloud discharges there.” He therefore advised his readers never “to take shelter under a tree, during a thunder gust.”

In the paper entitled “Opinions and Conjectures,” sent to Collinson in July of 1750 (containing the full statement of his theory of electrical action), Franklin also discussed the possible electrification of clouds and the nature of the lightning discharge. Immediately following the presentation of the property of pointed bodies to “draw on” and f“throw off” the electric fluid at great distances, Franklin indicated that this knowledge of the “power of points may possibly be of some use to mankind, though we should never be able to explain it.” Just as a grounded needle with its point upright could discharge a charged body and prevent a “stroke” to another nearby body, so Franklin argued that sharpened upright rods of iron, gilded to prevent rusting, fixed “on the highest parts of . . . edifices” and run down the outside of a building into the ground, or down “one of the shrouds of a ship” into the water, would “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.” Later, when the experiments were made, Franklin found that another function of the lightning rod, apart from “disarming” a passing cloud, would be to conduct a lightning stroke safely into the ground.

The experiment that Franklin devised required a sentry box large enough to contain a man and “an electrical [insulating] stand.” The sentry box was to be placed on a high building; a long, pointed rod was to rise out through the door, extending twenty or thirty feet in the air, terminating in a point. This rod was to be affixed to the middle of the insulated stand, which was to be kept clean and dry so as to remain an insulator. Then when clouds, possibly electrified, would pass low, the rod “might be electrified and afford sparks, the rod drawing fire to” the experimenter, “from a cloud.” To avoid danger, Franklin advised the man to be well insulated and to hold in his hand a wax handle affixed to a “loop of a wire” attached to the ground; he could bring the loop to the rod so that “the sparks, if the rod is electrified, will strike from the rod to the wire, and not affect him.” Some years later, when Richmann performed this experiment in [St. Petersburg](#), he did not fully observe all of Franklin’s warnings and was electrocuted.

The sentry-box experiment was first performed at Marly, France, in May 1752. After Franklin’s book had appeared in a French translation in 1752, the experiments he described were performed for the king and court; Buffon, Dalibard, and De Lor were then inspired to test Franklin’s conjectures “upon the analogy of thunder and electricity.” On 13 May 1752 Dalibard reported to the Paris Academy of Sciences: “In following the path that Mr. Franklin has traced for us, I have obtained complete satisfaction.”

The account of this experiment was printed in the second French edition of Franklin’s book on electricity and was later included in the English editions. A letter addressed from France to [Stephen Hales](#), describing both the presentation of the Philadelphia experiments to the king of France and the success of the sentry-box experiment, was published in the *Philosophical Transactions* and was also reprinted in Franklin’s book. Soon the lightning experiments were repeated by others in France, Germany, and England; and Franklin had the satisfaction of achieving an immediate and widespread international renown.

Later, Franklin devised a second experiment to test the electrification of clouds, one which has become more popularly known: the lightning kite. Franklin reported this experiment to Collinson in a letter of 1 October 1752, written after Franklin had read “in the publick papers from Europe, of the success of the *Philadelphia-Experiment* for drawing the electrick fire from clouds by means of pointed rods of iron erected on high buildings. . . .” Actually, Franklin appears to have flown his electrical kite prior to having learned of Dalibard’s successful execution of the sentry-box experiment. The kite letter, published in the *philosophical Transactions*, referred to the erection of lightning rods on public buildings in Philadelphia.

The lightning experiments caused Franklin’s name to become known throughout Europe to the public at large and not merely to men of science. [Joseph Priestley](#), in his *History . . . of Electricity*, characterized the experimental discovery that the lightning discharge is an electrical phenomenon as “the greatest, perhaps, since the time of [Sir Isaac Newton](#).” Of course, one reason for satisfaction in this discovery was that it subjected one of the most mysterious and frightening natural phenomena to rational explanation. It also proved that Bacon had been right in asserting that a knowledge of how nature really works might lead to a better control of nature itself: that valuable practical innovations might be the fruit of pure disinterested scientific research.

No doubt the most important effect of the lightning experiments was to show that the laboratory phenomena in which rods or globes of glass were rubbed, to the accompaniment of sparks, and induced charges and electrical shocks, belong to a class of phenomena occurring naturally. Franklin’s experiments thus proved that electrical effects do not result exclusively from man’s artifice, from his intervention in phenomena, but are in fact part of the routine operations of nature. And every “electrician” learned that experiments performed with little toys in the laboratory could reveal new aspects of one of the most dramatic of nature’s catastrophic forces. “The discoveries made in the summer of the year 1752 will make it memorable in the history of electricity,” William Watson wrote in 1753. “These have opened a new field to philosophers, and have given them room to hope, that what they have learned before in their museums, they may apply, with more propriety than they hitherto could have done, in illustrating the nature and effects of thunder; a phenomenon hitherto almost inaccessible to their inquiries.”

Franklin’s achievement of a highly successful career wholly in the field of electricity marked the coming of age of electrical science and the full acceptance of the new field of specialization. On 30 November 1753, awarding Franklin the [Royal Society](#)’s Sir Godfrey Copley gold medal for his discoveries in electricity, the earl of Macclesfield emphasized this very point: “Electricity is a neglected subject,” he said, “which not many years since was thought to be of little importance, and was at that time only applied to illustrate the nature of attraction and repulsion; nor was anything worth much notice expected to ensue from it.” But now, thanks to the labors of Franklin, it “appears to have a most surprising share of power in nature.”

Some Later Contributions to Electricity

Spurred on by the success of the sentry-box and kite experiments, Franklin continued to make investigations of the lightning discharge and the electrifi cation of clouds. He erected a test rod on his house, so as to make experiments and observations on clouds passing overhead. One of the results was most interesting, because he discovered: “*That the clouds of a thunder-gust are most commonly in a negative state of electricity, but sometimes in a positive state.*” This statement led him to the following astonishing conclusion: “So that, for the most part, in thunderstrokes, *it is the earth that strikes into the clouds, and not the clouds that strike into the earth.*” Of course, this discovery did not alter the theory or practice of lightning rods, which Franklin found perform two separate functions. One is to disarm a cloud and

to prevent a stroke, while the other is to conduct a stroke safely to the ground. His theory of the direction of the stroke (from clouds to earth or from earth to clouds) depends upon the identification of vitreous electrification (glass rubbed with silk) with the positive state and of resinous electrification (amber rubbed with wool or fur) with the negative. Franklin was aware that he had no definitive evidence for this identification, and hoped that others might provide a crucial experimental test.

To this day one still talks of a “Franklinian” fictitious “positive” current in circuit theory, and also thinks physically of a flow of electrons in the opposite direction.

One question of great interest to Franklin was whether the gross dimensions or the mass of a body may be the determining factor in the amount of “electric fluid” it can acquire. He discovered that an “increase of surface” makes a given mass or quantity of matter “capable of receiving a greater amount of charge.” The surface is what counts, not the mass. As usual, Franklin had a pretty experiment to support his conclusion. In this case he used a small silver can on an insulating wine glass; in the can there were three yards of brass chain, one end of which was attached to a long silk thread that went over a pulley in the ceiling so that the chain could be drawn partly or completely out, thereby increasing the “surface” and making the body (can and chain) capable of receiving an additional charge.

In a closely related experiment Franklin studied the distribution of charge on a metal can placed on an insulated base. He showed that the charge “resides” wholly on the outside of the can; that there is no charge inside. He did not know the reason at first, but he later concluded that the symmetry of the situation produced mutual repulsion that drove any charge from the inside surface of the can to the outer one. [Joseph Priestley](#), arguing from the analogy of a cylinder to a sphere, showed that by the reasoning of Isaac Newton’s *Principia*, it would be possible for one to conclude that the law of electrical force must, like gravitation, be a law of the inverse square of the distance.

A Major Defect Remedied by Aepinus

Franklin’s theory failed to give a satisfactory explanation of the observed phenomenon of the mutual repulsion of two negatively charged bodies. This defect was remedied by Franz Aepinus. Perplexed by the difficulties in explaining repulsion, Kinnorsley thought that perhaps one could get rid of the doctrine of repulsion altogether. Franklin disagreed, putting forth the argument that repulsion occurs “in other parts of nature.”

Aepinus, who altered Franklin’s system, was an ardent Franklinian and a teacher of and collaborator with J. C. Wilcke, who translated Franklin’s book on electricity into German. Wilcke made the first major table of what we would call today a triboelectric series, thus accounting for the production of joint negative and positive charges in different combinations of two materials.

Aepinus aimed to establish a theory of magnetic phenomena based upon “principles extremely similar to those on which the Franklinian electric theory is built,” that is, using the concept of a magnetic fluid, with laws of action much like those of Franklin’s electric theory. To complete his analogy, however, Aepinus introduced the revolutionary idea that in solids, liquids, and gases the particles that Franklin called “common matter” would—in the pure state—repel one another just as the particles of the electric fluid did. Aepinus’ revision introduced a complete duality, the particles of common matter and the particles of electric matter each having the property of repelling particles of their own kind while having the additional property of attracting particles of the other kind. Normally one does not encounter particles of pure matter repelling one another, because their natural repulsion is reduced to zero by the presence of the magnetic or the electric fluid in the normal state of bodies. Hence, the Newtonian universal gravitation remains unaffected by the new postulate. Repulsion exists only when we deprive bodies of a part of their normal complement of either electric fluid or magnetic fluid.

Furthermore, certain experiments devised by Aepinus and Wilcke, using condensers separated by air instead of glass, showed that the Franklin doctrine of “atmospheres” could not exist in a physical sense. This was a position that Franklin himself had eventually more or less adopted, coming to conceive that the concept of “electrical atmospheres” was no more than a way of describing collections or distributions of electric charge whose parts have repulsive forces acting at a distance.

In one set of experiments to test the effect of “electrical atmospheres,” Aepinus blew a stream of dry air on a charged body and found, just as Franklin had, that the charge of the body was not diminished. Franklin had then assumed that such experiments indicated only that the “atmosphere” of a charged body is an integral part of it, and he even thought to make the atmosphere “visible” by dropping rosin on a hot piece of iron near a charged body. Aepinus carried the matter through to its logical conclusion, saying that by “electrical atmosphere” one intended only to denote the “sphere of action” of the electrical charge on a body. Franklin, in commenting on Aepinus’ book, expressed admiration for the magnetic theory which Aepinus had constructed along lines analogous to his own electrical theory, and he himself began to write of a magnetic fluid in the terms introduced by Aepinus. We do not know whether Franklin read the book very thoroughly, since he never referred to the great revision of his theory which Aepinus introduced. Indeed, by the time Aepinus’ book (1759) reached him, Franklin was no longer actively pursuing his researches into electricity.

Gulf Stream, Convection Currents, and Storms

From his boyhood days Franklin had a passion for the sea. In his eight crossings of the Atlantic, he was always fascinated by problems of seamanship, ship design, and the science of the seas; and he made careful observations of all sorts of marine phenomena. He made experiments to see if oil spread on the waters would still the waves, and he put on a spectacular exhibition of this phenomenon for a group of fellows of the Royal Society in Portsmouth harbor.

Franklin’s name is associated with the Gulf Stream, of which he printed the first chart. His interest in this subject began about 1770, when the Board of Customs at Boston complained that it seemed to require two weeks more for mail packets to make the voyage to [New England](#) from England than the time of voyage for merchant ships. Franklin, then still postmaster general, discussed the matter with a Nantucket sea captain, who explained that the Nantucketers were “well acquainted with the Stream, because in our pursuit of whales, which keep to the sides of it but are not met within it, we run along the side and frequently cross it to change our side, and in crossing it have sometimes met and spoke with those packets who are in the middle of it and stemming it.” Franklin asked the caption, Timothy Folger, to plot the course of the Gulf Stream; this was the basis of the chart he had engraved and printed by the General [Post Office](#). As early as 1775 Franklin had conceived of using a thermometer as an instrument of navigation in relation to the Gulf Stream, and he made several series of surface temperature measurements during the Atlantic crossings. In 1785, on his last return voyage from France, Franklin devised a special instrument to attempt to measure temperatures below the surface to a depth of 100 feet.

Franklin’s studies of cloud formation and the electrification of clouds constitute a major contribution to the science of meteorology. He appears to have been the earliest observer to report that northeast storms move toward the southwest. He is also the first to have observed the phenomenon of convection in air.

Heat and Light

Franklin rejected the currently accepted corpuscular theory of light because of a mechanical argument. If “particles of matter called light” be ever so small, he wrote, their momentum would nevertheless be enormous, “exceeding that of a twenty-four pounder, discharged from a cannon.” And yet, despite such “amazing” momentum, these supposed particles “will not drive before them, or remove, the least and lightest dust they meet with.” The sun does not give evidence of a copious discharge of mass, since its gravitational force on the planets is not constantly decreasing.

Franklin’s arguments were long considered the primary statement of the mechanical inadequacy of the “emission” theory and were still cited in 1835 in Humphrey Lloyd’s report on optical theories to the British Association. Bishop Horsley, editor of Newton’s *Opera*, made the official Newtonian reply in the *Philosophical Transactions* in 1770, noting that: “Dr. Franklin’s questions are of some importance, and deserve a strict discussion.” And when [Thomas Young](#) revived the wave theory toward the beginning of the nineteenth century, he cited Franklin as one of those predecessors who had believed in the wave theory: “The opinion of Franklin adds perhaps little weight to a mathematical question, but it may tend to assist in lessening the repugnance which every true philosopher must feel, to the necessity of embracing a physical theory different from that of Newton.”

Franklin was perhaps more successful in his doctrine of fire. Here he tried to apply the principle of conservation to heat, assuming that there is a constant amount of heat, which is simply distributed, redistributed, conducted, or nonconducted, according to the kind of material in question. Interested in problems of heat conductivity, he designed a famous experiment, still performed in most introductory courses, in which a number of rods of different metals are joined together at one end and fanned out at the other, with little wax rings placed on them at regular intervals. The ends that are joined together are placed in the flame, and the “conductivity” is indicated by the relative speeds with which the wax rings melt and fall off. Franklin (in France) never had the occasion to perform the experiment, although he did obtain the necessary materials for doing so, and he suggested that Ingenhousz and he might do the experiment together. Ingenhousz, however, did it on his own. Franklin’s experiments on heat were not fully understood until [Joseph Black](#) introduced the concepts of [specific heat](#) and [latent heat](#).

Franklin’s only major contribution to the theory of heat is in the specific area of differential thermal conduction. The success of his fluid theory of electricity, and his writings on heat as a fluid, did, however influence the later development of the concept of “caloric.” Lavoisier wrote in 1777 that if he were to be asked what he understood by “matter of fire,” he would reply, “with Franklin, Boerhaave, and some of the olden philosophers, that the matter of fire or of light is a very subtle and very elastic fluid”

Medicine and Hospitals

Throughout his life Franklin had a passion for exercise (notably swimming), for which he was an active propagandist. He was always an advocate of fresh air and had many arguments in France with those who held the night air to be bad for health and who believed—then as how—in the evil effects of drafts. I have referred to his invention of bifocal glasses; he also designed a flexible catheter. He wrote on a variety of medical subjects: [lead poisoning](#), gout, the heat of the blood, the physiology of sleep, deafness, nyctalopia, infection from dead bodies, infant mortality, and medical education.

Although Franklin at one time had opposed the practice of inoculation, he later regretted his action and lamented the death of his own son from smallpox—which he publicly admitted might have been prevented by inoculation. He gathered a set of impressive statistics in favor of the practice, which were published in a pamphlet (London, 1759) on the benefits of inoculation against smallpox, accompanying William Heberden’s instructions on inoculation.

Like others of his day, Franklin gave electric shocks in the treatment of paralysis. He concluded from his experiences that “I never knew any advantage from electricity in palsies that was permanent.” He would not “pretend to say” whether—or to what degree—there might have been an “apparent temporary advantage” due to “the exercise in the patients’ journey, and coming daily to my house” or even—we may note with special interest today—the “spirits given by the hope of success, enabling them to exert more strength in moving their limbs.”

Franklin’s opinion that the beneficial effects of electrotherapy might derive more from the patient’s belief in the efficacy of the cure than from any true curative powers of electricity is very much like one of the conclusions of the royal commission appointed in 1784 to investigate mesmerism, of which he was a member. This Commission was composed of four prominent members of the faculty of medicine and five members of the Royal Academy of Sciences (Paris), including Franklin, Bailly, and Lavoisier. Its report gave the death blow to mesmerism, and Mesmer had to leave Paris. The commission, apparently, did not see the psychological significance of their finding that “The imagination does everything, the magnetism nothing.”

Later Life and Career

In spite of his extraordinary scientific accomplishments, the public at large knows of Franklin primarily as a statesman and public figure, and as an inventor rather than as a scientist—possibly because he devoted only a small portion of his creative life to scientific research. One of the three authors (along with [Thomas Jefferson](#) and [John Adams](#)) of the [Declaration of Independence](#), he was a member of the Second [Continental Congress](#) and drew up a plan of union for the colonies. Sent to Paris in 1776 as one of three commissioners to negotiate a treaty, his fame preceded him, both for his personification of many ideas cherished in the Age of Enlightenment and for his great reputation in electricity; in 1773 he had been elected one of the eight foreign associates of the Royal Academy of Sciences. To many Frenchmen, his simplicity of dress, his native wisdom, and his gentle manners without affectation seemed to indicate the virtues of a “natural man”. In September 1778 he was appointed sole plenipotentiary, and in 1781 he was one of three commissioners to negotiate the final peace with [Great Britain](#).

In France, Franklin enjoyed contact with [Great Britain](#). scientific and made the acquaintance of Volta, a strong supporter of Franklin’s one-fluid theory; Volta began the next stage of electrical science with his invention of the battery, which made possible the production of a continuous [electric current](#). Franklin appears to have been the first international statesman of note whose international reputation was gained in scientific activity.

Franklin returned to America in 1785, served the state of Pennsylvania, and was a member of the [Constitutional Convention](#). He died on 17 April 1790 and was buried in Christ Church burial ground, Philadelphia.

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