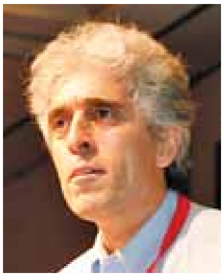


Happy 300th Birthday, Ben Franklin!

by Aziz S. Inan, 2006 IEEE International Symposium Committee Member

Introduction

Benjamin (Ben) Franklin was born in 1706 and this year marks his 300th birthday. Franklin is considered to be one of the first electrical engineers. He popularized the study of electrical science, performed an extremely dangerous kite experiment in 1752 to prove that lightning is a form of electrical discharge, and discovered the lightning rod. He laid the foundation of the distinction between conductors and insulators, the action of pointed bodies and the role of grounding in electrical experiments, the analysis of the Leyden jar, the design of parallel-plate capacitors, and the conservation of charge principle. He also coined terms such as positive (plus) charge, negative (minus) charge, and electric battery, which we still use in electrical engineering. Franklin's contributions to electrical science are considered to be a milestone in the history of IEEE and the shape of his famous kite led to IEEE's diamond-shaped logo. Although there are hundreds of books and book chapters written about Franklin's life and his achievements (e.g., see references in [1]), the goal of this article is to help us remember Franklin's life, and especially some of his contributions to electrical science.

Ben's early life

Ben Franklin was born in Boston, Massachusetts. His father, Josiah Franklin, was a tallow chandler, a maker of candles and soap, who emigrated from England and settled in Boston in 1683. He came to America to practice his faith and to improve his finances. His mother Abiah, Josiah's second wife, was the daughter of Peter Folger, a schoolmaster and surveyor of Nantucket. Josiah's two marriages produced seventeen children; Ben was the fifteenth child and the youngest son.

In 1714, Josiah sent Ben first to Boston Grammar School where traditional Latin education was offered, but he remained there less than a year. Then, Ben was sent to Brownell's English School where he studied English, writing and mathematics. There, he acquired fair writing skills but failed in mathematics. In 1716, Ben was removed from school by his father and became an assistant at his chandler's shop. In 1718, Ben was apprenticed to his half-brother, James, a newspaper printer. The printing job seemed like a good choice for Ben since he enjoyed reading and writing. Ben read as much as he could and also wrote articles under a pen name for James's newspaper. He also gained the habit of hard work, perseverance, and self-discipline while working in the printing business.

Young Ben reading books

Ben becomes a successful printer

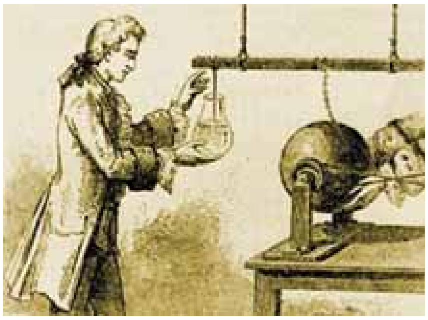
Ben and James did not get along, and in 1723 Ben left Boston and moved to Philadelphia. There, he first worked for a printer named Samuel Keimer. In 1724, he traveled to London, England, where he found employment as a journeyman printer. In this work, he met a number of men who became influential in the publishing world of the eighteenth century. After two years of experience in the printing business, Ben returned to Philadelphia in 1726 and began to work as a salesclerk for a merchant named Thomas Denham. In 1727, Ben fell severely ill with pleurisy and almost died. He recovered in about two months, but he then lost his job because his employer Denham died after a long sickness. Ben returned to work for Samuel Keimer in the printing trade. In 1728, Ben resigned to form a printing partnership with Hugh Meredith in Philadelphia. In 1729, Ben and Meredith purchased the failing Pennsylvania Gazette from Keimer, and Ben immediately turned it into a success. In 1732, Ben published Poor Richard's Almanac. Both of Ben's publications, the Pennsylvania Gazette and Poor Richard's Almanac, became very popular and made Ben a wealthy person. Ben retired from his printing business in 1748, at age forty-two.

In 1730, Ben married his former fiancée, Deborah Read, and they took Ben's illegitimate son William (who was born about 1728) into their home as their son. In 1732, Ben had another son named Francis Folger Franklin, but he died of smallpox at age four. Ben's third and last child Sarah (called Sally) was born in 1743.

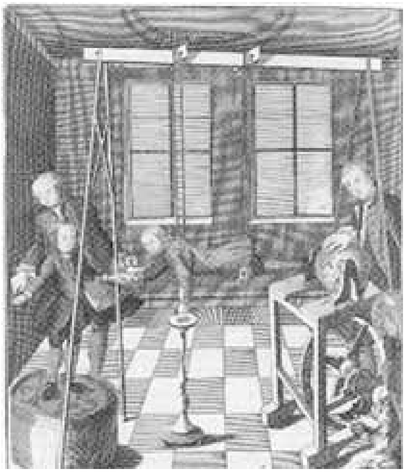
Ben was a person of multiple facets and interests in addition to his printing business. In 1727, he formed the Junto, a group comprised mainly of young artisans, which combined sociability and self-education. The Junto met regularly on Friday nights until 1765. He founded the Library Company in Philadelphia in 1732. In 1736, he was elected clerk of the Pennsylvania Assembly and also started the Union Fire Company. He was appointed postmaster of Philadelphia in 1737 and held this position until 1753. He founded the American Philosophical Society in 1743, became a member of the Philadelphia City Council in 1748, and a member of the Pennsylvania Assembly in 1750.

The eighteenth century—golden years for electrical science

During the eighteenth century, significant progress was accomplished in the study of electricity. This subject intrigued many people, both in Europe and America. The accidental discovery of the Leyden jar around 1745-1746 by Pieter van Musschenbroek and his pupil, Andreas Cunaeus, in Leyden, Holland and independently by Ewald Georg von Kleist in Germany marked a great advancement in electrical science. It demonstrated that electrical charge could not only be stored and built up, but also carried from one place to another. In almost every country in Europe, traveling performers amazed the public by carrying out dazzling and mysterious electrical experiments involving discharging Leyden jars—people were eager to observe electrical shocks and feel their effects. A standard trick during these performances involved suspending a boy from the ceiling with numerous insulating silk threads, rubbing his feet with either an electrostatic machine or a glass tube, and drawing electric sparks from his face or hands. From one end of the world to the other, traveling electricians made fortunes with their performances.



Musschenbroek experimenting with a Leyden jar



A suspended boy being charged via an electrostatic machine

Abbe Nollet, court electrician to King Louis XV of France, conducted Leyden jar discharge experiments on himself. He then, in the King's presence, discharged a Leyden jar through one hundred and eighty guardsmen with hands linked. The King was amused and impressed as the guardsmen all jumped up and down simultaneously. In another demonstration, he formed over two hundred monks connected by iron wires between every two persons and had a Leyden jar discharged through them all. The shrieking monks leaped into the air simultaneously with finer timing than could be achieved by the most skilled group of ballet dancers. Experimenters in France and elsewhere killed birds and other animals by the discharge of the Leyden jar; they sent Leyden jar discharges over long distances through water across rivers and lakes; they magnetized needles with it and melted thin wire. The Leyden jar certainly played a key role in all of these explorations.

Ben around 1748

Ben is introduced to electricity

Ben became acquainted with the wonders of electrical science for the first time when he met a Scottish lecturer named Dr. Archibald Spencer in Boston around 1743 and later in Philadelphia in 1744. Dr. Spencer traveled to different cities and offered courses including demonstrations on various scientific topics. Ben found Dr. Spencer's lectures and demonstrations on electrical phenomena to be intriguing and fascinating. This subject captured his attention.

During the next few years, Ben queried Peter Collinson, a Fellow of the Royal Society of London and the Library Company's London agent, regarding the subject of electricity. Collinson had a wide range of scientific interests and acquaintances, especially involving electricity. Collinson was accustomed to sending Ben an annual parcel of books, and included any work or curious object that chanced to be in vogue in London at the time. In 1746, he sent some apparatus including one of the new glass tubes then commonly used to excite electricity, and directions on how to use it based on an article published in The Gentleman's Magazine. These glass tubes were about two and a half feet long, and as thick as a man could conveniently grasp. They were rubbed with a piece of cloth or buckskin, and then held in contact with the object to be charged. Ben had already seen one of these tubes in Boston and was astonished by its properties. Ben wrote in his autobiography, "I eagerly seized the opportunity of repeating what I had seen in Boston, and, by much practice, acquired great readiness in performing those also which we had an account of from England, adding a number of new ones. I say with much practice, for my house was continually full, for some time, with people who came to see these new wonders."

Glass tube sent to Ben by Collinson

Ben joined forces with his colleagues in Philadelphia, Ebenezer Kinnersley (Ben's principal co-experimenter), Thomas Hopkinson and Philip Syng, forming a team to carry out electrical experiments and research electrical science. Electrical phenomena became Ben's passion. In 1747, Ben wrote to Collinson, "For my own part, I never was before engaged in any study that so totally engrossed my attention and my time as this has lately done." Ben described these initial experiments performed by his team in a series of five letters that he wrote to Collinson regularly from 1747 to 1750. With Ben's approval, Collinson shared these letters with the Royal Society of London. In 1751, Collinson also published the first five letters in a small booklet entitled "Experiments and Observations on Electricity, made at Philadelphia in America." This booklet later became one of the most widely reprinted scientific books of the eighteenth century. There were five editions printed in English, three in French, one in German, and one in Italian.

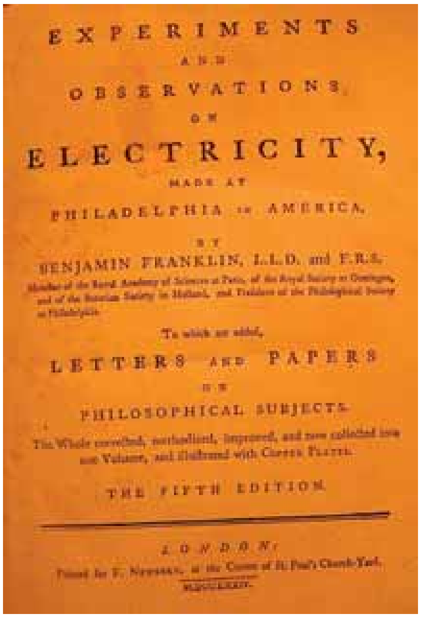
Electrostatic machine owned by Ben

One of Ben's first recorded discoveries concerned the action of pointed bodies. In a letter to Collinson dated 1747, Ben described this as "the wonderful effect of pointed bodies, both in drawing off and throwing off the electrical fire." In this letter, Ben reported that a pointed metal object causes an electrified (charged) insulated conducting body to lose (discharge) its electrical fire (charge) when the point was six to eight inches away; but a blunt metal object would not produce such an effect until it was an inch or so away, and then there would be an accompanying spark. He also reported that pointed wooden bodies would cause an effect similar to the pointed metal bodies, provided that the wood was not dry. According to Ben, the pointed object should be touching something (grounded) in order to have the maximum draw effect. Ben also introduced the concept that rubbing glass with leather does not actually create electricity; rather, during the friction process the glass simply takes some "electrical fire" out of the leather and leaves a deficiency behind. Ben introduced terms such as being electrified positively (or plus) and negatively (or minus) to describe these electrical states. The glass was assumed to be electrified positively and the rubbing material negatively. Ben's idea that there are two states of electricity, positive and negative, that charge is never created or destroyed but only transferred from one place to another, is what is known today as the principle of conservation of electric charge.

Ben working with his electrostatic machine

Ben analyzes the Leyden jar

Ben and his group carried out experiments on the Leyden jar when all the electricians in Europe wondered about how this device worked. Ben referred to this device as Musschenbroek's "wonderful bottle." The Leyden jar is basically a glass bottle partially filled with water or metal pellets on the inside; the outside is coated with metal foil. The interior material was connected electrically by a wire running through a cork in 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 a charged body, the jar seemed capable of accumulating and holding a vast amount of electricity. Ben discovered that if the wire and the water inside the glass bottle are electrified positively or plus, then the outer coating is simultaneously electrified negatively or minus in exact proportion. In a letter to Collinson written in 1747, Ben provided an analysis of the behavior of the Leyden jar by explaining the concept of equal plus and minus states combined with the non-electric characteristics of the glass bottle. In this letter, Ben expressed his astonishment on the operation of the Leyden jar as, "So wonderfully are these two states of electricity, the plus and minus, combined and balanced in this miraculous bottle (!), situated and related to each other in a manner that I can by no means comprehend!"


EXPERIMENTS

AND

OBSERVATIONS

ON

ELECTRICITY,

MADE AT

PHILADELPHIA IN AMERICA,

BY

BENJAMIN FRANKLIN, L.L.D. and F.R.S.

To which are added,

LETTERS AND PAPERS

ON

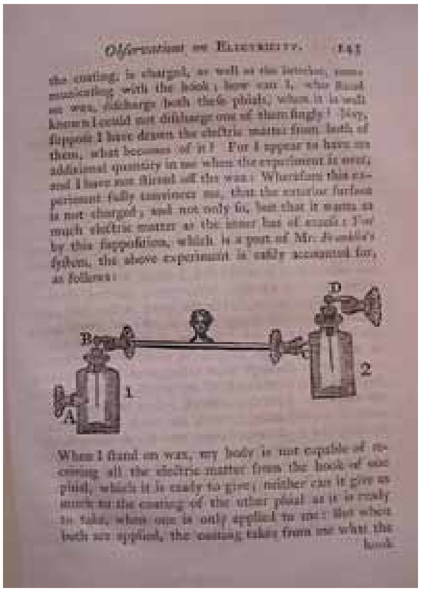
PHILOSOPHICAL SUBJECTS.

THE FIFTH EDITION.

LONDON:

5th edition of Ben's book, published in 1774

In another letter to Collinson, dated 1748, Ben used the terms charging and discharging in describing how a Leyden jar works, and he noted the importance of grounding when charging or discharging the jar. He then announced 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." Further, Ben's team carried out a series of experiments to investigate whether the geometry of the glass bottle affected its capacity. To study this question, Ben constructed a parallel-plate capacitor, which used a sheet of sash-glass with thin lead plates fastened to each side of the sheet. Ben reported that this capacitor produced the same type of electrical effects as the Leyden jar, and demonstrated that the force is a property of glass as glass, and is not related to its geometric shape. Ben also reported that he charged eleven panes of large sash-glass, each armed with lead plates pasted on both sides and hooked together in series by wire and chain. In his letter, he referred to this structure as an electric battery, a term he introduced for the first time.



From Ben's book

Ben discovers the lightning rod

Among all of Ben's achievements, his study of the phenomenon of lightning and his invention of the lightning rod are the ones that gained him international fame and popularity as a scientist. The resemblance of electrical sparks and crackling noises to lightning had led some scientists before Ben to speculate that lightning might be an electric phenomenon, but there had been no experiments to prove it. In performing his electrical experiments, Ben also began to sense some common patterns between the two, and in 1749, he listed in his notebook twelve similarities between lightning and electricity. He wrote, "Electrical fluid agrees with lightning in these particulars: 1. Giving light. 2. Color of the light. 3. Crooked direction. 4. Swift motion. 5. Being conducted by metals. 6. Crack or noise in exploding. 7. Subsisting in water or ice. 8. Rending bodies it passes through. 9. Destroying animals. 10. Melting metals. 11. Firing inflammable substances. 12. Sulfurous smell. Points attract the electric fluid. We do not know whether this property is in lightning. But since they agree in all particulars wherein we can already compare them, is it not probable they agree likewise in this? Let the experiment be made."

Ben put a metal object on an insulating stand and strongly electrified it. Then, using a blunt metal rod in his hand, he found that he had to bring it within an inch of the electrified object to discharge it and that this discharge was accompanied by a strong and noisy spark. Then, he repeated the same experiment using a sharp-pointed grounded metal rod and found that he could discharge the object even when the pointed end of the rod was as far as six or seven inches away from the object. Moreover, the discharge was silent and a pale glow appeared at the point of the rod. Now, the question Ben recorded in his notebook was whether a pointed grounded metal rod would have the same effect with lightning as it does in the electrical experiment. If so, this would imply that the thundercloud producing lightning is electrified. Also, such a pointed metal rod, even when it is at a considerable distance away from the cloud, could possibly be used to discharge the electrified cloud silently and without the destruction often caused by lightning.

To investigate this question, Ben proposed the following experiment: "On the top of some high tower or steeple, place a kind of sentry box big enough to contain a man and an electrical [insulating] stand. From the middle of the stand let an iron rod rise and pass bending out of the door, and then upright twenty to thirty feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when such clouds are passing low, might be electrified and afford sparks, the rod drawing [electric] fire to him from the cloud." To avoid danger, Ben advised the man to be well insulated and to hold in his hand a wax handle (insulator) 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."

Thomas-François Dalibard, who had translated Ben's Experiments and Observations book into French, first performed the sentry box experiment in May 1752, at Marly-la-Ville, France. Dalibard succeeded in drawing sparks from the base of a forty-foot tall vertical pointed iron rod that had been carefully insulated from ground. He reported his success to the Paris Academy of Sciences stating, "In following the path that Mr. Franklin has traced for us, I have obtained complete satisfaction."

Dalibard's experiment

Later, Ben devised a second experiment that involved a kite to test the electrification of clouds. He constructed the kite using a large, thin silk handkerchief, a cross of two light cedar strips, and a tail. He fastened a pointed wire to the top of the kite and to the kite string. The wire extended about a foot above the kite. The kite string was hemp twine, which is slightly conducting when dry, but more so when damp. It was joined at the bottom end to a silk ribbon about three feet long to serve as an insulator, and whose other end Ben would hold in his hand to control the kite. Ben tied a metal key to the twine where it joined the silk ribbon. Upon the approach of a thunderstorm, Ben and his son raised the kite and stood under a shed so that the silk ribbon by which they held the kite string would not get wet. In June of 1752, Ben, with the aid of his son William, flew the kite on a Philadelphia commons on a stormy day. When a thundercloud passed over the kite, and the string had become wet enough to conduct electricity, the loose ends of the fibers of the kite string suddenly stood erect from the string. Ben put his knuckle near the metal key and received a strong spark! He then charged a Leyden jar, and caused a spark from it to ignite a flare. Ben had demonstrated that lightning was an electrical phenomenon. He conducted this experiment without knowledge of Dalibard's success and reported his experiment to Collinson in October 1752.

Ben and his son William getting ready for the famous kite experiment

Having demonstrated that lightning was indeed an electrical discharge, Ben pursued his original concept that tall insulated metal rods could be used to determine whether thunderclouds are electrified or not and tall grounded metal rods could be used to protect against lightning by transferring a lightning flash harmlessly to ground. After learning about Dalibard's successful experiment, in September 1752, Ben installed a tall insulated test rod on the roof of his house to make experiments and observations on electrified clouds passing overhead. The conductor rod stretched from the roof down a stairwell to ground, but it had a gap in the middle. A small ball was suspended between the chimes mounted at each end of the gap, and the ball was placed so that the chimes would ring whenever the rod was electrified. (A similar "electric chime" had been invented a few years earlier by Andrew Gordon, a Scottish Benedictine teaching in Germany.) Using his apparatus, Ben discovered, "That the clouds of a thunder-gust are most commonly in a negative state of electricity, but sometimes in a positive state." He also concluded, "So that, for the most part, in thunder-strokes, it is the earth that strikes into the clouds, and not the clouds that strike into the earth." He posited, however, that the effects of lightning would be the same regardless of whether the current flowed up from the ground or down from the cloud.

Others repeated Ben's lightning experiments in countries such as France, Germany, and England. In 1753, in St. Petersburg, Georg Wilhelm Richmann was instantly struck dead by a bolt of lightning while performing a variation of Ben's sentry box experiment because he was standing on the floor and not on an electrical stand. Scientists published detailed reports on the effect of lightning on the various organs of Richmann's body. Richmann became the first human casualty of the new electrical science. In his 1767 "The History and Present State of Electricity" book, Joseph Priestley offered the following comment on Richmann's death: "But it is not given to every electrician to die in so glorious a manner as the justly envied Richmann."

In 1752, Ben published instructions for installing a lightning rod in his Poor Richard's Almanac. It was in Philadelphia that the first lightning rods ever to be installed were put in service. Since lightning was a potential threat in Philadelphia, protective rods were soon installed on some buildings. By 1782, there were about four hundred lightning rods in Philadelphia. At their early stages, lightning rods also faced some opposition by theologians because it was argued that thunder and lightning were symbols of God's power and that it would be unholy to try to interfere with their powers of destruction. To this argument, John Winthrop from Harvard College provided the common sense reply: "It is as much our duty to secure ourselves against the effects of lightning as against those of rain, snow, and wind, by the means God has put into our hands."

Ben's lightning experiments spread his fame to the public at large in Europe. Scientists in London were surprised by the success of both experiments and in 1753 the Royal Society of London awarded Ben the Sir Godfrey Copley gold medal, their highest award. In 1756, Ben was elected a Fellow of the Royal Society. In his "The History and Present State of Electricity," Priestley described the kite experiment as drawing "lightning from the heavens" and then characterized this discovery as "the greatest, perhaps, in the whole compass of philosophy since the time of Sir Isaac Newton." Ben also received honorary degrees from Harvard (1753), Yale (1753) and William and Mary (1756).

Other important events in Ben's life

Ben made a second trip to England in 1757 and remained there until 1762 as the Pennsylvania Assembly's agent. He was a moderate politically and worked hard for a peaceful resolution of the differences between the American colonies and the British. He was sent back again in 1764 for further negotiations.

In 1776, at the age of seventy, Ben was the oldest signer of the Declaration of Independence. After being elected a commissioner to France, Ben went to Paris in 1776 and played a crucial role as a political figure in getting support from France to win the American Revolutionary War against the British. When he left France to return to Philadelphia in 1785, he had a large stone in his bladder that made traveling very painful. Ben served as a delegate to the Constitutional Convention in 1787. He completed his service as president of the supreme executive council of Pennsylvania in 1788, after which he ended his career in public office. In 1787, he accepted the position of president of the Pennsylvania Society for Promoting Abolition of Slavery and he signed an important document against slavery in 1790. At age eighty-four, Ben died of pleurisy in Philadelphia on April 17, 1790.

Ben Franklin next to the electric chimes he installed to sense atmospheric electricity

Although Ben failed mathematics at an early age, he later overcame this deficiency. In midlife, for his amusement, he made magic squares and circles, some of which were very complex and obviously required math skills in computation. Published in England and France from 1767 to 1773, they have attracted much attention and comment ever since. Ben constructed a special 16 by 16 magic square containing consecutive numbers such that the sums of all numbers in each row, column, and diagonal are 2,056. Ben referred to this magic square as "the most magically magical of any magic square ever made by any magician."

Among Ben's other notable inventions are swim fins, the rocking chair, bifocal lenses, the Franklin stove, and the glass harmonica. Ben is also the first person who conceived the idea of daylight savings time.

Three hundred years after his birthday, Ben's legacy lives: every tall building around us is protected day and night by his most famous invention, the lightning rod. Ben also holds a special spot in the IEEE's history: in 1990, the Benjamin Franklin House in London where Ben lived between 1757 and 1775 was named an IEEE Milestone in Electrical Engineering and Computing. After the IEEE Foundation completed its restoration, this house was opened to the public on Ben's 300th birthday, January 17, 2006.

References:

[1] A. S. Inan, Remembering Benjamin Franklin on his 300th Birthday, presented during the Special Session titled, "Benjamin Franklin," at the 2006 IEEE International Symposium on Electromagnetic Compatibility, Portland, Oregon, August 14-18, 2006.

Editor's Note: Aziz Inan is a Professor of Electrical Engineering in the School of Engineering at the University of Portland in Portland, Oregon. He lent his considerable engineering talent and enthusiasm to the 2006 IEEE International Symposium on EMC, most notably in organizing the "Fundamentals of EMC" tutorial as well as the special session on the 300th anniversary of the birth of Benjamin Franklin. Professor Inan shared some of this information on Franklin to a wider audience at the EMC Awards Luncheon. Much of that material is included here for the reader's enjoyment. For more information, please contact Professor Inan at (503)-943-7429, e-mail: ainan@up.edu or visit the site: http://faculty.up.edu/ainan