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Franklin, Ingen-Housz, and Protecting Gunpowder From Lightning in the 18th Century

Invited Lecture

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1.0 Introduction

Because explosions of gunpowder have many similarities to thunder and lightning - extremely loud and bright, and often unexpected - many analogies were drawn between these phenomena after the introduction of gunpowder into Europe in the 14th century. On or before June, 1751, the Philadelphia “Experiments and Observations on Electricity” by Benjamin Franklin (1706-1790) and co-workers [1] showed that gunpowder could be ignited by a small spark [2], and lecturers and demonstrators used gunpowder to enhance the explosions of “thunder houses” to illustrate how grounded metallic rods can protect structures from lightning damage. Almost immediately after the sentry box and kite experiments demonstrated that thunderclouds contain electricity and that lightning is an electrical discharge [3], Franklin published a short note entitled “How to secure houses, etc. from Lightning” in *Poor Richard’s Almanack* for 1753 [4]. The basic idea was that a tall, well-grounded conductor with a sharp point on the top will either prevent a discharge by silently discharging the thundercloud overhead, or if a discharge does occur, the rod will provide a safe location for lightning to strike, and the grounding conductors will guide the current into the earth in a harmless fashion.

In modern terms, the three key elements of Franklin’s protective system are: (1) one or more metallic *air terminals* mounted above the roof of the structure, (2) horizontal *roof conductors* and vertical *down conductors* that connect the air terminals to (3) a *grounding system* that provides a safe electrical path into the earth [5-7]. Since Franklin initially thought that silent “point discharges” might provide protection, the first air terminals were thin, sharp needles inserted into the end of iron bars, and the first down conductors were chains of iron rods (used to make nails), each several feet long that were mechanically linked or hooked together. Clearly, these elements would work well at the very low current levels of point discharges, but they were not adequate at the very much larger currents that flow in lightning strikes [8].

By 1762 enough experience had been gained through practice for Franklin to make the following recommendations to improve his protection system:

- the air terminals should be one-inch diameter, steel rods, 5 to 6 feet long and tapered to a sharp point. If the building had any dimension longer that about 100 feet, a pointed rod should be mounted on each end of the building and there should be a conductor between them;

- all roof and down conductors should be continuous, at least half an inch in diameter, and they should be mounted on the outside of the building. If any links or joints must be made in these conductors, the links should be filled with lead solder so they have good electrical continuity; and
- the grounding conductor should be a one-inch diameter iron rod driven 10 to 12 feet into the earth, and if possible, this conductor should be kept at least 10 feet away from the foundation of the structure. Franklin also stated that the ground rods be painted in order to minimize rust, and that connecting them to the water of a well was best, if a well was nearby [8].

2. Protecting Gunpowder

In August 1769, lightning struck the tower of the church of St. Nazaire in Brescia, Italy, and the current passed through vaults where 207,000 pounds of gunpowder had been stored for safe-keeping. The resulting explosion killed about 3000 people and destroyed one-sixth of the city [9], and the incident was reported worldwide. In response to this disaster, the British parliament passed two acts establishing standards for the manufacture and storage of gunpowder. In May of 1772, the British Board of Ordnance asked Benjamin Wilson and later Benjamin Franklin to participate on a Committee to make recommendations for protecting their new arsenal at Purfleet [10, 11]. This request was the beginning of a long controversy between Franklin and Wilson about whether the air terminals should be tall and have sharp points, as recommended by Franklin, or whether they should be mounted just below the roof in the form of round balls or knobs, as recommended by Wilson. In August 1772, the Committee recommended points, and it also recommended some additional improvements at Purfleet:

- eliminate all vertical bars of iron in the roof because these together with the copper hoops on the barrels of gunpowder might form an incomplete conductor between the roof and the ground;
- tall rods (at least 10 feet long), 1 inch in diameter, should be mounted on each end of the building, and these should be connected to some lead coping that covered the ridge of the roof and led to the grounding conductors; and
- improve the grounding system by making the down conductors continuous, and connect them to wells of water that go below the water table [10].

In May 1777, a lightning strike produced minor damage to a protected building at Purfleet while Benjamin Franklin was in France seeking aid (including gunpowder) for the newly declared United States of America. Wilson renewed his efforts to prove his opinion by performing a large (but still inconclusive) experiment using an artificial cloud that was electrified so that it could discharge to model buildings. Soon afterward, a second Committee of the Royal Society again recommended points for protecting gunpowder [11-13]. By this time, the “points vs. knobs” controversy had become highly political in Britain, with sharp points being favored by people who supported the American insurgents and knobs being favored by King

George III and his party [10–13]. In a letter dated October 4, 1777, Franklin summarized his own opinion of the matter at that time,

> "I have no private Interest in the Reception of my Inventions by the World, having never made nor proposed to make the least Profit by any of them. The King's changing his pointed Conductors for blunt ones is therefore a Matter of small Importance to me. If I had a Wish about it, it would be that he had rejected them altogether as ineffectual, For it is only since he thought himself and Family safe from the Thunder of Heaven, that he dared to use his own Thunder in destroying his innocent Subjects." [14]

3. Jan Ingen-Housz

Jan Ingen-Housz (1730-1799) was born in the Netherlands at Breda and studied medicine at the Catholic University of Louvain in Belgium [15-17]. He practiced medicine in Breda until 1765, and then he went to London at the invitation of a distinguished physician, Sir John Pringle (and friend of Franklin), to learn about and practice the then-new method of inoculation against smallpox. In 1768, George III recommended Ingen-Housz to inoculate the Hapsburg royal family in Vienna, and the Empress Maria-Theresa was so impressed with his work that she awarded him a lifetime annuity and made him a Royal Physician of Austria.

Ingen-Housz met Franklin in the early 1770s in London and soon learned about the electrical and chemical experiments of Joseph Priestly, who had just discovered that plants "restored air," i.e. produced enough oxygen to keep a mouse alive even though it was covered by a glass jar. In the summer of 1779, Ingen-Housz performed more than 500 experiments on plants in less than 3 months and then published a book entitled "*Experiments Upon Vegetables, Discovering Their Great Power of Purifying the Common Air in the Sun-shine, and of Injuring it in the Shade and at Night* [18]. As the title implies, this work made it clear that (a) it is sunlight that produces oxygen (O_2) in plants, (b) the amount of oxygen is proportional to the intensity of the light, and (c) plants produce carbon dioxide (CO_2) at night. Ingen-Housz also showed that it is the action of the "green matter" in plants that is important, and he made other contributions in plant ecology [17]. In 1785, Ingen-Housz published a detailed description of the random motion of very small particles in a fluid that he saw under a microscope, and this was 42 years before Robert Brown is credited for discovering the random "Brownian motion" of small particles in fluids.

4. Benjamin Franklin in France

Benjamin Franklin went from London to America in 1775, and the next year he co-authored the well-known Declaration of Independence. In late 1776, he sailed to France to solicit aid for the American Revolution, and he remained there until 1785. While he was in Paris, Franklin regularly attended meetings of the French Académie Royale des Sciences and, because of his background in electricity and knowledge of lightning, he served on several official committees that made recommendations for protecting buildings and gunpowder against damage.

On January 29, 1777, Ingen-Housz wrote to Franklin about the best method for protecting gunpowder magazines at the request of Joseph II of Austria,

> "The Republic of Venise (sic) has just now asked the Emperour to get a thorough instruction made of the manner of building Gunpowder magazins, preserving the powder, and preventing mischief from lightning,"

and on May 3, 1780, he asked again,

> "If you could communicate to me some short hints, which may occur to you about the most convenient manner of constructing gun powder magazines, the manner of preserving the powder from moisture and securing the building in the best manner from the effects of lightning, you would ablidge me. Whatever may occur to you on this head, will be very acceptable. It seems to me very imprudent to heap up immense stores of that terrifying ingredient in stony vaulted buildings in the time of piece (sic), when there is no danger of any combustible matter being thrown upon it, and more so to place several of such storehouses so near one an other as may endanger them from being all blown up, when one should happen to be set on fire by what ever accident it may be." [20]

Franklin's reply is of particular interest here because it introduces a radically new approach for lightning protection that does not rely on any air terminals or even grounding conductors,

> "With regard to Powder Magazines
>
> My idea is,
>
> That to prevent the Mischief which might be occasion'd by the Stones of their Walls flying about in case of accidental Explosion, they should be constructed in the Ground; that the Walls should be lined with Lead; the Floor Lead; all ¼ Inch thick & the Joints well solder'd; the Cover Copper; with a little Scuttle to enter, the whole in the Form of a Canister for Tea. If the Edges of the Cover scuttle fall into a Copper Channel containing Mercury, not the smallest Particle of Air or Moisture can enter to the Powder, even tho' the Walls stood in Water or the whole was under Water." [21]

It is noteworthy that almost 96 years later (in 1876) the famous Scottish physicist, James Clerk Maxwell, made almost the same recommendation for protecting gunpowder,

> "What we really wish to prevent is the possibility of an electric discharge taking place within a certain region – say, in the inside of a gunpowder manufactory. If this is clearly laid down as our object, the method of securing it is equally clear."
>
> "It would, therefore, be sufficient to surround our powder-mill with a conducting material, to shield its roof, walls, and ground-floor with thick sheet-copper, and then no electrical effect could occur within it on account of any thunderstorm outside." [22]

Maxwell knew about Michael Faraday's experiments on electrostatic induction which included the construction of a 12 x 12 x 12 cubic foot demonstration room in the lecture hall of the Royal Institution, with all sides, top, and bottom conducting and insulated from ground. Using sensitive electrometers, candle flames, etc., Faraday could not find any electrical effects inside the room when it was highly charged on the outside, and “large sparks and brushes were darting off every part of its outer surface” [23]. Faraday’s experiments were patterned after those of Joseph Priestley, who following a suggestion by Benjamin Franklin in 1767, found that there was no electricity inside a metal cup when the cup it was electrified,

> “XV. Experiments with an Electrified Cup.
>
> I shall close the account of my experiments with a small set, in which, as well in the last, I have little to boast besides the honour of following the instructions of Dr. Franklin. He informed me, that he had found cork balls to be wholly unaffected by the electricity of a metal cup, within which they were held; and he desired me to repeat and ascertain the fact, giving me the leave to make public.”[24]

In fact, Priestley used this result to infer that the force of electrical attraction has an inverse square distance dependence (Coulomb’s Law),

> “May we not infer from this experiment, that the attraction of electricity is subject to the same laws with that of gravitation, and is therefore according to the squares of the distances; since it is easily demonstrated that were the earth in the form of a shell, a body in the inside of it would not be attracted to one side more than another.”[25]

In 1769, Franklin published a letter that he wrote to John Lining in 1755 (Lining flew an electrical kite in 1753) that described his prior experiment with a metal can,

> “The experiment you have heard so imperfect an account of, is merely this. I electrified a silver pint cann (sic), on an electric stand, and then lowered into it a cork ball, of about an inch diameter, hanging by a silk string, till the cork touched the bottom of the cann. The cork was not attracted to the inside of the cann as it would have been to the outside, and though it touched the bottom, yet, when drawn out, it was not found to be electrified by that touch, as it would have been by touching the outside. The fact is singular.”

He then continued the paragraph with some advice,

> “You require the reason; I do not know it. Perhaps you may discover it, and then you will be so good as to communicate it to me. I find a frank acknowledgment of one’s ignorance is not only the easiest way to get rid of a difficulty, but the likeliest way to obtain information, and therefore I practice it: I think it an honest policy. Those who affect to be thought to know every thing, and so undertake to explain every thing, often remain long ignorant of many things that others could and would instruct them in, if they appeared less conceited.” [25]

The modern lightning literature now terms the method of protecting sensitive material by surrounding it with a metal sheath a “Faraday cage” or “Maxwell shield” [5-7, 26], and the effects of such a cage or shield are the reasons one is generally safe inside a metal airplane or automobile during a lightning storm. This method has also been generalized to “topological shielding” [27, 28] which utilizes multiple layers of imperfect or partial shields, each nested inside the other and with a transient suppressor between them. What we have seen here is that these important ideas were first introduced into lightning protection by Benjamin Franklin (in the year 1780) and then forgotten until they were re-introduced by Maxwell, based the work of Priestley and Faraday, and apparently, no one had knowledge of Franklin’s priority.

5. Acknowledgement

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6. Notes and References

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

[2] Franklin references are taken from The Papers of Benjamin Franklin, Ed. By L. W. Labaree, W. B. Wilcox, C. A. Lopez, B. B. Oberg, E. R. Cohn et al., Yale University Press, New Haven, CT, Vol. I, 1959 to Vol. 40, 2011 with some capital letters suppressed to conform with modern usage. In the following notes, these volumes will be referred to as BF Papers; the volume number will be in italics, and the page numbers will be inclusive. The detonation of gunpowder by electricity is described in *BF Papers, 4*, 145.

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

[4] *BF Papers, 4*, 408-409.

[5] Golde, R. H., *Lightning Protection*, Chemical Publishing Co., New York, 1975.

[6] Krider, E. P. and M. A. Uman, "Lightning, Lightning Protection and Test Standards," in *Wiley Encyclopedia of Electrical and Electronic Engineering* – Online and in Print, John Wiley, 1999.

[7] Uman, M. A., *The Art and Science of Lightning Protection*, Cambridge University Press, 2008, 240 pp.

[8] Krider, E. P., "Benjamin Franklin and Lightning Rods," *Physics Today, 59* (1), 42-48, 2006.

[9] Harris, W. S., *On the Nature of Thunderstorms; and on the Means of Protecting Buildings and Shipping Against the Destructive Effects of Lightning*, John W. Parker, London, 1743. p.163.

[10] See Headnote on BF letter to Richard Dawson, *BF Papers, 19*, 153-154 and also, *19*, 244-265.

[11] Tomlinson, C., "On lightning and gunpowder magazines," *Philosophical Magazine* (London), Series 5, *28:174*, 368 – 375, 1889.

[12] Schonland, B. F. J., "Benjamin Franklin: Natural Philosopher," *Proc. Roy. Soc. London, A, 235*, 433-444, 1956.

[13] Mitchell, T. A., "The Politics of Experiment in the Eighteenth Century: The Pursuit of Audience and the Manipulation of Consensus in the Debate over Lightning Rods," *Eighteenth-Century Studies*, *31* (3), 307-331, 1998.

[14] BF Papers, *25*, 25-26.

[15] Jenkins, J. S., "The English Innoculator: Jan Ingen-Housz," *J. Roy. Soc. Medicine*, *92*, 534-537, 1999.

[16] Conley, T. K., and M. Brewer-Anderson, "Franklin and Ingenhousz:A Correspondence of Interests," *Proc. Am. Phil. Soc., 141* (3), 276-296, 1997.

[17] Magiels, G., *From Sunlight to Insight, Jan IngenHousz, the discovery of photosynthesis & science in the light of ecology*. Brussels: VUB Press, 2010, 407 pp.

[18] Ingen-Housz, J., *Experiments upon Vegetables - Discovering Their Great Power of Purifying the Common Air in the Sunshine and of Injuring It in the Shade and atNight, to Which is Joined a New Method of Examining the Accurate Degree of Salubrity of the Atmosphere.*London, Elmsly and Payne, 1779.

[19] Hill, J. F., “Early Pioneers of Photosynthesis Research,” Chapter 30 in *Advances in Photosynthesis and Respiration*, *34*, 771-800, 2012.

[20] BF Papers *32*, 341-346.

[21] *Ibid*, *32*, 346-349.

[22] Maxwell, J. C., Report for the British Association for the Advancement of Science, 1876; Quotations taken from *Lightning Conductors, their history, nature, and mode of operation*, 3rd Edition, by Richard Anderson, E. and F. N. Spon, London, 257-262, 1885.

[23] Faraday, M., “Experimental Researches in Electricity,” *Phil .Trans. Roy. Soc. London*, Series 11, #1173-1174, 1838.

[24] Priestley, J., *The History and Present State of Electricity, With Original Experiments*. London: J. Dodsley, 1767, pp. 731-732.

[25] BF Papers, *5*, 525-526.

[26] NFPA 780, Standard for the Installation of Lightning Protection Systems, National Fire Protection Association, Quincy, MA, 2004.

[27] Tesche, F. M., “Topological concepts for internal EMP interaction,” *IEEE Trans. EMC*, *20*, 60-64, 1978.

[28] Vance, E. F., “Electromagnetic interference control,” *IEEE Trans. EMC*, *22*, 319-328, 1980.