Who Invented the Earliest Capacitor Bank ("Battery" of Leyden Jars)? It's Complicated

By ADAM ALLERHAND

In this article, the author surveys the scientific literature in order to settle the question of who should be credited with inventing the capacitor bank. The story shows how international science was in the 18th century, in spite of the limitations of communications technology.

I. INTRODUCTION

Capacitor banks are essential for the proper functioning of motors and electric transmission systems. Fig. 1 shows a capacitor bank of a high-voltage substation, which contains sets of high-power capacitors in series and in parallel.

Banks of Leyden jars, at first called "Leyden jar batteries" and "electrostatic batteries," were the first capacitor banks. The Leyden jar was invented in 1745, independently by Ewald Georg Jürgen von Kleist of Kammin, Prussia (now Kamień Pomorski in Poland) and by Pieter van Musschenbroek of Leiden (Leyden in archaic Dutch), Holland, although nationalist attitudes have led to preferences for the former or latter inventor in some narratives [1], [2]. Kleist first reported his discovery in letters dated November 4 and November 28, 1745 [3]. The letter of November 28, 1745 has survived; an image is accessible online [4]. Musschenbroek first reported his discovery in a letter (in Latin) dated January 20, 1746 [5]. The letter included the illustration of Fig. 2. Translation of Musschenbroek's letter [6]:

> I would like to tell you about a new but terrible experiment, which I advise you never to try yourself, nor would I, who have experienced it, and survived by the grace of God, do it again for all the kingdom of France. I was engaged in displaying the powers of electricity. I suspended an iron tube (***AB***) from blue-silk lines. A globe, rapidly spun and rubbed, was located near ***A***, and communicated its electrical power to ***AB***. A brass wire (***C***) hung from a point near the other end (***B***). In my right hand (***F***) I held the glass globe (***D***), partly filled with water, into which the wire dipped. With my left hand (***E***) I tried to draw the snapping sparks that jump from the iron tube to the finger; thereupon my right hand (***F***) was struck with such force that my whole body quivered, as if hit by lightning. Generally, the blow does not break the glass, no matter how strong the blow, nor does it knock the hand away *[from the globe]*; but the arm and the entire body are affected so terribly I cannot describe it. I thought I was done for. However, here are some peculiarities: When the globe ***D*** is made of English glass, there is no effect, or almost none; German glass must be used. Dutch does not work either; ***D*** does not have to be a globe; a drinking glass will do. ... I have found out so much about electricity that I have reached the point where I understand nothing and can explain nothing.

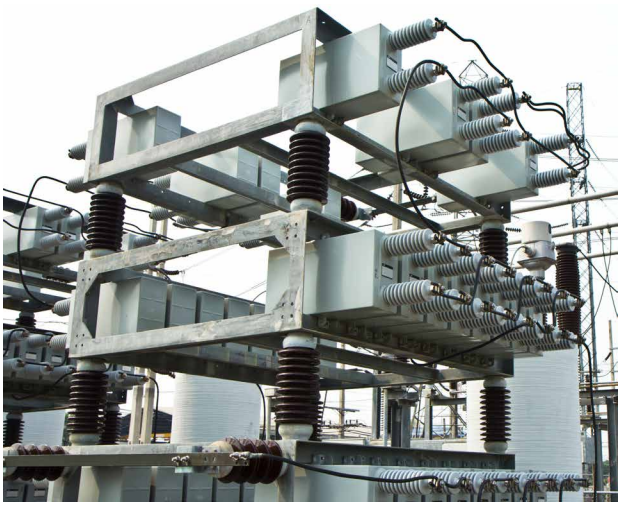

Fig. 1. ***A capacitor bank of an electric power transmission substation. Digital image courtesy of 123rf.com.***

Digital Object Identifier: 10.1109/JPROC.2018.2795846

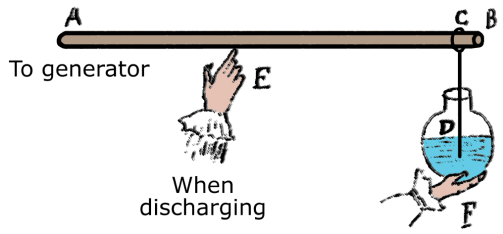

Fig. 2. ***Drawing in Musschenbroek's letter of January 20, 1746 [5], colorized by the author. The experimenter is grounded.***

Leyden jar batteries were introduced soon after van Musschenbroek's announcement. Historians have adequately described the invention of the Leyden jar. However, there are conflicting versions about the invention of electrostatic batteries, mainly attributed to Daniel Gralath (Fig. 3), but also to Johann Heinrich Winkler and Benjamin Franklin. Below are examples of attribution to each of the three.

II. ATTRIBUTIONS TO DANIEL GRALATH

1769, J. Priestley, *History and Present State of Electricity*, 2nd ed. [7]: "...he *[Gralath]* was the first who made what we now call an electrical battery; for he increased the shock by charging several phials at the same time." Priestley's reference is "p. 552" of the second part of Gralath's *Geschichte der Electricität*, published in 1754 [3], where there is no page 552. A Gralath article published in 1747 describes an electrostatic battery on page 522 [8].

Fig. 3. ***Portrait of Daniel Gralath (1708–1767) by Jacob Wessel, a painter in Danzig, Polish–Lithuanian Monarchy. Digital image courtesy of Marcin Kłos, Historical Museum of Gdańsk (Danzig in German), Poland. I have not found a portrait of Johann Heinrich Winkler. Images of Benjamin Franklin are ubiquitous (see $100 bill).***

1810, *Encyclopaedia Britannica* [9]: "The first electrical battery appears to have been constructed in the year 1746 by Mr. Gralath, a German."

1873, *Scientific American* [10]: "The electric shock produced by the Leyden jar attracted then so much general interest that many persons traveled around Europe and made a living by administering it, some of them pretending to cure by it all kinds of diseases. Foremost of those who advanced this branch of science must be mentioned Gralath, in Germany, who, in 1746, gave the shock at great distances and through twenty persons at once, and invented the electric battery, consisting of a number of Leyden jars."

1884, E. Hoppe, *Geschichte der Elektricität* (History of Electricity) [11]: "A crucial contribution of Gralath is to have invented the electric battery."

1885, G. Albrecht, *Geschichte der Elektricität—mit Berücksichtigung ihrer Anwendungen* (History of Electricity and its Applications) [12]: "The mayor of Danzig, Daniel Gralath, 1708–67, was the first to pursue the recent, at the time, discovery *[of the Leyden jar]*. He pointed out the necessity of the simultaneous touching of the metal knob at the end of the wire and of the outside of the bottle. In April 1746, he constructed the first battery by connecting the wires of several *[Leyden jar]* bottles."

1898, P. Benjamin, *A History of Electricity—From Antiquity to the Days of Benjamin Franklin* [13]: "Gralath destroyed life in beetles and worms; but not succeeding in so doing in birds, sought still further to intensify the discharge, and thus reached the idea of combining the effects of several jars, which he placed in metal pans, with their lead balls in contact with the prime conductor of his machine, while from each pan a wire proceeded to a copper globe placed within sparking distance of the conductor. This was the first grouping of electric generators in battery, in which they were obviously disposed in parallel, or multiple arc - an arrangement which for some time was the only one known. Gralath now killed birds easily, and reports minutely on the physiological changes produced."

1939, A. Wolf, *A History of Science, Technology, and Philosophy in the Eighteenth Century* [14]: "Gralath formed batteries of Von Kleist's bottles, arranged in parallel, and discovered that 'residual charges' remained in the bottles after their apparent discharge. He used such batteries to kill small birds, upon whose bodies his medical friends conducted post mortem examinations."

1978, W. D. Hackman, *Electricity from Glass—The History of the Frictional Electrical Machine 1600–1850* [15]: "Gralath observed that the shock *[from a Leyden jar]* could be given instantaneously to a number of persons, and he

probably constructed the first electrical battery, with the jars in series."

1979, J. L. Heilbron, *Electricity in the 17th and 18th Centuries—A Study of Early Modern Physics* [16]: "Gralath connected jars in parallel, in what he called an electrical battery; a stroke from two such phials, taken to the forehead, felt like a blow from a bludgeon."

2010, H. Schlesinger, *The Battery—How Portable Power Sparked a Technological Revolution* [17]: "Daniel Gralath found that connecting several jars in parallel in what he first called an 'electrical battery'—appropriating military terminology—increased the power."

2017, M. Křepelková, "Evolution of Batteries: From Experiments to Everyday Usage," *21st Student International Conference on Electrical Engineering*, Prague, Czech Republic [18]: "This discovery *[the Leyden jar]* was important for later experiments and studies of electricity. A Polish physicist, Daniel Gralath, experimented with connecting more Leyden jars in parallel."

III. ATTRIBUTION TO JOHANN HEINRICH WINKLER

1884, E. Hoppe, "*Geschichte der Elektricität* (History of Electricity) [19]: "On July 28, 1746, Winkler placed three large *[Leyden]* jars filled with water, each with a wire inside, into the Pleisse River*[in Leipzig]*, and surrounded the outer coverings with a chain which ended in a button on the nearby river bank. He attached the connected inner wires to the conductor of the electric machine, and, after this connection was broken, there was so violent a blast when the bottles discharged that the resulting spark could be seen 200 paces away on a bright day, and heard even further."

IV. ATTRIBUTIONS TO BENJAMIN FRANKLIN

2003, M. B. Schiffer: *Draw the Lightning Down—Benjamin Franklin and Electrical Technology in the Age of Enlightenment* [20]: "In experiments with plate capacitors and Leyden jars, Franklin also invented "an electrical battery." He found that interesting effects were produced when capacitors were connected together, as batteries, in different configurations. On the one hand, when capacitors were wired in series, the overall charge that could be stored drastically decreased. On the other hand, the stored charge increased when a battery's capacitors were wired in parallel."

2003, W. Isaacson, *Benjamin Franklin—An American Life* [21]: "He lined up a series of glass plates flanked by metal, charged them up, wired them together, and created (and gave a name to) a new device: what we call an electrical battery."

V. REPORTS PUBLISHED IN 1746, 1747, AND 1749

The various inconsistencies presented above can be cleaned up by examining what was written by Winkler in 1746 (in German), by Gralath in 1747 (also in German), and by Franklin in 1749.

A. Johann Heinrich Winkler (1703–1770)

A meeting of the Royal Society (London) on May 29, 1746, featured a letter from Winkler, Professor at the University of Leipzig [22]. I present here an extract of the letter, as published in *Philosophical Transactions*, because it illustrates the excitement caused by the Leyden jar immediately after it was invented:

> When I heard of *Mr. Muschenbroek*'s Experiment, I tried the same; but I found great Convulsions by it in my Body. It put my Blood into great Agitation; so that I was afraid of an ardent Fever; and was obliged to use refrigerating Medicines. I felt a Heaviness in my Head, as if I had a Stone lying upon it. It gave me twice a Bleeding at my Nose, to which I am not inclined. My wife, who had only received the electrical Flash twice, found herself so weak after it, that she could hardly walk. A Week after, she received only once the electrical Flash; a few Minutes after, she bled at the Nose.
>
> I read in the News-papers from *Berlin*, that they had tried these electrical Flashes upon a Bird, and had made it suffer great Pain thereby. I did not repeat this Experiment; for I think it is wrong to give such Pain to living Creatures. I therefore take, instead of Men or Brutes, a piece of Metal, and I put it upon a Stand under the electrical Pipe, which Pipe propagates the Electricity. To this Metal is fasten'd an iron Chain, which goes about the Bottle with Water, in which the brass Wire is put, which Wire is fastened to the electrical Pipe.
>
> When then Electrification is made, the Sparks that fly from the Pipe upon the Metal are so large and so strong, that they can be seen (even in the Day time) and heard at the Distance of fifty Yards. They represent a Beam like Lightning, of a clear and compact Line of Fire; and they give a Sound that frightens the People that hear it.

In his letter, Winkler described experiments with a single Leyden jar. However, the letter is pertinent here. First, it illustrates the transition from the relatively small amounts of electrical energy produced by electrostatic generators alone to the large amounts that became accessible with Leyden jars. Second, Winkler eliminated the human body as part of the external conductors (as in Fig. 2). Instead, he ended up using only metal conductors, converting Leyden jars from demonstration novelties (Fig. 4) to scientific instruments (Fig. 5) [23].

Fig. 4. *A 1777 painting by Flemish painter Charles Amédée Philippe van Loo, now located at the Arkhangelskoye Museum in Moscow, depicts a parlor demonstration of a Leyden jar. The electrostatic generator at the right is connected via a metal rod to the left hand of a woman whose right hand holds a metal rod connected to the water in a Leyden jar. A boy, who is grounded, holds the outside of the glass of the jar with his right hand. His left hand is not part of the circuit during charging. The Leyden jar discharges through the boy's body when he touches the rod inserted in the jar. Image licensed from Heritage Images Partnership.*

Winkler initially worked as a teacher at the Thomasschule (School of St. Thomas) in Leipzig, a boarding school founded in 1212. Johann Sebastian Bach was the musical director of the boys' choir at the school from 1723 to 1750. The choir still exists. Winkler was the librettist for Bach's 1732 cantata "Froher Tag, verlangte Stunden," composed for the dedication of the renovated Thomasschule. In the period of emergence of experimental physics (from about 1710 to about 1780), Winkler was the only noteworthy physics professor at the University of Leipzig, called Pauliner Collegium at the time (Fig. 6). He was appointed Extraordinary Philosophy Professor in 1739, from 1742 to 1750 he was Full Professor of Greek and Latin, and from 1750 Professor of Physics. Winkler started electrical experiments shortly after joining the university [24], [25].

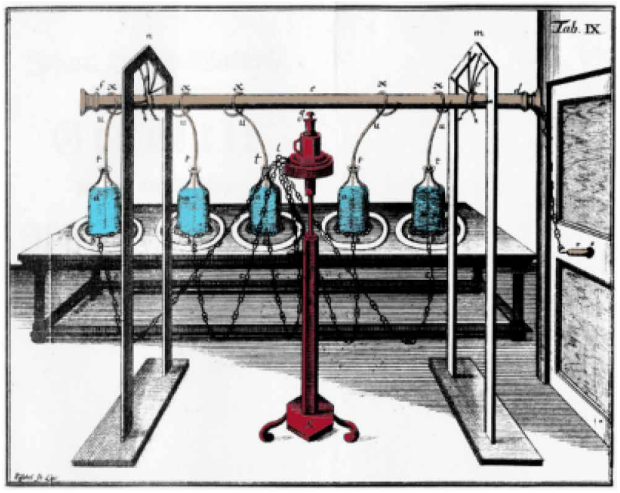

Fig. 5. *Engraving in Winkler's Die Stärke der Electrischen Kraft des Wassers in gläsernen Gefäßen, published in 1746 [23], shows an electrostatic battery with five Leyden jars in parallel. The connection to an electrostatic generator is at the right. The connection to ground is red. Winkler's drawing colorized by the author.*

Fig. 6. *A portion of Leipzig in the first half of the 18th century. Pauliner Collegium is the building on the right. Circa 1701–1750 copperplate engraving by Gabriel Bodenehr the elder (1664–1758). Source: Karl Große, Geschichte der Stadt Leipzig, Leipzig, Germany: Zangenberg & Himly, 1897, plate after p. 304.*

Winkler described his electrostatic batteries in his 1746 book, *Die Stärke der Electrischen Kraft des Wassers in gläsernen Gefäßen, welche durch den Musschenbrökischen Versuch bekannt geworden* (The Strength of the Electric Power of Water in Glass Vessels, which Became Known Through Musschenbroek's Experiments) [23]. Excerpts (author's translation from the German):

> *Pages 27–28:* On July 28 *[1746]*, I threw three large *[Leyden]* bottles of water into the Pleisse *[River, Fig. 7]* in Mr. Apel's garden. A chain connected the wires in the bottles to an electrified tube. I placed another chain, 30 cubits long, on the ground on the water's edge,

Fig. 7. *A portion of the Pleisse River in Leipzig in the 18th century. Copper engraving by Daniel Adam Hauer (1734–1789). Colorized image courtesy Museum de Lakenhal, Leiden.*

inserted it in the river, and touched the round metal under the *[electrified]* tube. There were flashes between the links of the two chains. A spark between the *[round]* metal and the *[electrified]* tube produced a bang.

Pages 48–49: In hope of finding an even stronger force, I tried five filled bottles of equal size, connected together with five chains. As I had hoped, the experiment was successful. Plate IX *[Fig. 5]*. The electric sparks produce an even greater force when the water in these jars is electrified with the use of many large glass spheres.

Winkler's experiment on July 28, 1746, using an electrostatic battery of three Leyden jars, was the first instance on record when a body of water was used deliberately as an electrical conductor to complete a circuit [26]. The location of the experiment, "Apel's garden," is of historical interest. In 1700, merchant and factory owner Andreas Dietrich Apel inherited a large and elegant garden in Leipzig, and expanded it into one of the most famous gardens in Prussia at the time [27].

Not fully satisfied with his three-jar battery, Winkler constructed the five-jar version of Fig. 5, described it in detail, and used it to perform various experiments. Winkler's five-jar apparatus is the earliest instance on record of an electrostatic battery described with enough detail to be clearly reproducible.

B. Daniel Gralath (1708–1767)

Gralath was born in Danzig (Fig. 8), Polish–Lithuanian Monarchy (now Gdańsk, Poland). He studied there at the Academic Gymnasium, a school for Lutheran clergy. He also studied in Halle (Prussia), Leyden (Holland), and Marburg (Prussia). He returned to Danzig on August 20, 1734, two months after the end of the siege and bombardment by Saxon and Russian forces. At first, he carried out experiments as a private citizen. Gralath's greatest achievement was the creation in 1742 of the *Societas Physicæ Experimentalis* (Experimental Physics Society) in Danzig. The aim of the society was to practice and popularize science through weekly public demonstrations of the most interesting experiments in physics. Gralath was elected judge in 1754 and he was mayor of Danzig in the period 1763–1767 [28], [29].

Gralath reported in 1747 that he had constructed two-jar and three-jar batteries in April 1746 [30]. He did not include a drawing and his description is not detailed enough to visualize his battery. Author's translation from the German:

> When I made the experiment with two bottles, the shock felt by the man who was touching the tinned tube was much stronger than when the experiment was done with just one, but still tolerable. However, if I used three bottles, there were few who wanted to make the attempt more than once, because of the violent and painful shock. Note that a person who held only one of the three bottles experienced the same sensation as a person holding an isolated single bottle.

C. Benjamin Franklin (1706–1790)

Franklin's life and achievements have been amply reported [20], [21], [31], [32]. I will just quote introductory words of a eulogy delivered on March 1, 1791, in Philadelphia (Fig. 9), by a Vice-President of the American Philosophical Society (founded by Franklin), before both Houses of Congress and the American Philosophical Society [33]:

> I shall consider him in *three* distinct relations: 1st, As a *Citizen* of *Pennsylvania*, eminent in her Councils, the

Fig. 8. *A view of Danzig in the 18th century. Copper engraving by Balthasar Friedrich Leizel (1727–1802). Colorized image courtesy Museum de Lakenhal, Leiden.*

Fig. 9. *A view of Philadelphia across the Delaware river, from an engraving dated 1754, produced in London, based on sketches by George Heap, coroner of Philadelphia from 1749 to 1751. Portion of a digital image from the Library of Congress, Washington, DC, USA. Information about Heap from Joseph Jackson, "Iconography of Philadelphia," Pennsylvania Magazine of History and Biography, vol. 59, No. 1, 1935, pp. 57–73.*

Founder and Patron of most of those useful Institutions which do honour to her name. 2nd, As a *Citizen* of *America*, one of the chief and greatest Workmen, in the foundation and establishment of her Empire and Renown. 3rd, As a *Citizen* of the *World*, by the invention of useful Arts, and the diffusion of liberal Science, incessantly and successfully labouring for the happiness of the whole Human Race.

Franklin first experimented with electrostatic batteries in 1748 and described his observations in a letter dated April 29, 1749, to English merchant and botanist Peter Collison [34]. Pertinent excerpts:

> ...suspend *two or more phials* on the prime conductor, one hanging on the tail of the other; and a wire from the last to the floor, an equal number of turns of the wheel shall charge them all equally, and every one as much as one alone would have been. What is driven out at the tail of the first, serving to charge the second; what is driven out of the second charging the third; and so on. By this means a great number of bottles might be charged with the same labour, and equally high, with one alone, were it not that every bottle receives new fire, and loses its old with some reluctance, or rather gives some small resistance to the charging, which in a number of bottles becomes more equal to the charging power, and so repels the fire back again on the globe, sooner in proportion than a single bottle would do....
>
> ...*we made what we called an electrical battery*, consisting of eleven panes of large sash-glass, armed with thin leaden plates, pasted on each side, placed vertically, and supported at two inches distance on silk cords, with thick hooks of leaden wire, one from each side, standing upright, distant from each other, and convenient communications of wire and chain, from the giving side of one pane, to the receiving side of the other; that so the whole might be charged together, and with the same labour as one single pane; and another contrivance to bring the giving sides, after charging, in contact with one long wire, and the receivers with another, which two long wires would give the force of all the plates of glass at once through the body of any animal forming the circle with them. The plates may also be discharged separately, or any number together that is required. But this machine is not much used, as not perfectly answering our intention with regard to the ease of charging, for the reason given. ...
>
> Chagrined a little that we have been hitherto able to produce nothing in this way of use to mankind; and the hot weather coming on, when electrical experiments are not so agreeable, it is proposed to put an end to them for this season, somewhat humorously, in a party of pleasure, on the banks of Skuylkil [*Schuylkill*]. Spirits, at the same time, are to be fired by a spark sent from side to side through the river, without any other conductor than the water; an experiment which we some time since performed, to the amazement of many. A turkey is to be killed for our dinner by the *electrical shock*, and roasted by the *electrical jack*, before a fire kindled by the *electrified bottle*: when the health of all the famous electricians in *England*, *Holland*, *France*, and *Germany* are to be drank in *electrified bumpers*, under the discharge of guns from the *electrical battery*.

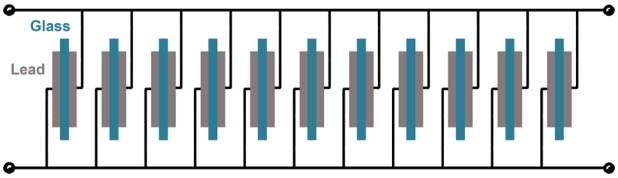

Fig. 10. ***Diagram of Franklin's eleven-capacitor electrostatic battery. Illustration created by the author.***

There are two noteworthy innovations in Franklin's letter. First, some historians have alleged that Gralath referred to his multiple-jar devices as "electrical batteries" [16], [17], when in fact no one before Franklin used that designation or any designation other than some version of "multiple-jar device." Second, although Franklin used Leyden jars to make some of his batteries, he discovered that the "Leyden jar" did not have to be a jar at all [35]. He invented and used the much more practical glass-plate capacitor for that purpose (Fig. 10).

VI. SUMMARY

Winkler reported in 1746 that on July 28 of that year he performed an experiment with a battery of three Leyden jars on the bank of the Pleisse river, and he also described in detail a battery of five Leyden jars in parallel (Fig. 5).

Gralath reported in 1747 that in April 1746 he subjected a man to the shock from one Leyden jar, a set of two jars, and a set of three jars. He observed that the man suffered more pain as the number of jars increased. Gralath did not describe his electrostatic battery and did not indicate if he connected the jars in parallel or in series. However, his assertion that a person who held only one of the bottles of his three-jar device experienced the same sensation as a person holding an isolated single bottle implies that the jars were connected in series. W. D. Hackmann correctly asserted that Gralath connected his Leyden jars in series [15], while at least five other historians claimed that Gralath's jars were connected in parallel [13], [14], [16]–[18]. It is surprising that most historians have anointed Gralath as *the* inventor of the electrostatic battery, without giving credit to Winkler for his earlier published detailed description of a reproducible electrostatic battery. Perhaps we have here the influence of Joseph Priestley as initiator in 1769. Park Benjamin's 1898 *History of Electricity* [13] was probably the initiator for

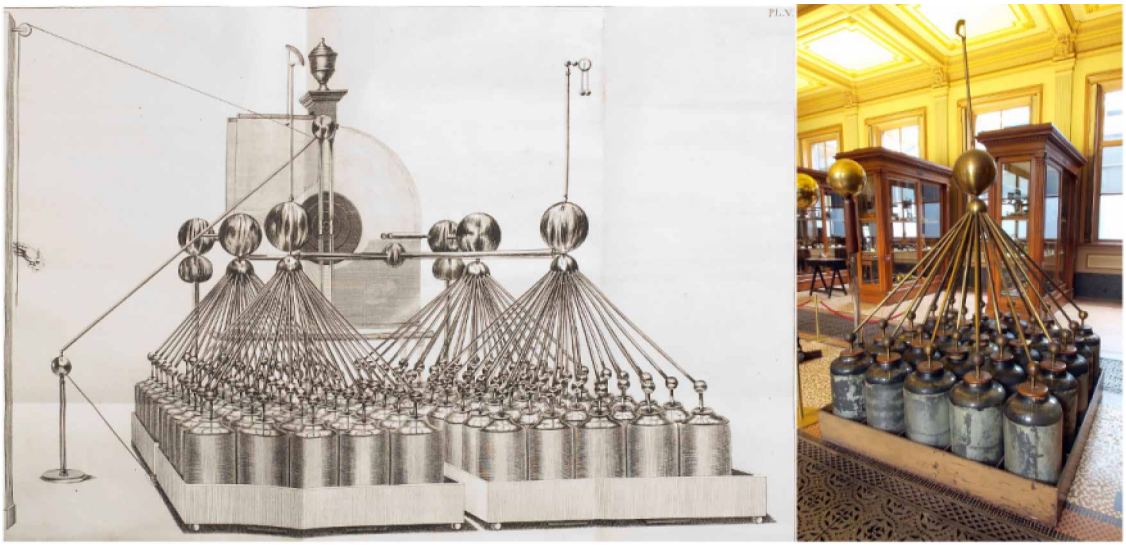

Fig. 11. *(Left) Martinus van Marum's 100-jar battery of 1790 [37]. Its size can be deduced by comparing with the hand pulling the cord. (Right) A 25-jar section of this battery, on display at the Teylers Museum in Haarlem, The Netherlands (photo from Wikimedia Commons, courtesy of AlfvanBeem).*

various later narratives which claimed that Gralath invented a battery of Leyden jars in parallel [14], [16]–[18].

As for Franklin, he reported in 1749 that he had constructed and used electrostatic batteries in 1748, he described the batteries in detail, and he coined the designation "electrical battery." Franklin's electrical inventions and one-fluid theory of electricity were major advances in the history of electrical science, but Franklin did not invent the earliest electrostatic battery.

There are analogies between the invention of the Leyden jar and the invention of the electrostatic battery. In both cases, there were two competing announcements very close together, and in both cases, there was one relatively slapdash inventor and one who was meticulous, but there were different credit outcomes in the two cases. Kleist's letters of November 1745 omitted crucial details which made it difficult to reproduce his Leyden jar, while Musschenbroek's letter of January 1746 was detailed enough. Be that as it may, Kleist and Musschenbroek have been generally designated as having independently invented the Leyden jar. Gralath was the slapdash inventor of an electrostatic battery while Winkler was the meticulous one. Furthermore, Winkler published his observations in 1746 and Gralath published his in 1747. Nevertheless, most historians ascribe the invention of the electrostatic battery to Gralath without mentioning Winkler's more detailed description. Why is that? I can only speculate. Perhaps Gralath's *Geschichte der Electricität* (History of Electricity), published in three installments (1747, 1754, and 1756) became more familiar to early historians than Winkler's *Die Stärke der Electrischen Kraft des Wassers in gläsernen Gefäßen, welche durch den Musschenbrökischen Versuch bekannt geworden* (The Strength of the Electric Power of Water in Glass Vessels, which Became Known Through Musschenbroek's Experiments), published in 1746.

Specifically, Priestley's 1769 book cites Gralath's *Geschichte* extensively, mentions some of Winkler's work, but does not cite Winkler's 1746 book. Furthermore, a "catalogue of books on electricity" appended in Priestley's book omits Winkler's book. It is fair to assume that Priestley was unaware of Winkler's electrostatic batteries.

Table 1 Energy Available in 18th Century Spark Discharges [36]

Date	Electrostatic generator	Electrostatic battery (number of Leyden jars)	Spark length (inches)	Voltage (volts)	Energy (joules)
1758	Cylinder machine (Franklin)	1	9	120,000	14
1773	Cylinder machine (Edward Nairne)	64	14	170,000	2,000
1790	Plate machine (van Marum)	100	24	330,000	30,000

VII. EPILOG

Table 1 shows the energy of 18th century spark discharges, using data from Bernard S. Finn's article about the output of 18th century electrostatic machines [36]. Fig. 11 shows Martinus van Marum's giant 100-jar battery of 1790, which had 550 square feet of glass [37] and yielded a spark energy of 30 000 joules. ■

Acknowledgement

The author would like to thank two reviewers and Dr. Alexander B. Magoun, Outreach Historian at the IEEE History Center, for very helpful comments and suggestions.

REFERENCES

[1] F. M. Feldhaus, *Die Erfindung der Elektrischen Verstärkungsflasche durch Ewald Jürgen von Kleist*. Heidelberg, Germany: Carl Winter's Universitätsbuchhandlung, 1903.

[2] C. Dorsman and C. A. Crommelin, "The invention of the Leyden Jar," *Janus*, vol. 46, pp. 275–280, 1957.

[3] D. Gralath, "Geschichte der electricität—Zweite anschnitt," *Versuche Abhandlungen Naturforschenden Gesellschaft Danzig*, vol. 2, pp. 355–460, 1754.

[4] "Schreiben das herr von kleist, decanus des domcapituls in camin [dean of the cathedral chapter in kammin] an herr swietlicki von 20 Nov, 1745," *Acta Soc. Phys. Experim. (Gdańsk)*, vol. 3, 1745, accessed: Nov. 25, 2017. [Online]. Available: http://pbc.gda.pl/dlibra/docmetadata?id=20443&from=pubindex&dirids=9&lp=1385

[5] "Letter from Pieter van Musschenbroek to René Antoine Ferchault de Réaumur, dated January 20, 1746," in *Procés Verbaux—Academie Royale des Sciences (Paris)*, vol. 65, pp. 4–6, 1746.

[6] "The translation from the Latin is a modification by the author of the one in Kevin Desmond," in *Innovators in Battery Technology*. Jefferson, NC, USA: McFarland & Company, 2016, p. 141.

[7] J. Priestley, *History and Present State of Electricity*, 2nd ed. London, U.K.: J. Dodsley, 1769, p. 86.

[8] D. Gralath, "Nachricht von einigen electrischen versuchen," *Versuche Abhandlungen Naturforschenden Gesellschaft Danzig*, vol. 1, pp. 506–534, 1747.

[9] *Encyclopaedia Britannica*, vol. 7, 4th ed. Edinburgh, Scotland: Archibald Constable Company, 1810, p. 677.

[10] "The invention of the leyden jar," *Sci. Amer.*, vol. 28, p. 177, 1873.

[11] E. Hoppe, *Geschichte der Elektrizität*. Leipzig, Germany: Johann Ambrosius Barth, 1884, p. 19.

[12] G. Albrecht, *Geschichte der Elektricität—Mit Berücksichtigung Ihrer Anwendungen*, Leipzig, Germany: A. Hartleben's Verlag, 1885, pp. 31–32.

[13] P. Benjamin, *A History of Electricity—From Antiquity to the Days of Benjamin Franklin*. New York, NY, USA: Wiley, 1898, pp. 522–523.

[14] A. Wolf, *A History of Science, Technology, and Philosophy in the Eighteenth Century*. New York, NY, USA: Macmillan Company, 1939, p. 222.

[15] W. D. Hackman, *Electricity From Glass—The History of the Frictional Electrical Machine 1600–1850*. Alphen aan den Rijn, The Netherlands: Sijthoff & Noordhoff, 1978, p. 94.

[16] J. L. Heilbron, *Electricity in the 17th and 18th Centuries—A Study of Early Modern Physics*. Berkeley, CA, USA: Univ. California Press, 1979, p. 317.

[17] H. Schlesinger, *The Battery—How Portable Power Sparked a Technological Revolution*. New York, NY, USA: HarperCollins, 2010, p. 28.

[18] M. Křepelková, "Evolution of batteries: From experiments to everyday usage," in *Proc. 21st Int. Student Conf. Elect. Eng.*, Prague, Czech Republic, May 2017, pp. 1–7.

[19] *Ref. 11*, p. 20.

[20] M. B. Schiffer, *Draw the Lightning Down—Benjamin Franklin and Electrical Technology in the Age of Enlightenment*. Berkeley, CA, USA: Univ. California Press, 2003, p. 49.

[21] W. Isaacson, *Benjamin Franklin—An American Life*. New York, NY, USA: Simon and Schuster, 2003, p. 136.

[22] J. H. Winkler, "An extract of a letter from Mr. John Henry Winkler, Graec. & Lat. Litt. Prof. publ. Ordin. at Leipsick, to a friend in London; Concerning the effects of electricity upon himself and his wife," *Philos. Trans. Roy. Soc.*, vol. 44, pp. 211–212, May 1746.

[23] J. H. Winkler, *Die Stärke der Electrischen Kraft des Wassers in gläsernen Gefäßen, Welche Durch den Musschenbrökischen Versuch Bekannt Geworden* (The Strength of the Electric Power of Water in Glass Vessels, which Became Known Through Musschenbroek's Experiments), Leipzig, Germany: Bernhard Christoph Breitkopf, 1746.

[24] Accessed: Nov. 26, 2017. [Online]. Available: https://www.physgeo.uni-leipzig.de/fakultaet/geschichte

[25] Accessed: Nov. 26, 2017. [Online]. Available: http://bach-cantatas.com/BWVAnh18.htm

[26] T. D. Lockwood, "Earth wires; or, the earth as an electric circuit completer," *Trans. Amer. Inst. Elect. Eng.*, vol. 1, no. 1, pp. 75–84, Oct. 1884.

[27] M. North, *Material Delight and the Joy of Living: Cultural Consumption in the Age of Enlightenment in Germany*. Aldershot, U.K.: Ashgate Publishing Limited, 2008, p. 83.

[28] F. Schumann, "Der Bürgermeister daniel gralath, der stifter der naturforschenden gesellschaft in danzig," *Schriften der Naturforschenden Gesellschaft Danzig*, vol. 6, no. 4, pp. 192–205, 1887.

[29] H. Strehlau, "Bürgermeister daniel gralath (1708-1767) als begründer der naturforschenden gesellschaft zu danzig," *Arch. Sippenforschung Alle Verwandten Gebiete*, vol. 28, pp. 315–318, 1962.

[30] *Ref. 8*, pp. 519–522.

[31] B. Franklin, *The Life of Benjamin Franklin, Written Chiefly by Himself*. Philadelphia, PA, USA: M. Carey, 1817.

[32] R. W. Clark, *Benjamin Franklin—A Biography*. New York, NY, USA: Random House, 1983.

[33] W. Smith, *Eulogium on Benjamin Franklin, LL. D., President of the American Philosophical Society, &c. &c.* London, U.K.: T. Cadell, 1792.

[34] B. Franklin, "Further experiments and observations in electricity," in *Experiments and Observations on Electricity Made at Philadelphia in America*, 5th ed. London, U.K.: F. Newberry, 1774, pp. 21–38.

[35] B. S. Finn, "Franklin as electrician," *Proc. IEEE*, vol. 64, no. 9, pp. 1270–1273, Sep. 1976.

[36] B. S. Finn, "Output of eighteenth-century electrostatic machines," *Brit. J. Hist. Sci.*, vol. 5, no. 3, pp. 289–291, 1971.

[37] M. van Marum, *Tweede Vervolg der Proefneemingen Gedaan Met Tyler's Electrizeer-Machine*, Haarlem, The Netherlands: Johannes Jacobus Brets, 1795, ch. 1, pp. 194–223.

ABOUT THE AUTHOR

Adam Allerhand is Professor Emeritus of Chemistry at Indiana University. He is the author of about 100 research papers, most of them in the field of nuclear magnetic resonance spectroscopy. Recently, he is the author of *An Illustrated History of Electric Lighting* (Bloomington, IN, USA: Bez Bujda Press, 2016).