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The Art of Making Leyden Jars and Batteries According to Benjamin Franklin

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Abstract

The Leyden jar was arguably the most important instrument for electrical experiments in the second half of the 18th century, and Benjamin Franklin's fame as a natural philosopher was based largely on his explanation of how it worked. In two remarkable letters written in the 1750s to scholars in Boston, Franklin offers instruction on the making of Leyden jars and assembling them into batteries. The letters also illustrate the challenges of getting and maintaining natural philosophical apparatus in colonial America, and a culture of recycling goods in order to make do.

In the 1750s, Benjamin Franklin sent supplies and instructions for making Leyden jars to James Bowdoin, a Boston merchant and statesman interested in natural philosophy,[1] and to John Winthrop, Hollis Professor of Mathematics and Natural Philosophy at Harvard College. Given the importance of Leyden jars to the development of Franklin's own electrical theory, we are curious to know how Franklin made his own and what his recommendations might have been. The letters also illustrate the culture of repurposing goods and bricolage that was part of early modern science, particularly in the American colonies.[2]

[1] James Bowdoin (1726-1790) was elected to the Massachusetts House of Representatives in 1753 and in 1757 began decades of service in the Council. His later leadership positions included governorship of the Commonwealth of Massachusetts in 1785-1787. Gordon E. Kershaw, "Bowdoin, James," *American National Biography Online*, Feb. 2000, http://www.anb.org/articles/01/01-00089.html.

[2] Sara J. Schechner, "Boston Electric: Making Do with 'Mail Order' and Recycled Goods for Teaching and Research at Colonial Harvard," in *Oxford Handbook of History and Material Culture: World Perspectives* (Oxford: Oxford University Press, forthcoming 2016).

What Is a Leyden Jar?

Devised in 1745 independently by Ewald Jürgen von Kleist in Pomerania and Pieter van Musschenbroek in Leiden, the Leyden jar was a device that stored and condensed electricity in order to have a good, strong supply of it for experiments. An early form was simply a glass flask filled with water and held in the hand of an assistant who was grounded. The jar was electrified by a wire with one end dipped into the water and the other connected to the prime conductor of an electrical machine. If the person holding the jar also touched the wire leading into it, he received a strong shock. The water in the glass jar was soon replaced by metal in the form of lead shot, crumpled gold foil, or an interior coating of lead or tin foil. The assistant's hand was replaced by a foil coating on the jar's exterior. The early jars were made from ready-to-hand, narrow necked, glass bottles like those used for medicines. In the 1760s, however, many European experimenters began to use a common design. It was a purpose-made, wide-mouthed glass jar with tin foil coating the lower two-thirds of its exterior and interior. The jar had a tight-fitting, mahogany lid through which a brass conducting rod extended. The lower end of the rod was connected to the tin foil inside the jar by means of a hanging brass chain, or sometimes by water.[3] An array of interconnected Leyden jars could be charged and discharged simultaneously, thereby offering increased power to the experimenter. Benjamin Franklin coined the term "electrical battery" in 1748 to describe the combined instruments, perhaps because the array reminded him of a military unit of gunners and artillery pieces combined for action.[4] Today, we consider the Leyden jar a type of capacitor, but still refer to electrical batteries.

Leyden jars were deployed long before their operation was understood. In Franklin's day, the nature of electricity was an open question. Natural philosophers debated whether electricity was an exhalation, a spirit, an imponderable fluid, or some kind of fire. Electricity could cause attraction and repulsion of bits of paper and gold leaf, sparks of light and luminous halos, snapping and crackling sounds. It could be transferred and bottled, but the Leyden jar was a

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[3] Willem D. Hackmann, *Electricity from Glass: The History of the Frictional Electrical Machine, 1600-1850* (Alphen aan den Rijn: Sijthoff & Noordhiff, 1978), chap. 5; J.L. Heilbron, *Electricity in the 17th and 18th Centuries* (Berkeley: University of California Press, 1979), chaps. 13 and 14.

[4] Benjamin Franklin to Peter Collinson, 1748, published in Benjamin Franklin, *Experiments and Observations on Electricity, Made at Philadelphia in America* (London, 1751), 26: "We made what we call'd an *electrical-battery*, consisting of eleven panes of large sash-glass, arm'd 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." Note that the first electrical battery was made of recycled window glass.

puzzle. Since the type of electricity inside a charged jar was opposite to that on its outer foil, there appeared to be two kinds of electricity. Franklin solved the conundrum with the idea that electrical charge was conserved. Every object had a natural amount of a single "electrical fluid". When two bodies were rubbed together—such as a cushion against the spinning glass globe of an electrical machine—one received fluid from the other and became positively charged, while the deficient body became negatively charged. If the positive fluid supply were conducted into a Leyden jar, its repulsive force acted through the glass wall to drive off an equal amount of electrical fluid from the outer foil coating into the ground. The result was a Leyden jar whose interior conductor was positively charged and its external conductor negatively charged. No fluid was created nor destroyed, but simply transferred from one body to another. Nature wanted to restore the balance, so charge always flowed from the positive to the negative body. This led to Franklin's lightning experiments and his study of atmospheric electricity, which not only proved that electricity was as much a part of the physical world as gravity, light, and heat, but also led to the useful invention of the lightning rod.[5]

Making Do in New England

Getting one's hands on electrical apparatus in the mid-18th century in colonial North America was difficult. Because of the British policy of forced dependency known as mercantilism, Boston had no local glass manufactories nor did it have philosophical instrument makers who made and sold electrical apparatus. Philadelphia had access to bottles made by the Wistarburgh Glassworks in New Jersey at this time, but like Boston, it also had no local, commercial, philosophical instrument makers. Those wanting to study electricity could write to London for apparatus made by George Adams, Edward Nairne, Benjamin Martin, or Peter Dollond, but the time and expense of importing apparatus meant that colonists often chose to make do with whatever came to hand. There was a lot of trading, recycling, and sharing.[6]

This is seen in the first letter, which Benjamin Franklin in Philadelphia wrote to James Bowdoin on April 12, 1753:[7]

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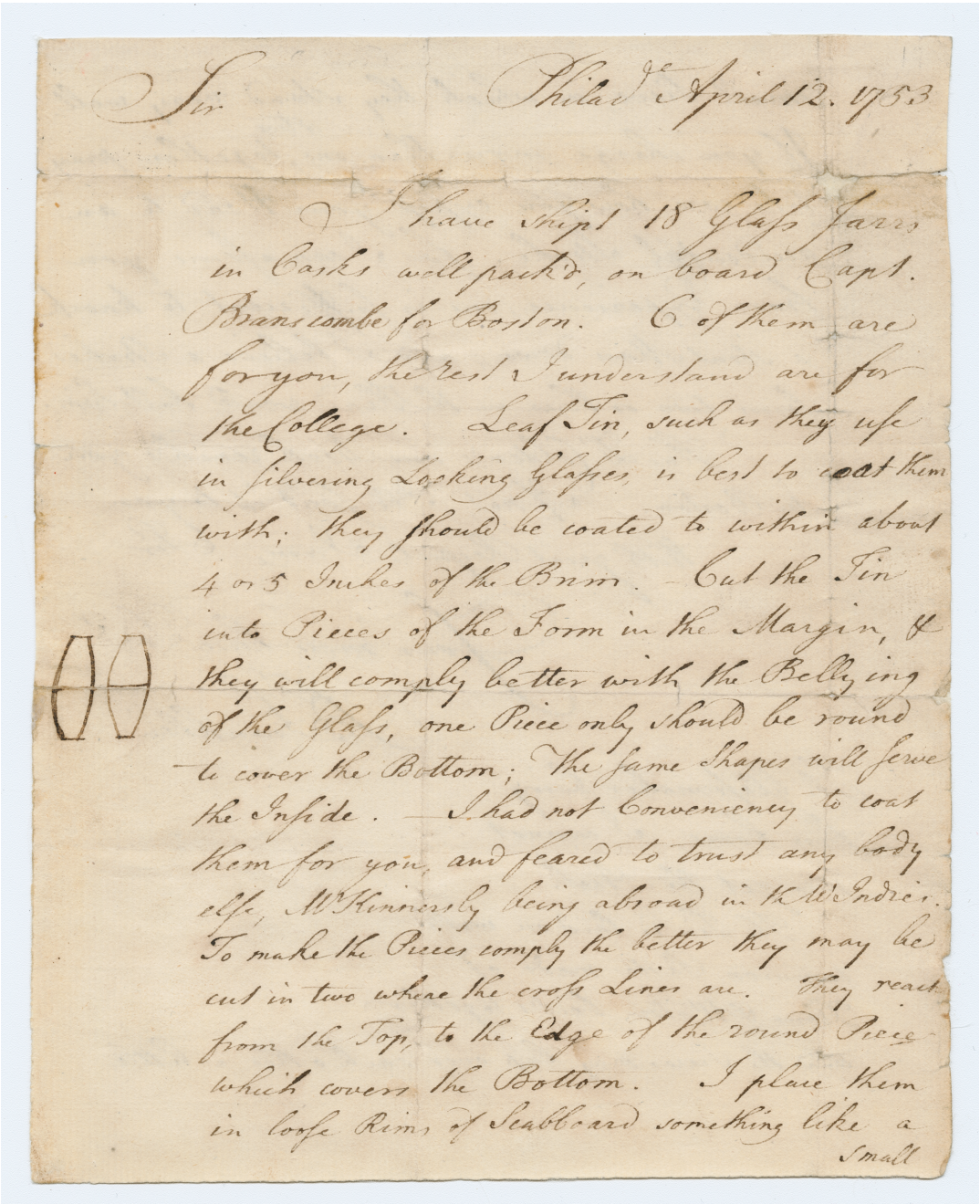
[5] Benjamin Franklin, *Benjamin Franklin's Experiments; a New Edition of Franklin's Experiments and Observations on Electricity*, ed. I. Bernard Cohen (Cambridge: Harvard University Press, 1941); I. Bernard Cohen, *Benjamin Franklin's Science* (Cambridge: Harvard University Press, 1996), 10.

[6] Schechner, op. cit., ref. 2.

[7] Benjamin Franklin to James Bowdoin, Philadelphia, 12 April 1753, Bowdoin and Temple Papers within the Winthrop Family Papers, Massachusetts Historical Society; printed in *The Papers of Benjamin Franklin* (New Haven: Yale University Press, 1959 -) **4**, 462-463.

I have shipt 18 Glass Jarrs in Casks well pack'd, on board Capt. Branscombe for Boston. 6 of them are for you, the rest I understand are for the College. Leaf Tin, such as they use in silvering Looking Glasses, is best to coat them



Sir Philad.a April 12. 1753

I have shipt 18 Glass Jarrs in Casks well packd, on board Capt. Branscombe for Boston. 6 of them are for you, the rest I understand are for the College. Leaf Tin, such as they use in silvering Looking Glasses, is best to coat them with; they should be coated to within about 4 or 5 Inches of the Brim. Cut the Tin into Pieces of the Form in the Margin, & they will comply better with the Bellying of the Glass, one Piece only should be round to cover the Bottom; the same Shapes will serve the Inside. I had not Convenience to coat them for you, and feared to trust any body else, M.r Kinnersly being abroad in the Indies. To make the Pieces comply the better they may be cut in two where the cross Lines are. They reach from the Top, to the Edge of the round Piece which covers the Bottom. I place them in loose Rims of Scabboard something like a Small

Fig. 1 In the margin of a letter, Benjamin Franklin drew a pattern for cutting tin foil before applying it to the inside of a Leyden jar. Benjamin Franklin to James Bowdoin, Philadelphia, 12 April 1753, Bowdoin and Temple Papers within the Winthrop Family Papers, Collection of the Massachusetts Historical Society.

> with; they should be coated to within about 4 or 5 inches of the Brim. Cut the Tin into Pieces of the Form in the Margin [fig. 1], and they will comply better with the Bellying of the Glass, one Piece only should be round to cover the Bottom; the same Shapes will serve the Inside. I had not Conveniency to coat them for you, and feared to trust any body else, Mr. Kinnersly[8] being abroad in the W Indies.

After apologizing for sending a do-it-yourself project, Franklin continued:

> To make the [leaf tin] Pieces comply the better they may be cut in two where the cross Lines are. They reach from the Top, to the Edge of the round Piece which covers the Bottom.

A postscript to the letter added a recipe for glue:

> The Tin is laid on with common Paste made of Flour and Water boil'd together and the Pieces may lap over each other a little.

Franklin also offered instructions on how to arrange multiple jars in a box to form a battery:

> I place them in loose Rims of Scabboard [thin slips of wood used by printers to justify type] something like a small sieve, in which they stand very well.

Franklin then cautioned:

> If you charge more than one or two together, pray take care how you expose your Head to an accidental Stroke; for I can assure you from Experience, one is sufficient to knock a stout Man down; and I believe a Stroke from two or three in the Head, would kill him.

Indeed! And there was a second postscript: "The Glassmaker being from home, I cannot now get the Account."

This last line tells us two things: first, that Franklin expected to be reimbursed, but kindly sent the materials on ahead; and second, that the glassmaker was local. This person would have been Richard Wistar, who had inherited the glass foundry of his father, Caspar Wistar, in 1752. The foundry was in Salem County, New Jersey, but Wistar lived in Philadelphia and sold American-made glass from his house.[9]

From Franklin's letter we also learn that the jars were rounded and bulging. The leaf tin was

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[8] Ebenezer Kinnersley was Franklin's friend and collaborator in electrical experiments. In 1749, he embarked on a twenty-five year career as an itinerant lecturer on electricity.

[9] Richard Wistar, "Made at the subscriber's glass works, now on hand, and to be sold at his house in Market-street, opposite the Meal-market," *Pennsylvania Chronicle*, (July 27-31, 1769) **3**, issue 27, p. 222.

shaped to accommodate the "Bellying of the Glass." The bottles were likely a type of wine bottle of dark green glass with a long neck, but they could have been pharmaceutical bottles, often referred to as phials, with shorter necks.[10]

Fig. 2 Bottles of various shapes in the mid-18th century (from left to right): a rounded bottle or phial, a wine bottle, and a case bottle. Artwork by the author.

Fig. 3 Leyden jar made out of a wine bottle, English?, circa 1785. Collection of Historical Scientific Instruments, Harvard University, DW0020.

[10] Leyden jar made from a wine bottle, English?, ca. 1785, Collection of Historical Scientific Instruments, Harvard University, DW0020, http://waywiser.rc.fas.harvard.edu/view/objects/asitem/items$0040:13684; "Richard Wistar Bottle," Corning Museum of Glass, http://www.cmog.org/video/richard-wistar-bottle; and elsewhere online; for British bottles, see "Bottles, 17th and 18th century," http://archive.museumoflondon.org.uk/ceramics/pages/category.asp?cat_id=948; Ivor Noël Hume, *A Guide to Artifacts of Colonial America,* Philadelphia: University of Pennsylvania Press, (2001), 60-76.

Professor Winthrop must have been pleased to have a new set of Leyden jars, even if he had to coat them himself, but he reported that their quality was not very good. The problem was that Wistarburgh crown glass was produced using the old forest glass formula, making it green and impure. It was highly unsuitable for Leyden jars, which in Europe were made from clear flint glass.[11] In late December 1757 or early January 1758, he wrote to Thomas Hubbard, Harvard's treasurer and at this time Speaker of the Massachusetts House of Representatives. Winthrop observed that "the electric globes which were sent us some years ago from Pennsylvania breaking almost as soon as we fitted them on their wooden caps, Mr. Franklin was so kind as to give us encouragement that he would send the College some others from London;….The pint & quart phials, which were sent us at the same time, are rather too thick; so that they don't admit of a very high Charge; and our large Jars are exceeding[ly] apt to crack, so that we lose them frequently." Winthrop wanted Hubbard to get in touch with Franklin in London and solicit his help. And, when he did, he should ask "whether instead of such large Jars, it would not be better to have square bottles, of a moderate size, fitted in a wooden box, like what they call *case bottles* for spirits; and to make them without Necks & open at the top, so that they might be lined with tin foil on the inside, as well as coated on the outside, (as the Jars are), & of a sufficient thickness round the mouth to strengthen them?" Winthrop continued, "The advantages of this construction would be, that one might have a good deal of surface in a small compass, that one might electrify one or more of these bottles at pleasure, by a single wire coming down from the prime conductor, with chains; that they would stand more secure from accidents; & might be safely moved from place to place, upon occasion."[12]

Hubbard forwarded Professor Winthrop's memorandum to Harvard's London agent, the merchant Joseph Mico, who contacted Franklin in London.[13] By April 1758, Franklin had procured the fittings to make a 35-jar battery of case bottles just as Winthrop suggested.[14] This included not only the glass jars and a mahogany crate, but also 4 lbs. 12 oz. tin foil, wire, and

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[11] Sara J. Schechner, "Glass and Power: Sourcing Scientific Glass in North America, 1600-1850," work-in-progress.

[12] John Winthrop's proposal respecting electrical globes and jars, ca. 1758, Harvard University Archives, UAI 15.1068, http://pds.lib.harvard.edu/pds/view/51416476.

[13] Thomas Hubbard to Joseph Mico, January 23, 1758, letter enclosing a copy of Winthrop's memorandum. The letter is reported in the reply, Joseph Mico to Thomas Hubbard, London, May 13, 1758, Harvard College Papers, 1st series, vol. **1**, item 194, Harvard University Archives, UAI 5.100.

[14] Benjamin Franklin to Thomas Hubbard, Harvard's treasurer, London, 28 April 1758, Benjamin Franklin Letters, 1755-1764, Houghton Library, Harvard University, MS Am 1310; printed in *Papers of Benjamin Franklin*, **8**: 51-53.

wooden stoppers, which he had personally prepared for Winthrop's use.[15] This battery was not an off-the-shelf product purchased from one of London's instrument makers, but state-of-the-art research apparatus in which Franklin and Winthrop collaborated on the design and construction.

Franklin delivered the goods to Mico, who reimbursed him £10 3*s*. 7*d.* for his purchases. The costs relating exclusively to the Leyden jar battery were:

an Electrical Case, with 35 Glass Bottles, & handles &c… 6. 6. _
4lb 12oz Foyle ……at d18….. __. 7. 1
Wire ……..….. __. 1.6

On May 13, 1758, after shipping the goods onboard the *America*, Mico forwarded the bill of lading to Hubbard.[16] He also enclosed the following letter that Franklin had written to Hubbard, which contained instructions to be passed on to Professor Winthrop:[17]

London April 28th. 1758

Sir/

In pursuance of Mr. Winthrop's memorandum, which I lately rece'd from you, thro' the hands of Mr. Mico, I have procured & delivered to him the follow[in]g things, viz.

A Mahogany Case lined with lead contain[in]g 35. Square Glass Bottles, in 5 Rows, 7 in a Row.

A Glass Globe of the Same Size & Kind with that I used at Philadelphia and Mounted in the Same manner.

A large Glass Cylinder mounted on an Iron Axis with brass Caps, this form being most used here & thought better than the Globe as a long narrow Cushion will Electrify a greater surface at the same time.

The Bottles have Necks, which I think better then to be quite open, for so they would either be exposed to the dust & damp of the Air, if they had no Stoppers or the Stoppers would be too near together to admit of electrifying a single Bottle, or Row of Bottles, there is only a little more deficulty in lining the Inside with Tinfoil, but that is chiefly got over, by cutting it into narrow Stripes, & guiding them in with a Stick flatt at one end to apply the more conveniently, the pasted Side to the Glass; I would have coated them myself if the time had not been too short; I send the Tinfoyl which I got made of a proper

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[15] "Invoice of the following Goods Shipt on board the America Robt Smith Masr bound for Boston in New England on the proper Accot. of The President and Fellows of Harvard College, London, 13 May 1758." Harvard College Papers, 1st series, 1636-1825, 1831, vol. **1**, item 195, Harvard University Archives, UAI 5.100.

[16] Joseph Mico to Thomas Hubbard, London, May 13, 1758, stating that he had now paid Franklin and shipped the "Electrifying Instruments." Harvard College Papers, 1st series, vol. **1**, item 194, Harvard University Archives, UAI 5.100. "Invoice of …Goods Shipt on board the America," 13 May 1758.

[17] Benjamin Franklin to Thomas Hubbard, Harvard's treasurer, London, 28 April 1758.

breadth for the purpose. They should be coated nine Inches high which brings the Coating just even with the edge of the Case, the Tinfoyl is 10 Inches broad, which allows for lapping over the bottom.

I have bored the holes in all the Stoppers for the communicating Wires, provided all the Wires, & fixed one or two to show the manner, Each Wire to go into a Bottle, is bent so that the two ends go in & spring against the Inside Coating or Lining. The middle of the Wire goes up into the Stopper with an Eye, thro' which the long communicating Wires pass that connect all the Bottles in one Row.

To form occasional Communications with more Rowes, there must be on the long Wires of the 2nd. & 4th. Rows, four other moveable Wires, which I call Cross Wires about 2½ Inches long with a small Ball of any Metal about the size of a Pistol Bullet at each end, the Ball of one end to have a hole thro' the middle, so that it may be slipt on the long wire, & one of these Cross Wires is to be placed between the 3d. & 4th. Bottles of the Row at each end, & on each of the above mention'd Rows, that is, two to each Row, they must be made to turn easy on the Wires so that when you would charge only the middle Rowe, you turn two of them back on the first, & two on the fifth Rows, then the middle Row will be unconnected with the others, when you would charge more Rows you turn them forwards or backwards so as to have the communication compleated with just the number of Rows you want.

The Brass handles of the Case communicate with the outside of the Bottles when you want to make the Electrical Circuit.

I see now I have wrote it, that the greatest part of this Letter, would have been more properly addressed to Mr. Winthrop himself, but probably you will send it him with the things, & that will answer the end. Be pleased to tender my best Respects to him & the rest of the Gentlemen of the College. I am with great Esteem & Regard.

Sir, Your most obed[ien]t hum[b]le Serv[an]t
B. Franklin

P. S. I beg the College will do me the favour to accept a Virgil I send in the Case, thought to be the most curiously printed of any Book hitherto done in the World.[18]

To Thomas Hubbard Esqr
Boston
Endorsed: From B. Franklin Esqr
April 28th. 1758
Dr. 70

[18] The book was John Baskerville's edition of *Virgil, Bucolica, Georgica, et Aeneis* (Birmingham, 1757), which is still in Houghton Library, *AC7.F8545.Zz757v.

When assembled the battery probably looked like the 35-jar battery associated with Franklin that is now at the American Philosophical Society in Philadelphia.[19] The conducting wire of each Leyden jar was doubled over inside the stopper. The two legs exiting the stopper were bent to form an inverted "V" so that each leg was sprung against the coated interior of a bottle. This avoided the use of a chain that hung down from the conductor to the floor of the bottle. The doubled-over wire inside the stopper was pressed tightly against a brass rod that went through the eye of the stopper and linked all bottles in the row. Along the connecting rods of the second and fourth rows were four switches. Called "cross wires" by Franklin, the switches were short

Fig. 4 Battery of 35 Leyden jars in a mahogany case (14 x 18 x 13 inches), made of English materials by or for Benjamin Franklin, after 1758. Instrument: glass and metal; box: wood. Courtesy of American Philosophical Society. Gift of Joseph Hopkinson, 1836.

brass rods with a metal ball at each end. One terminal ball on each switch was pierced, enabling it to slide onto a long, row-connecting rod and rotate at right angles to it. The other terminal ball was a weight to bring the switch down against the long rod in an adjacent row. By rotating the four switches, the user could decide whether to charge one to five rows of Leyden jars in the battery.

It appears that none of the Leyden jars made of the dark green Wistarburgh glass bottles or the clear English case bottles survive today at Harvard, but these letters give us a sense of what they looked like and the challenge of making and working with them. From the time of Winthrop's

[19] Electrical battery of 35 bottles, English materials, after 1758, each bottle 12.25 x 2 x 2 inches; case 13 x 18 x 14 inches (HxWxD), American Philosophical Society, 58-36. This battery was allegedly used by Franklin and willed by him to Francis Hopkinson, whose son donated it to the APS in 1836. Franklin would have had it made to his specifications while in London.

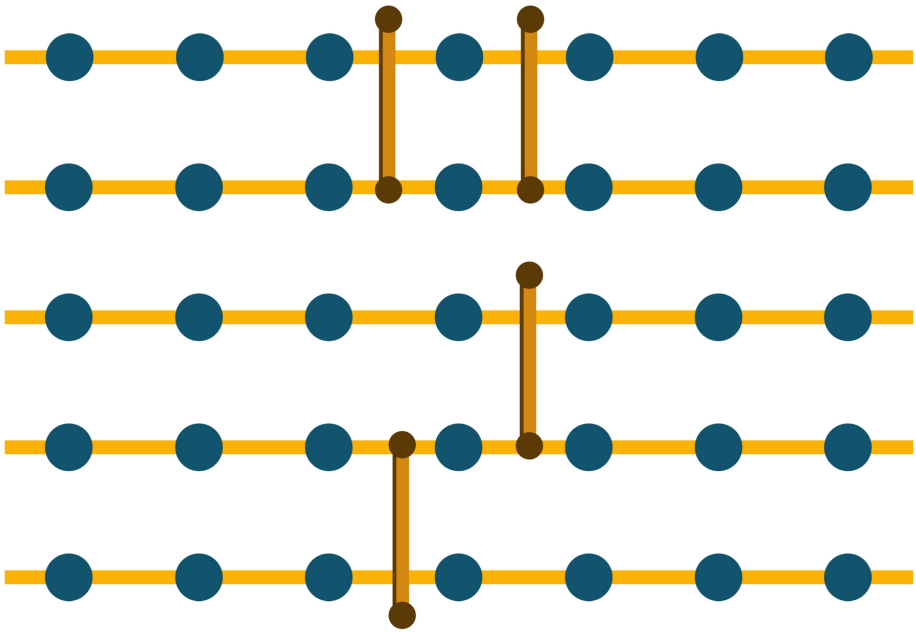

Fig. 5 Schematic diagram of the connecting rods and switches on Franklin's 35-jar battery, as seen from above. Each blue circle represents the pierced wooden knob on the lid of a Leyden jar. The long golden lines represent the brass conducting rods that pass through the knobs of every jar in a row. The short cross bars represent the switches that have been slid onto the rods of the second and fourth rows and freely rotate around them. In the positions shown, the switches are set for the user to charge either the top two rows or the bottom three rows of jars. Artwork by the author.

writing his memorandum to Franklin, reminding him of his kind promise to send glass from London, until the date that the shipment arrived, more than six months had passed. If we consider that the Franklin's offer had been made about four years before that, we see that natural philosophy by "mail order" was of necessity a leisurely pursuit by elite members of colonial American society so far removed from the intellectual and commercial metropolis.