Franklin and Electrostatics-
Ben Franklin as my Lab Partner

A Workshop on Franklin's Experiments in Electrostatics

Developed at the Wright Center for Innovative Science Teaching
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Part IV. Further experiments on the Leyden jar described in letter to Peter Collinson

Experiments which dissect the Leyden jar and show the importance of the dielectric. Construction of a flat plate capacitor, the magical picture and two forms of electrostatic motor.

Letter IV. Benjamin Franklin to Peter Collinson

April 29, 1749 *Bigelow vol II. p. 237-253*

4.01
TO PETER COLLINSON
PHILADELPHIA,__, 1748
SIR:

§ 1. There will be the same explosion and shock if the electrified phial is held in one hand by the hook and the coating touched with the other, as when held by the coating and touched at the hook.

4.02

2. To take the charged phial safely by the hook, and not at the same time diminish its force, it must first be set down on an electric *per se*.[insulator]

An"electric *per se*" is an insulator. Franklin often used a piece of wax. We will use foam plastic cups.

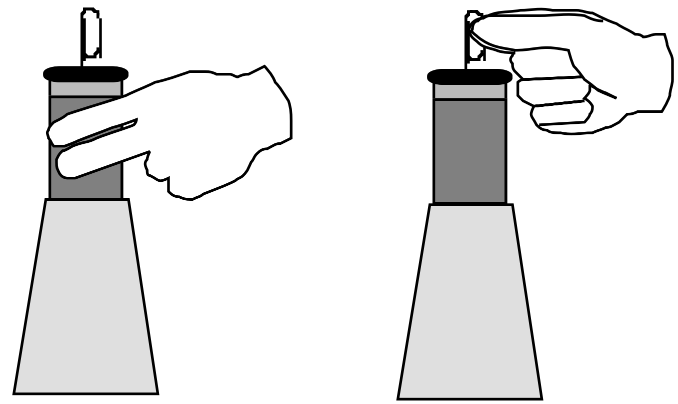
4.03

3. The phial will be electrified as strongly, if held by the hook and the coating applied to the globe or tube as when held by the coating and the hook applied.[1]

[1] This was a discovery of the very ingenious Mr. Kinnersley, and by him communicated to me.–F.

4.04

4. But the *direction* of the electrical fire, being different in the charging, will also be different in the explosion. The bottle charged through the hook will be discharged through the hook; the bottle charged through the coating will be discharged through the coating, and not otherways, for the fire must come out the same way it went in.



Set it down on a foam cup, pick it up by the wire, then touch the outside foil.

Franklin makes this point from his theory, although there is a difference in the appearance of the 'corona discharge' from points for positive and negative charges, which he alludes to in a later letter. (See extract below and the figure in Section VIII) In 4.05 he proposes his clever test of this idea.

You can test this directly with the neon bulb. Charge the jar by holding the outside and touching the clip to the positive terminal of your machine. Watch the neon flash. Then hold the jar by the clip and touch the outside to the machine. Test again with the bulb. What do you find?

Excerpt of letter to E. Kinnersley, Bigelow Vol II, p. 366 Morse p 74:

2. I observe that the stream or brush of fire appearing at the end of a wire connected with the conductor, is long, large and much diverging, when the glass globe is used, and makes a snapping (or rattling) noise; but when the sulphur one is used, it is short, small, and makes a hissing noise... When the brush is long, large, and much diverging, the body to which it joins seems to me to be throwing the fire out; and when the contrary appears, it seems to be drinking in.

4.05

5. To prove this, take two bottles that were equally charged through the hooks, one in each hand; bring their hooks near each other, and no spark or shock will follow, because each hook is disposed to give fire and neither to receive it. Set one of the bottles down on glass, take it up by the hook, and apply its coating to the hook of the other, then there will be an explosion and shock, and both bottles will be discharged.

In 4.05 and 4.06, Franklin describes a clever test of the direction of charging by balancing the effects of charging and discharging two identically charged jars.

Follow his directions, using the foam cup instead of glass to set the phial on when switching from holding it by the clip and by the coating.

Do you agree with Franklin's result?

4.06

6. Vary the experiment by charging two phials equally, one through the hook, the other through the coating; hold that by the coating which was charged through the hook, and that by the hook which was charged through the coating; apply the hook of the first to the coating of the other, and there will be no shock or spark. Set that down on glass which you held by the hook, take it up by the coating, and bring the two hooks together; a spark and shock will follow, and both phials be discharged.

4.07

In this experiment the bottles are totally discharged, or the equilibrium within them restored. The *abounding* of fire in one of the hooks (or rather in the internal surface of one bottle) being exactly equal to the *wanting* of the other; and therefore, as each bottle has in itself the *abounding* as well as the *wanting*, the wanting and abounding must be equal in each bottle. See § 8, 9, 10, 11. But if a man holds in his hands two bottles, one fully electrified, the other not at all, and brings their hooks together, he has but half a shock, and the bottles will both remain half electrified, the one being half discharged, and the other half charged.

You can try the experiment in the last sentence of 4.07 either by feeling the shock, or by using a neon bulb in between the two jars and judging the brightness of the flash. Follow Franklin and try it. (You may have to repeat it several times to be sure.)

4.08

7. Place two phials equally charged on a table, at five or six inches distance. Let a cork ball suspended by a silk thread. hang between them. If the phials were both charged through their hooks, the cork, when it has been attracted and repelled by the one, will not be attracted, but equally repelled by the other. But if the phials were charged, the one through the hook and the other through the coating,[1] the ball, when it is repelled from one hook, will be as strongly attracted by the other, and play vigourously between them, fetching the electric fluid from the one, and delivering it to the other, till both phials are nearly discharged.

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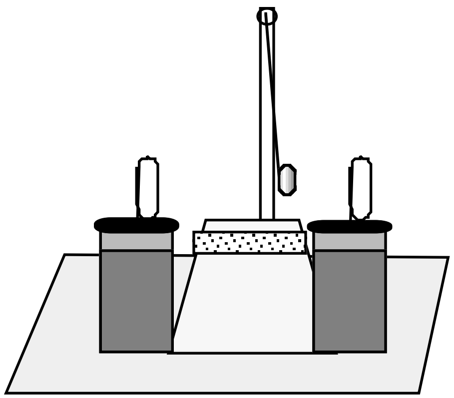
[1] To charge a bottle commodiously through the coating, place it on a glass stand; form a communication from the prime conductor to the coating, and another from the hook to the wall or floor. When it is charged, remove the latter communication before you take hold of the bottle, otherwise great part of the fire will escape by it.–F.

Use a foam cup with straw and hanging foil bit. Since most modern tables are insulators, make sure you set the Leyden jars on a sheet of foil.



4.09

8. When we use the terms of *charging* and *discharging* the phial, it is in compliance with custom, and for want of others more suitable. Since we are of opinion that there is really no more electrical fire in the phial after what is called its *charging*, than before, nor less after its *discharging;* excepting only the small spark that might be given to, and taken from, the non-electric matter, if separated from the bottle, which spark may not be equal to a five-hundredth part of what is called the explosion.

Franklin makes an excellent point here, one that is still relevant today. We say a dry cell or chemical battery is ‘charged’ or ‘discharged’, but the amount of electrical charge in it is the same at all times. What is different is the arrangement of the charges which determines how much electrical energy is stored. At the time Franklin was writing, the ideas of energy were still very poorly defined.

4.10

For if, on the explosion, the electrical fire came out of the bottle by one part, and did not enter in again by another, then, if a man, standing on wax, holding the bottle in one hand, takes the spark by touching the wire hook with the other, the bottle being thereby *discharged*, the man would be *charged*; or whatever fire was lost by one, would be found in the other, since there was no way for its escape; but the contrary is true.

4.11

9. Besides, the phial will not suffer what is called *a charging*, unless as much fire can go out of it one way, as is thrown in by another. A phial cannot be charged standing on wax or glass, or hanging on the prime conductor, unless a communication be formed between its coating and the floor.

Support a Leyden jar on a foam cup and try to charge it without touching the coating.

Test for a spark. Compare with the charging that occurs when you hold it by the outside foil.

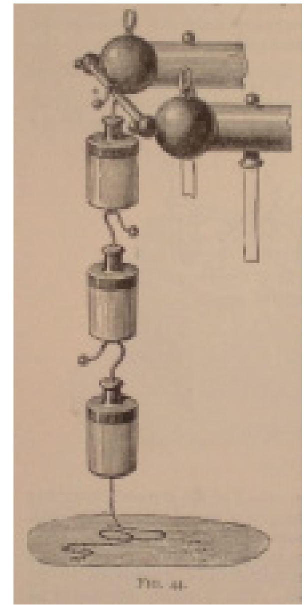
4.12

10. But 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, and 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 given 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 labor, 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.

Franklin is partly right, but incorrect on the point that all the jars could be charged with the same energy. In modern terms the maximum voltage of each jar in the series would be the maximum voltage of the generator divided by the number of jars.

To charge the jars equally to their maximum energy they should be arranged in parallel.

In his later work Franklin recognized this and used lots of jars in parallel in an arrangement he called an electric battery, illustrated at the end of this section.



A series of Leyden jars suspended from the prime conductor of a generator.
p 78, Foster, G.C., Atkinson, E, *Elementary Treatise on Electricity and Magnetism, founded on Jaubert's Traite Elementaire d'Electricite*, London, Longmans Green and Co, 1896
(public domain)

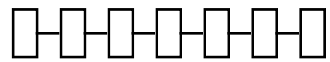
4.13

11. When a bottle is charged in the common way, its *inside* and *outside surfaces* stand ready, the one to give fire by the hook, the other to receive it by the coating; the one is full and ready to throw out, the other empty and extremely hungry; yet, as the first will not *give out*, unless the other can at the same instant *receive in*, so neither will the latter receive in, unless the first can at the same instant give out. When both can be done at once, it is done with inconceivable quickness and violence.

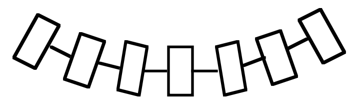
Franklin is emphasizing here that a circuit is needed for the Leyden bottle to discharge. He is recognizing that there is some form of interaction between the inner and outer coating.

4.14

12. So a straight spring (though the comparison does not agree in every particular), when forcibly bent, must, to restore itself, contract that side which in the bending was extended, and extend that which was contracted; if either of these two operations be hindered, the other cannot be done. But the spring is not said to be *charged* with elasticity when bent, and *discharged* when unbent; its quantity of elasticity is always the same.



A straight spring or beam of wood shown as a series of connected blocks.



A bent spring or beam. Note that the gaps between the blocks are smaller at the top than at bottom.

4.15

13. Glass, in like manner, has within its substance always the same quantity in proportion to the mass of glass, as shall be shown hereafter.

4.16

14. This quantity, proportioned to the glass, it strongly and obstinately retains, and will have neither more nor less, though it will suffer a change to be made in its parts and situation; that is, we may take away part of it from one of the sides, provided we throw an equal quantity into the other.

In the next several paragraphs, Franklin, giving first his conclusion, and then recounting a set of experiments that led him to that conclusion, lays out the essential theory of the Leyden jar or capacitor as it is now called. It would be about 75 years until any significant increase in understanding the role of the glass was achieved, when Michael Faraday carried out a series of investigations on the properties of insulators or dielectrics.

4.17

15. Yet, when the situation of the electrical fire is thus altered in the glass, when some has been taken from one side and some added to the other, it will not be at rest, or in its natural state, till it is restored to its original equality. And this restitution cannot be made trhough the substance of the glass, but must be done by a non-electric communication formed without, from surface to surface.

4.18

16. Thus, the whole force of the bottle and power of giving a shock is in the *glass itself;* the non-electrics in contact with the two surfaces serving only to *give* and *receive* to and from the several parts of the glass; that is, to give on one side and take away from the other.

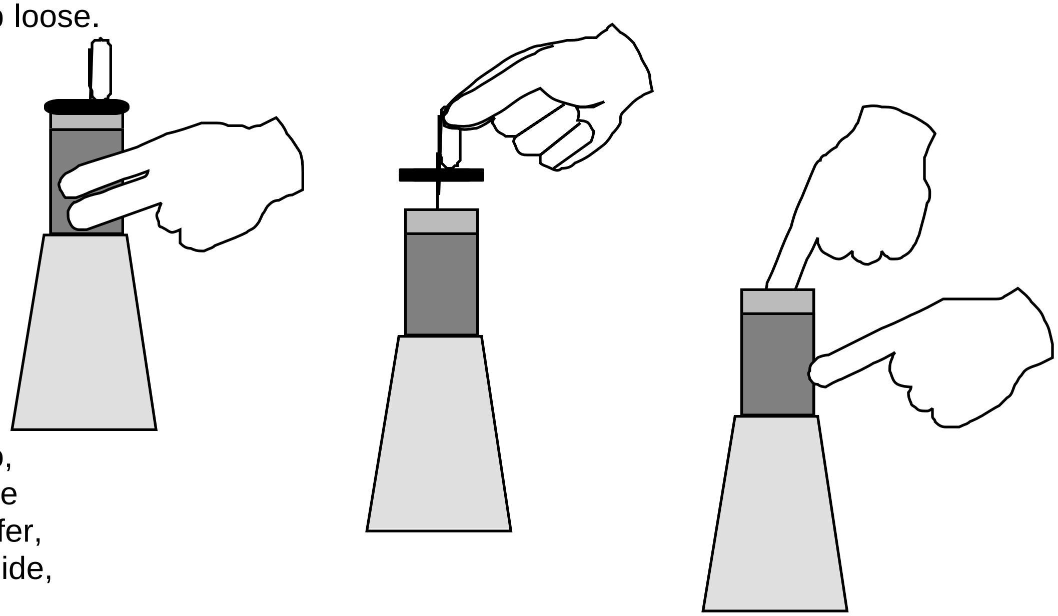
This is Franklin's conclusion- now we will follow the set of experiments. For these you will need film can Leyden jars using water for the inner conductor. and some additional water. You will also need foam cups.

The First Test- is "strength" of charge stored in the wire?

4.19a

17. This was discovered here in the following manner: purposing to analyze the electrified bottle, in order to find wherein its strength lay, we placed it on glass, and drew out the cork and wire, which for that purpose had been loosely put in. Then taking the bottle in one hand, and bringing a finger of the other near its mouth, a strong spark came from the water, and the shock was as violent as if the wire had remained in it, which showed that the force did not lie in the wire.

Before charging the jar, pop the cap loose.

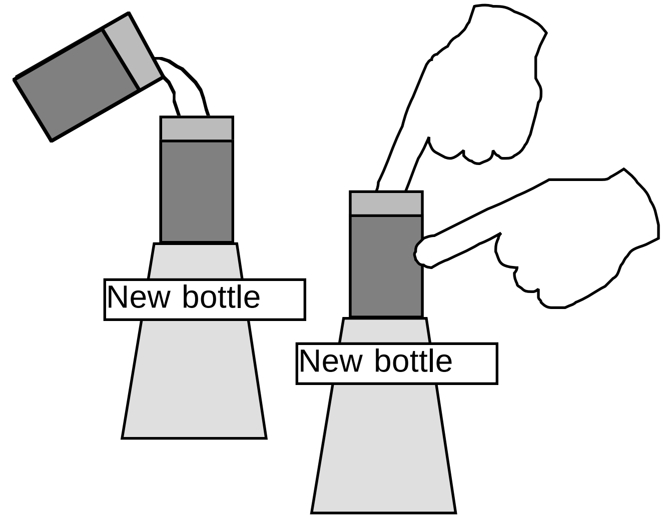


Franklin tries the possibilities- is the wire charged? If so, removing the wire should remove the charge. Follow the steps and try it–use a neon bulb to discharge if you prefer, or use the thumb and finger of one hand–thumb to outside, finger tip to water.

Second Test – is “strength” of charge stored in the water?

4.19b

Then, to find if it resided in the water, being crowded into and condensed in it, as confined by the glass, which had been our former opinion, we electrified the bottle again, and placing it on glass, drew out the wire and cork as before; then taking up the bottle, we decanted all its water into an empty bottle, which likewise stood on glass; and taking up that other bottle, we expected, if the force resided in the water, to find a shock from it; but there was none.

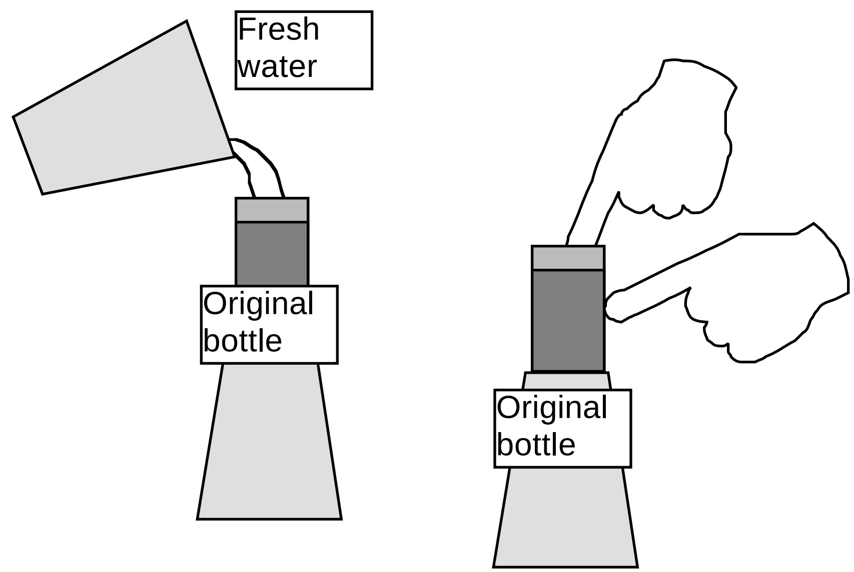


Notice the propositional reasoning that Franklin uses in his experimental arguments to support his theory:
IF the charge is stored in the water,
THEN transferring the water should transfer the charge.

Third Test – is “strength” of charge still in the original bottle?

4.19c

We judged then that it must either be lost in decanting or remain in the first bottle. The latter we found to be true; for that bottle on trial gave the shock, though filled up as it stood with fresh unelectrified water from a tea-pot.



Fourth Test – does the storage of charge depend on the shape or 'form' of the jar?

4.19d

To find, then, whether glass had this property merely as glass, or whether the form contributed any thing to it, we took a pane of sash-glass, and laying it on the hand, placed a plate of lead on its upper surface; then electrified that plate, and bringing a finger to it, there was a spark and shock.

Franklin does a quick test, using his hand as one of the conducting surfaces. I suggest a little more care.

Take a stiff 9 inch plastic picnic plate – not foam plastic, but the thinner colored plastic. Cut two circles of aluminum foil, about 6.5 inches diameter. (Template at end of section.)

Glue the foil circles to the plate, one to the top, one to the bottom, making sure they are smooth, and tight to the surface. (You will use this later to make the "Magical Picture."

Charge the plates by supporting the plate with your fingers on the inside foil, while pressing the outside foil against the terminal of your generator. You may also handle the plate by the rim where there is no foil.

Test for charge by touching the top and bottom foils with thumb and forefinger, or support the plate on a foam cup and use a neon bulb to test.

Fifth Test – does the storage of charge depend on the metal at all?

4.19e

We then took two plates of lead of equal dimensions, but less than the glass by two inches every way, and electrified the glass between them by electrifying the uppermost lead; then separated the glass from the lead, in doing which what little fire might be in the lead was taken out, and the glass being touched in the electrified parts with a finger, afforded only very small pricking sparks, but a great number of them might be taken from different places.

Cut two more circles of foil and take another plate. Use just a few spots of glue to hold the foil temporarily in place – you might leave little tabs bent up on the edges of the circles that you can use to pull the circles free of the plate.

Charge as before, then holding the plate only by the plastic rim, carefully peel off the two foil circles, one at a time.

Hold the plate by the rim in one hand. Use thumb and forefinger to lightly touch both surfaces of the plate in different places. Do you feel the 'pricking'?
(This may be hard to perceive–Franklin used a larger plate more strongly electrified.)

Fifth Test – final result

4.19f

Then dexterously placing it again between the leaden plates, and completing a circle between the two surfaces, a violent shock ensued, which demonstrated the power to reside in glass as glass, and that the non-electrics in contact served only, like the armature of a loadstone, to unite the force of the several parts, and bring them at once to any point desired; it being the property of a non-electric that the whole body instantly receives or gives what electrical fire is given to, or taken from, any one of its parts.

Movie file: 11. Conspirators or the Treason

Carefully replace the foils – smoothing first if needed – touching only one at a time until they are both in place, then test for charge, by touching one plate with your thumb and the other with the forefinger of the same hand. What do you find?

4.20

18. Upon this 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 labor 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, §10. We made also of large glass panes magical pictures and self-moving animated wheels, presently to be described.

Franklin also made electrical batteries by connecting standard Leyden bottles together in parallel arrangments–see illustration at the end of this section.

4.21

19. I perceive by the ingenious Mr. Watson's last book, lately received, that Dr. Bevis had used, before we had, panes of glass to give a shock[1] though till that book came to hand I thought to have communicated it to you as a novelty. The excuse for mentioning it here is, that we tried the experiment differently, drew different consequences from it (for Mr. Watson still seems to think the fire *accumulated on the non-electric [conductor]*, that is, in contact with the glass, p. 185), and, as far as we hitherto know, have carried it farther.

[1] I have since heard that Mr. Smeaton was the first who made use of panes of glass for that purpose.–F.

Sir William Watson was an English physician who also studied electricity. He was favorably impressed with Franklin's ideas and helped to introduce Franklin's letters to the Royal Society in London. His own theories had some similarities to those of Franklin, but were not as clearly thought out.

In spite of their differences on the correct theory, Watson promoted Franklin's writings and was instrumental in arranging the award of the Royal Society's Copley Medal to Franklin, and in having Franklin made a Fellow of the Royal Society.

SR. WM. WATSON, M.D.

William Watson
Image SIL14-W001-08a
The Smithsonian Libraries
The Dibner Library of the History of Science and Technology
Washington, DC

4.22

20. The magical picture[1] is made thus. Having a large mezzotinto with a frame and glass, suppose of the KING (God preserve him), take out the print and cut a pannel out of it near two inches distant from the frame all round. If the cut is through the picture, it is not the worse. With thin paste or gum-water, fix the border that is cut off on the inside the glass, pressing it smooth and close; then fill up the vacancy by gilding the glass well with leaf-gold or brass. Gild likewise the inner edge of the back of the frame all round, except the top part, and form a communication between that gilding and the gilding behind the glass; then put in the board, and that side is finished. Turn up the glass and gild the fore side exactly over the back gilding, and when it is dry cover it by pasting on the pannel of the picture that hath been cut out, observing to bring the correspondent parts of the border and picture together, by which the picture will appear of a piece, as at first, only part is behind the glass and part before. Hold the picture horizontally by the top, and place a little movable gilt crown on the King's head. If now the picture be moderately electrified, and another person take hold of the frame with one hand, so that his fingers touch its inside gilding, and with the other hand endeavour to take off the crown, he will receive a terrible blow and fail in the attempt. If the picture were highly charged, the consequence might perhaps be as fatal[2] as that of high treason; for when the spark is taken through a quire of paper laid on the picture by means of a wire communication, it makes a fair hole through every sheet, that is, through forty-eight leaves, though a quire of paper is thought good armour against the push of a sword, or even against a pistol bullet, and the crack is exceedingly loud. The operator, who holds the picture by the upper end, where the inside of the frame is not gilt, to prevent its falling, feels nothing of the shock, and may touch the face of the picture without danger, which he pretends is a test of his loyalty. If a ring of persons take the shock among them, the experiment is called *The Conspirators.*

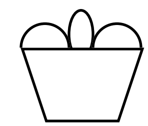
[1] Contrived by Mr. Kinnersley.–F.

[2] We have since found it fatal to small animals, though not to large ones. The biggest we have yet killed is a hen. 1750–F.

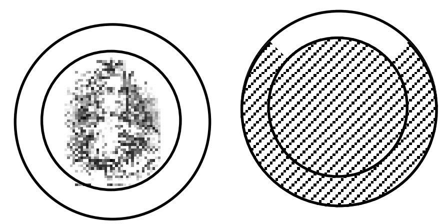
Make a copy of the picture of George II printed at the end of this section, and cut it out around the border. Cut a slit across the top where the crown sits on his hair. Take the thin 9 inch plastic picnic plate used for the previous experiments with the foil circles glued front and back. Glue the picture on top of the foil on the inside of the plate, leaving the area around the slit for the crown unglued.

Fold a piece of foil in half and in half again to get four thicknesses, and cut a crown that will fit in the slit, with a wide top so that it does not slide all the way in.

foil crown



On the back add pieces of foil on both sides, so that foil reaches the rims on both sides, but not on the top. (You may leave the bottom unfoiled if you wish.)



To charge the picture, insert the crown, and connect the crown to one terminal of your generator while connecting the foil on the back to the other

Being much smaller than Franklin's version, the shock from this version is perfectly safe, even to small animals. If you hold it by the top rim – no foil, you can safely remove the crown. Hold it by the side or bottom and you get a shock.

Although Franklin is doing serious science, it is very obvious that he is also having a great deal of fun!

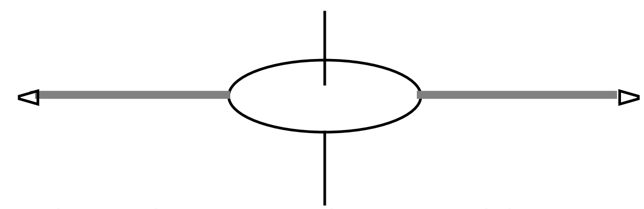
The first electric motor

4.23a

21. On the principle in §7 that hooks of bottles differently charged will attract and repel differently, is made an electrical wheel that turns with considerable strength. A small upright shaft of wood passes at right angle through a thin round board of about twelve inches diameter, and turns on a sharp point of iron fixed in the lower end, while a strong wire in the upper end, passing through a small hole in a thin brass plate, keeps the shaft truly vertical.

4.23b

About thirty *radii* of equal length, made of sash-glass cut in narrow strips, issue horizontally from the circumference of the board, the ends most distant from the centre being about four inches apart. On the end of every one a brass thimble is fixed.



A portion of the construction of Franklin's motor, showing two of the glass strips with thimbles mounted on the ends.

4.23c

If now the wire of a bottle electrified in the common way be brought near the circumference of this wheel, it will attract the nearest thimble, and so put the wheel in motion; that thimble in passing by receives a spark, and thereby being electrified is repelled, and so driven forwards, while a second being attracted approaches the wire, receives a spark, and is driven after the first, and so on till the wheel has gone once round, when the thimbles before electrified approaching the wire, instead of being attracted as they were at first, are repelled, and the motion presently ceases.

4.23c

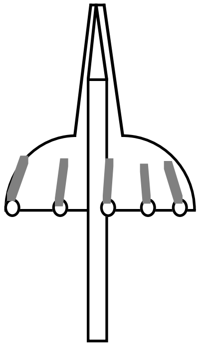
But if another bottle which has been charged through the coating be placed near the same wheel, its wire will attract the thimble repelled by the first, and thereby double the force that carries the wheel round, and not only taking out the fire that had been communicated to the thimbles by the first bottle, but even robbing them of their natural quantity, instead of being repelled when they come again towards the first bottle, they are more strongly attracted, so that the wheel mends its pace till it goes with great rapidity, twelve or fifteen rounds in a minute, and with such strength as that the weight of one hundred Spanish dollars, with which we once loaded it, did not seem in the least to retard its motion. This is called an electrical jack, and if a large fowl were spitted on the upright shaft, it would be carried round before a fire with a motion fit for roasting.

Movie file: 12. Electrostatic Motors

A simple version of Franklin' s more powerful motor can be made using four film can Leyden jars and a rotor made of a plastic champagne glass pivoted on a sharpened pencil. The reliability can be improved if a piece of card with a hole in the center is taped to the top of the glass so that the pencil goes through the card. The pencil is supported in a base of thick styrofoam, or in a hole drilled in a wood block. Place a strip of aluminum foil on the table to set the Leyden jars on.

Instead of thimbles, you may glue strips of aluminum foil at equal intervals around the cup, glue pennies to the cup, or perhaps simplest, slip 12 to 16 small brass fasteners onto the edge of the cup.

Set it up as in the pictures making sure that adjacent Leyden jars are oppositely charged. It may need a little push to start it moving, and you will need to make small adjustments to the film can positions to get smooth motion.



Plastic champagne glass pivoted on pencil point, with brass fasteners slipped on rim.

4.24a

22. But this wheel, like those driven by wind, water, or weights, moves by a foreign force, to wit, that of the bottles. The self-moving wheel, though constructed on the same principles, appears more surprising. It is made of a thin, round plate of window-glass, seventeen inches diameter, well gilt on both sides, all but two inches next the edge.

Directions for constructing a version of this motor are given on page 17 below.

4.24b

Two small hemispheres of wood are then fixed with cement to the middle of the upper and under sides, centrally opposite, and in each of them a thick strong wire eight or ten inches long, which together make the axis of the wheel. It turns horizontally on a point at the lower end of its axis, which rests on a bit of brass cemented with a glass salt-cellar. The upper end of the axis passes through a hole in a thin brass plate cemented to a long strong piece of glass, which keeps it six or eight inches distant from any non-electric, and has a small ball of wax or metal on its top to keep in the fire.

4.24c

In a circle on the table which supports the wheel, are fixed twelve small pillars of glass, at about four inches distance, with a thimble on the top of each.

4.24d

On the edge of the wheel is a small leaden bullet, communicating by a wire with the gilding of the *upper* surface of the wheel; and about six inches from it is another bullet, communicating in like manner with the *under* surface. When the wheel is to be charged by the upper surface, a communication must be made from the under surface to the table.

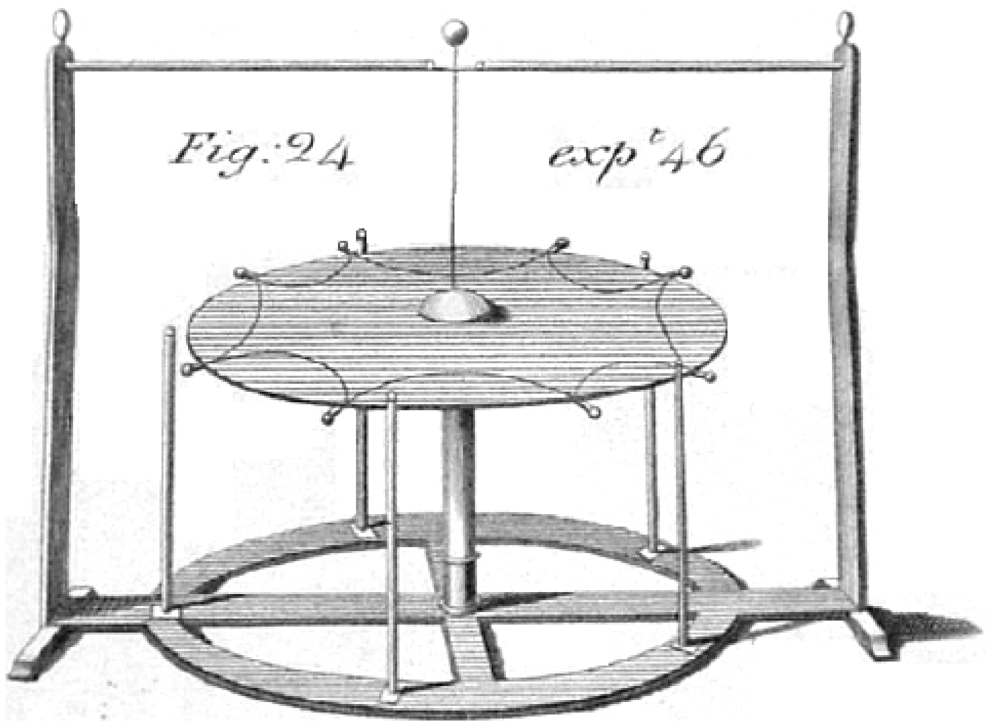
4.24e

When it is well charged it begins to move; the bullet nearest to a pillar moves towards the thimble on that pillar, and passing by electrifies it, and then pushes itself from it; the succeeding bullet, which communicates with the other surface of the glass, more strongly attracts that thimble on account of its being before electrified by the other bullet; and thus the wheel increases its motion till it comes to such a height that the resistance of the air regulates it.

4.24f

It will go half an hour, and make, one minute with another, twenty turns in a minute, which is six hundred turns in the whole; the bullet of the upper surface giving in each turn twelve sparks to the thimbles, which makes seven thousand two hundred sparks; and the bullet of the under surface receiving as many from the thimbles; those bullets moving in the time near two thousand five hundred feet. The thimbles are well fixed, and in so exact a circle that the bullets may pass within a very small distance of each of them. If, instead of two bullets, you put eight, four communicating with the upper surface and four with the under surface, placed alternately, which eight at about six inches distance completes the circumference, the force and swiftness will be greatly increased, the wheel making fifty turns in a minute; but then it will not continue moving so long. These wheels may be applied, perhaps, to the ringing of chimes,[1] and moving of light made orreries.

1 This was afterwards done with success by Mr. Kinnersley.–F.

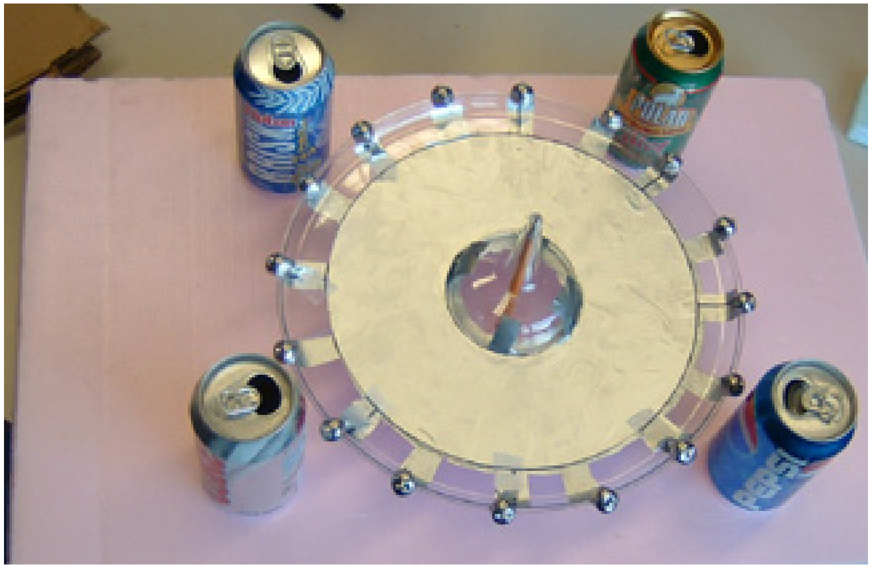


1821 Commercial version of Franklin's Self-Moving Wheel from Plate IV,
J. Cuthbertson, *Practical Electricity & Galvinism*, London, 1821
The Burndy Library, Dibner Institute for the History of Science & Technology, Cambridge, Massachusetts

MORE INFORMATION

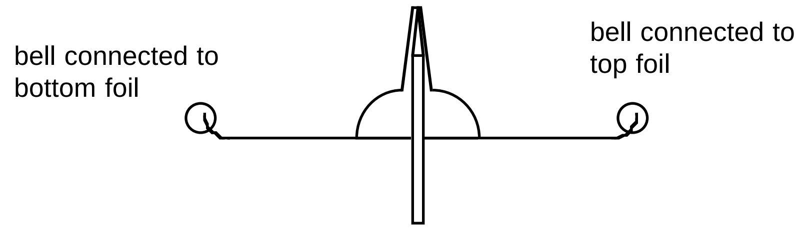
More information on electrostatic motors can be found in the book by Oleg Jefimenko, *Electrostatic Motors*, Electret Scientific Co., PO Box 4132 1973, Star City, WV
or in the article by Jefimenko and Walker
"Electrostatic motors," Phys. Teach. **9**, 121-129 (1971).

A homemade version of the self moving wheel is shown on the next page.



This version of Franklin's self moving wheel is made from a 14 inch diameter disposable acrylic plastic serving plate from a party store. A hole, bigger than a pencil diameter, was carefully drilled through the center, making sure not to crack the plate. A plastic champagne glass is fastened with rubber cement and duct tape to the plate, carefully centered.

Two circles of foil with large holes in the center are then glued to the top and bottom of the plate.



Each circle has a set of tabs that reach to the rim of the plate, and they are offset from each other so that a tab from the top foil is in between two tabs from the bottom foil and vice-versa. Small metal jingle bells from a craft store are pried partly open with a screwdriver and placed on the rim so that alternate bells contact the top and bottom plates.

A sharpened pencil is mounted vertically in a sheet of foam insulation board. The wheel is then charged by connecting top and bottom to an electrostatic generator. BE CAREFUL- the shock from this is not dangerous, but would be more painful than those from smaller capacitors.

With the charged wheel on the pivot, move empty soda cans in close to the bells. The picture shows four, but more might be better. Start the wheel moving slightly and it should continue to turn. I found that it took patience to adjust it, but I could get it to turn for a few minutes fairly easily. Longer operation took more patience and adjustment.

Issues- how close you can get the cans without bumping into the bells. Care in construction will probably pay off.

Movie file: 12. Electrostatic Motors

4.25

23. A small wire bent circularly, with a loop at each end; let one end rest against the under surface of the wheel,and bring the other end near the upper surface, it will give a terrible crack, and the force will be discharged.

4.26

24. Every spark in that manner drawn from the surface of the wheel, makes a round hole in the gilding, tearing off a part of it in coming out; which shows that the fire is not accumulated on the gilding, but is in the glass itself.

4.27

25. The gilding being varnished over with turpentine varnish, the varnish, though dry and hard, is burnt by the spark drawn through it, and gives a strong smell and visible smoke. And when the spark is drawn through paper, all round the hole made by it the paper will be blacked by the smoke, which sometimes penetrates several of the leaves. Part of the gilding torn off is also found forcibly driven into the hole made in the paper by the stroke.

4.28

26. It is amazing to observe in how small a portion of glass a great electrical force may lie. A thin glass bubble, about an inch diameter, weighing only six grains, being half filled with water, partly gilt on the outside, and furnished with a wire hook, gives, when electrified, as great a shock as a man can well bear. As the glass is thickest near the orifice, I suppose the lower half, which, being gilt, was electrified and gave the shock did not exceed two grains; for it appeared when broken, much thinner than the upper half. If one of these thin bottles be electrified by the coating, and the spark taken out through the gilding, it will break the glass inwards, at the same time that it breaks the gilding outwards.

4.29

27. And allowing (for the reasons before given, §8, 9, 10) that there is no more electrical fire in a bottle after charging than before, how great must be the quantity in this small portion of glass! It seems as if it were of its very substance and essence. Perhaps if that due quantity of electrical fire so obstinately retained by glass could be separated from it, it would no longer be glass; it might lose its transparency, or its brittleness, or its elasticity. Experiments may possibly be invented hereafter to discover this.

In these sections Franklin describes several experiments made with the large charged glass plate which is part of the self-moving wheel.

SAFETY NOTE

The large size of the glass wheel Franklin describes and the high electrical breakdown voltage of glass made it possible to charge his wheel with a significant charge to a high voltage, giving it enough stored energy to represent a serious shock hazard.

A plate the size Franklin describes could have a capacitance of a few nanoFarads, and at a voltage of 50,000 Volts could store about 2 Joules of energy.
A. D. Moore notes that a shock of 10 Joules of energy is dangerous to people and that a discharge of 0.25 Joules gives a heavy shock. Thus I would advise against making a large capacitor. (Moore, *Electrostatics, 2nd ed*1997 LaPlacian Press, Morgan Hill, CA pp 114-116).

4.30

28. We were surprised at the account, given in Mr. Watson's book, of a shock communicated through a great space of dry ground, and suspect there must be some metalline quality in the gravel of that ground; having found that simply dry earth, rammed in a glass tube, open at both ends, and a wire hook inserted in the earth at each end, the earth and wires making part of a circuit, would not conduct the least perceptible shock; and, indeed, when one wire was electrified, the other hardly showed any signs of its being in connexion with it.[1] Even a thoroughly wet packthread sometimes fails of conducting a shock, though it otherwise conducts electricity very well. A dry cake of ice, or an icicle held between two in a circle, likewise prevents the shock, which one would not expect, as water conducts it so perfectly well. Gilding on a new book, though at first it conducts the shock extremely well, yet fails after ten or a dozen experiments, though it appears otherwise in all respects the same, which we cannot account for.[2]

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[1] Probably the ground is never so dry.–F.

[2] We afterwards found that it failed after one stroke with a large bottle; and the continuity of the gold appearing broken, and many of its parts dissipated, the electricity could not pass the remaining parts without leaping from part to part through the air, which always resists the motion of this fluid, and was probably the cause of the gold's not conducting so well as before; the number of interruptions in the line of gold, making, when added together, a space larger, perhaps, than the striking distance.–F.

A large Leyden jar in the collection of the Burndy Library. It would hold about 5 gallons or 20 liters of liquid.
R. Morse photograph, 2004
courtesy The Burndy Library,
Dibner Institute for the History of Science & Technology
Cambridge, Massachusetts

4.31

29. There is one experiment more which surprises us, and is not hitherto satisfactorily accounted for; it is this. Place an iron shot on a glass stand, and let a ball of damp cork, suspended by a silk thread, hang in contact with the shot.

Take a bottle in each hand, one that is electrified through the hook, the other through the coating; apply the giving wire to the shot, which will electrify it *positively*, and the cork shall be repelled; then apply the requiring wire, which will take out the spark given by the other, when the cork will return to the shot; apply the same again and take out another spark, so will the shot be electrified *negatively*, and the cork in that case shall be repelled equally as before.

Then apply the giving wire to the shot and give the spark it wanted, so will the cork return; give it another, which will be an addition to its natural quantity, so will the cork be repelled again; and so may the experiment be repeated as long as there is any charge in the bottles.

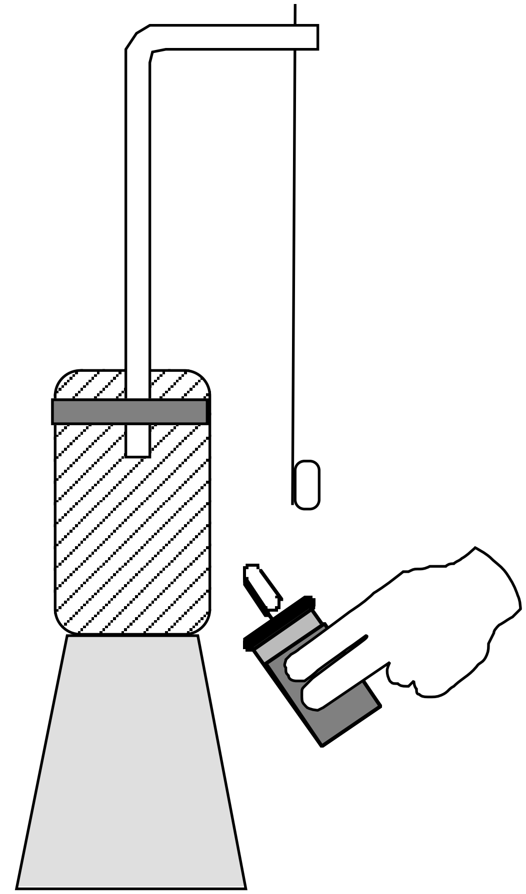
Which shows that bodies having less than the common quantity of electricity repel each other, as well as those that have more.

Franklin is surprised because according to his theory, objects with too much electrical fluid (positively charged) should repel each other, but two objects each with less than the normal amount of electrical fluid (negative) should not affect each other, since the ACTIVE agent is the electrical fluid.This problem with Franklin's theory later led to its modification by Aepinus.

Place an aluminum soda can on a foam cup – tape in place, and fasten a bendy straw to it with a rubber band. Hang a foil covered straw bit from it.

Charge one film can Leyden jar with the wire positive (it will have the 'giving' wire in use since it gives back the excess electrical fluid).

Charge another with the coating positive, and wire negative. (It will have the 'requiring' wire, since in Franklin's model it has too little electrical fluid and the wire will take fluid from another conductor.)



Follow Franklin's instructions, and compare your observations with his.

4.32

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 the 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 the *Skuykill.*[1] 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.[2] A turkey is to be killed for our dinner by *electrical shock,* and roasted by the *electrical jack,* before a fire kindled by the *electrified bottle;* when the healths of all the famous electricians in England, Holland, France, and Germany are to be drank in *electrified bumpers*[3] under the discharge of guns from the *electrical battery*.

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[1] The river that washes one side of Philadelphia, as the Delaware does the other; both are ornamented with the summer habitations of the citizens and the agreeable mansions of the principal people of this colony.–F.

[2] As the possibility of this experiment has not been easily conceived, I shall here describe it. Two iron rods, about three feet long, were planted just within the margin of the river, on the opposite sides. A thick piece of wire, with a small round knob at its end, was fixed on the top of one of the rods, bending downwards, so as to deliver commodiously the spark upon the surface of the spirit. A small wire fastened by one end to the handle of the spoon, containing the spirit, was carried across the river and supported in the air by the rope commonly used to hold by in drawing the ferry-boats over. The other end of this wire was tied round the coating of the bottle; which being charged, the spark was delivered from the hook to the top of the rod standing in the water on that side. At the same instant the rod on the other side delivered a spark into the spoon and fired the spirit; the electric fire returning to the coating of the bottle, through the handle of the spoon and the supported wire connected with them.

That the electric fire thus actually passes through the water, has since been satisfactorily demonstrated to many by an experiment of Mr. Kinnersley's, performed in a trough of water about ten feet long. The hand, being placed under water in the direction of the spark (which always takes the straight or shortest course, if sufficient, and other circumstances are equal), is struck and penetrated by it as it passes.–F.

[3] An *electrified bumper* is a small, thin, glass tumbler, nearly filled with wine, and electrified as the bottle. This when brought to the lips gives a shock, if the party be close shaved, and does not breathe on the liquor.–April 29, 1749.–F.

Besides serious scientific investigation, electrical experiments were popular parlor entertainments. Although Franklin's picnic proposal may be a little tongue in cheek, there are numerous plates from 18th and 19th century books showing electrical apparatus used for entertainments.

On the next page you see two children playing with paper bits between two metal plates, while a gentleman standing on wax and touching the prime conductor with one hand uses a sword to ignite a spoonful of brandy held by the lady at the left.

The electricity for these experiments is being provided by the gentlmen at the right, one of whom is turning the globe and the other is rubbing it with his hand or perhaps a piece of buckskin.
(See Schiffer, *Draw the Lighting Down*.)

Electrical experiments as entertainment.

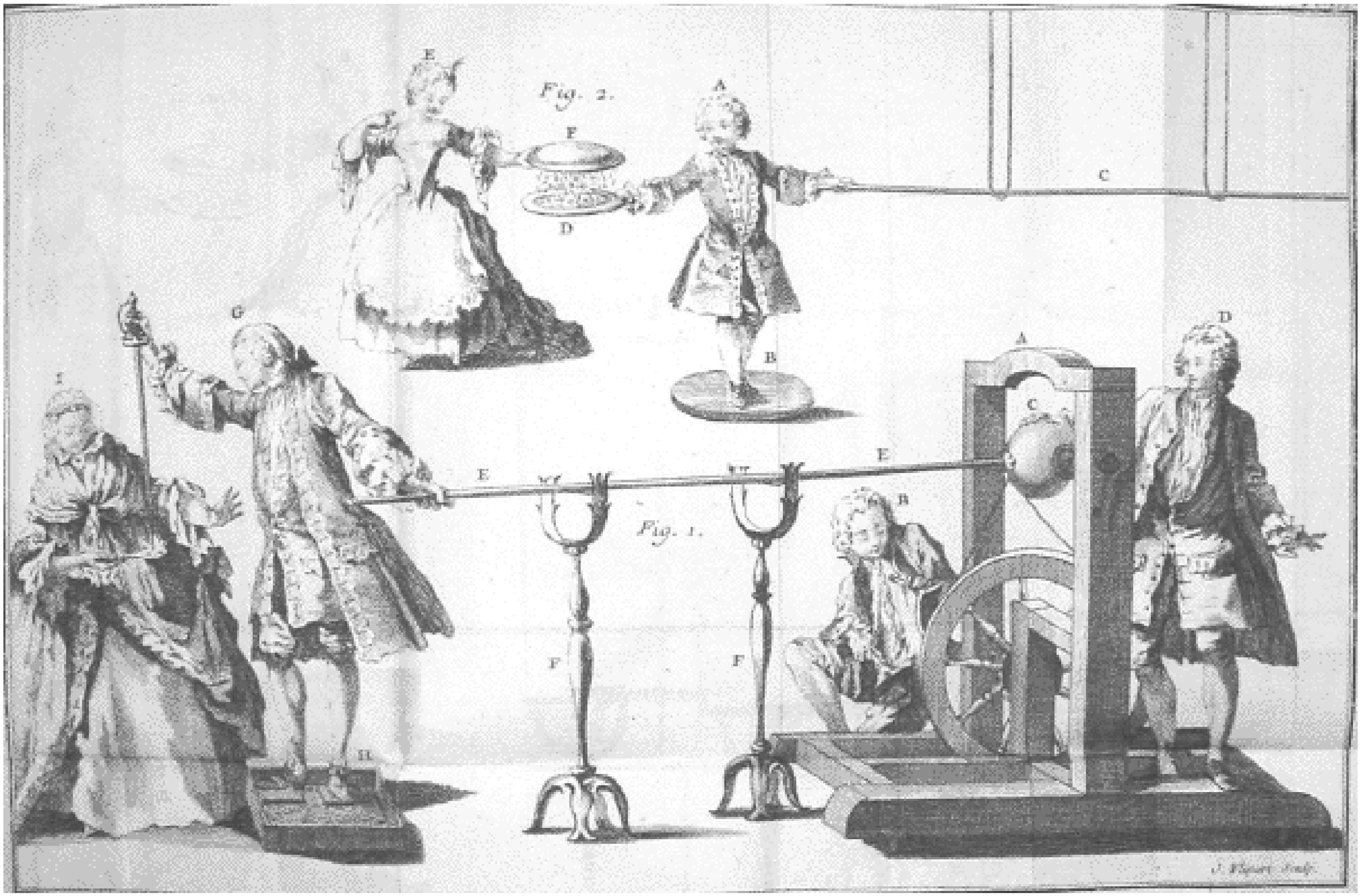

Plate III, William Watson, trans. by Jean Freke, *Essai sur la Cause de L'Electricité*, Paris, 1748
The Burndy Library, Dibner Institute for the History of Science & Technology,Cambridge, Massachusetts

R A. Morse photograph 2004, courtesy Burndy Library,
Dibner Institute for the History of Science and Technology,
Cambridge, MA

The Electrical Battery

The electrical battery referred to by Franklin consists of a number of Leyden jars connected together so they could all be discharged at once. This gave an effect like that of a single very large Leyden jar, as shown earlier, but the jars were easier to handle, and could be charged individually and connected after they were charged, which was both convenient and safer for the user. This battery or box of jars dates from the 19th century and was made in Europe. The box held 25 jars, each 30 cm tall. In the collection of the Burndy Library.

The term ‘battery’ comes from analogy with the term for a ‘battery’ of guns rather than a single cannon. Here we have a ‘battery’ of jars. After Volta’s discovery of the electrochemical cell in 1800, the term was then applied to a group of electrochemical cells (also called a Voltaic pile), and has now come into common use to refer to even a single cell.

In a letter to Thomas Hubbard in Boston, dated 28 April, 1758, Franklin describes a battery which he is sending to Harvard.

> A mahogany case lined with lead, containing thirty-five square glass bottles, in five rows, seven in a row.

Later in the letter he continues: The middle of the wire goes up into the stopper, with an eye, through which the long communicating wires pass, that connect all the bottles in one row.

To form occasional communications with more rows, there must be, on the long wires of the second and fourth rows, four other movable wires, which I call cross-wires, about two inches and a half long, with a small ball of any metal about the size of a pistol-bullet at each end. The ball of one end is to have a hole through the middle, so that it may be slipped on the long wire; and one of these cross-wires is to be placed between the third and fourth bottles of the row at each end; and on each of the above-mentioned 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 row, you turn tow of them back on the first, and tow on the fifth row, 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 completed with just the number of rows you want.

The brass handles of the case communicate with the outside of the bottles, when you wish to make the electrical circuit.