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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Sept. 2004

Part III. Experiments and theory of the Leyden jar described in a letter to Peter Collinson

Franklin's second letter begins with his theory of the transfer of electrical fluid in charging the Leyden jar, followed by a series of experiments to support the theory.

Letter III. Benjamin Franklin to Peter Collinson
1 September 1747 *Bigelow vol II. p. 197-205*

In the early published editions of Franklin's work this letter appeared first dated July 28, 1747. Franklin corrected this in the fourth and fifth editions.

3.01

TO PETER COLLINSON

PHILADELPHIA. 1 September, 1747

SIR:–The necessary trouble of copying long letters, which perhaps, when they come to your hands, may contain nothing new, or worth your reading (so quick is the progress made with you in electricity), half discourages me of writing any more on that subject. Yet I cannot forbear adding a few observations on M. Muschenbroek's wonderful bottle.

Mr. Muschenbroek's bottle, referred to as the "phial" by Franklin, is also known as the Leyden Jar. We will further explore its behavior in the experiments in this section.

Bigelow, 1904 vol VIII, frontispiece
Engraving from C.W. Peale's copy of portrait by David Martin
(public domain)

In this letter, Franklin first lays out his theory of the behavior of the Leyden jar. He describes his theoretical ideas in five numbered points, and then proceeds to demonstrate the application of the theory to the Leyden jar by a series of experiments or demonstrations. He uses the terminology of the time, which is unfamiliar to our ears as our present terminology comes from terms that were introduced by Franklin.

An 'electric' is the term for what we now call an insulator- so called because it became 'electrified' or 'electrized' when rubbed.

A 'non-electric' is what we now call a conductor. It apparently could not become electrified by rubbing, but when insulated could become electrified by contact with a charged 'electric.' Eventually it was shown that insulated conductors could become charged by friction.

A Leyden jar arranged with a pair of bells for a musical discharge.

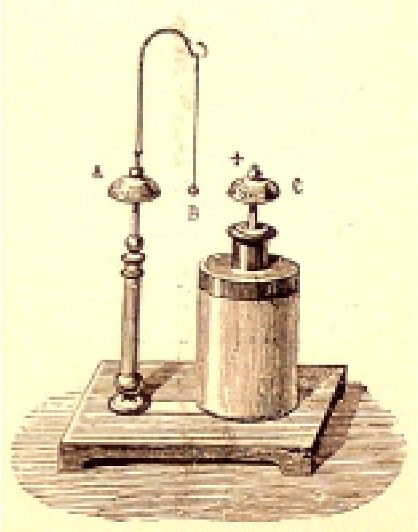


FIG. 46.

p. 84, 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)

In a later letter, extracted below, Franklin himself comments on the terminology.

Extract from a later letter to Cadwallader Colden
Bigelow Vol. II: page 368

23 April, 1752

We have been used to call those bodies *electrics per se,* which would not conduct the electric fluid. We once imagined that only such bodies contained that fluid; afterwards that they had none of it, and only educed it from other bodies; but further experiments showed our mistake. It is to be found in all matter we know of; and the distinction of *electrics per se* and *non-electrics* should now be dropped as improper, and that of *conductors* and *non-conductors* assumed in its place, as I mentioned in those answers.

Drink cup Leyden jar

3.02

1. The non-electric [conductor] contained in the bottle differs, when electrized, from a non-electric electrized out of the bottle, in this: that the electrical fire of the latter is accumulated on its surface, and forms an electrical atmosphere round it of considerable extent; but the electrical fire is crowded into the substance of the former, the glass confining it.[1]

[1] See this opinion rectified in §16 and 17 p 242. The fire in the bottle was found by subsequent experiments not to be contained in the non-electric [conductor], but in the glass. 1748.

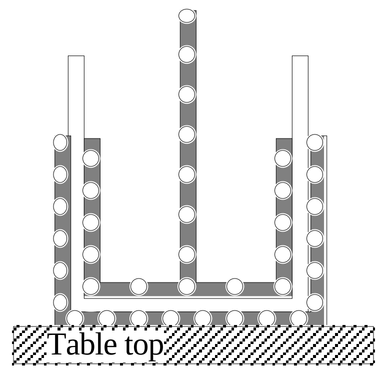
Franklin envisions an electrical atmosphere surrounding the outside conductor (non-electric)

Franklin changed his idea, and refers to Letter IV, section 16 & 17 - this footnote was added in a later edition of Franklin's book.

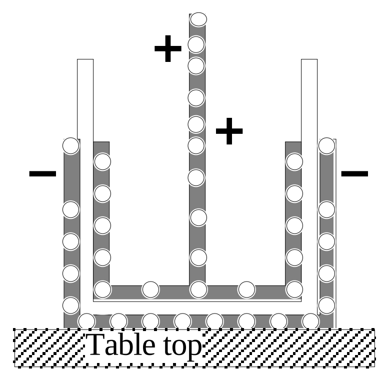
3.03

2. At the same time that the wire and the top of the bottle, &c., is electrized *positively* or *plus*, the bottom of the bottle is electrized *negatively* or *minus*, in exact proportion; that is, whatever quantity of electrical fire is thrown in at the top, an equal quantity goes out of the bottom.[1] To understand this, suppose the common quantity of electricity in each part of the bottle, before the operation begins, is equal to twenty; and at every stroke of the tube, suppose a quantity equal to one is thrown in; then, after the first stroke, the quantity contained in the wire and upper part of the bottle will be twenty-one, in the bottom nineteen; after the second, the upper part will have twenty-two, the lower eighteen; and so on, till after twenty strokes, the upper part will have a quantity of electrical fire equal to forty, the lower part none; and then the operation ends, for no more can be thrown into the upper part when no more can be driven out of the lower part. If you attempt to throw more in, it is spewed back through the wire, or flies out in loud cracks through the sides of the bottle

[1] What is said here, and after, of the *top* and *bottom* of the bottle is true of the *inside* and *outside* surfaces, and should have been so expressed.



The diagram shows a cross-section of a Leyden jar, with 20 circles to represent the normal electric matter in each.

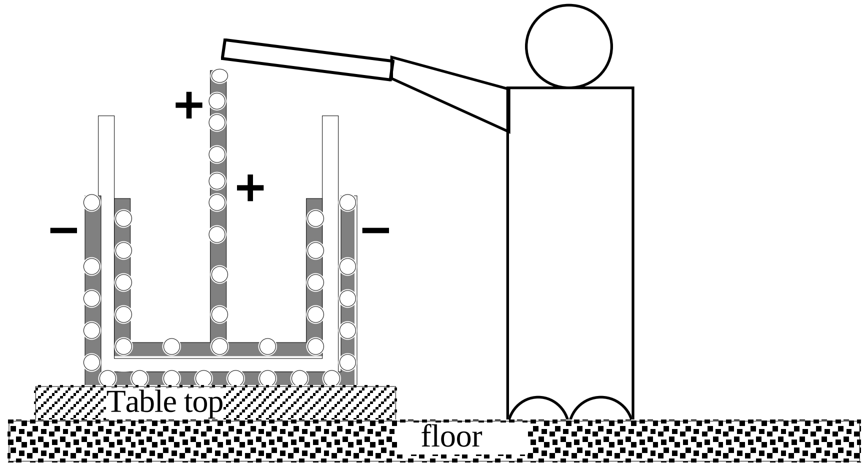


In the lower diagram two parts of the 20 in the outer coating have been moved to the inner coating, marked by **+**, since it now has an extra quantity of electricity. The outer coating, having lost electricity, has less than its normal quantity marked by **-**.

NOTE- As Franklin points out below, there has to be a path for the electric fluid to be removed from the outer coating! This would be through the table top , the floor and the body of the person electrizing the jar. See diagram on next page.

3.04

3. The equilibrium cannot be restored in the bottle by inward communication or contact of the part, but it must be done by a communication formed without the bottle, between the top and bottom, by some non-electric [conductor], touching or approaching both at the same time; in which case it is restored with a violence and quickness inexpressible; or touching each alternately, in which case the equilibrium is restored by degrees.

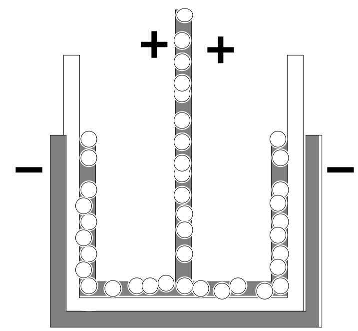


The discussion in these paragraphs lays out the idea that will become the Law of Conservation of Charge, which Franklin is the first to really appreciate, and to apply to understanding the action of the Leyden jar.

3.05

4. As no more electrical fire can be thrown into the top of the bottle, when all is driven out of the bottom, so, in a bottle not yet electrized, none can be thrown into the top when none can get out at the bottom; which happens either when the bottom is too thick, or when the bottle is placed on an electric *per se* [insulator]. Again, when the bottle is electrized, but little of the electrical fire can be *drawn out* from the top, by touching the wire, unless an equal quantity can at the same time *get in* at the bottom.[1] Thus, place an electrized bottle on clean glass or dry wax, and you will not, by touching the wire, get out the fire from the top. Place it on a non-electric [insulator], and touch the wire, you will get it out in a short time,– but soonest when you form a direct communication as above.

[1] see the preceding note, relating to top and bottom [paragraph 3.03]



Here the Leyden jar has all of the normal amount of electrical fire that was on the outer coating transferred to the inner coating. I have not drawn the 20 plus signs and 20 minus signs that should appear

3.06

So wonderfully are these two states of electricity, the *plus* and *minus*, combined and balanced in this miraculous bottle! situated and related to each other in a manner that I can by no means comprehend! If it were possible that a bottle should in one part contain a quantity of air strongly compressed, and in another part a perfect vacuum, we know the equilibrium would he instantly restored *within*. But here we have a bottle containing, at the same time a *plenum* of electrical fire and a *vacuum* of the same fire, and yet the equilibrium cannot be restored between them but by a communication *without*, though the *plenum* presses violently to expand, and the hungry vacuum seems to attract as violently in order to be filled.

Franklin is reasoning by analogy with compressed air and rarefied air. One of the ideas was that the electrical fire was a kind of fluid like a gas. The action of the tube or the generator was to 'pump' the electrical fluid from one material to another. In the receiving material, the fluid would be 'compressed' and in the giving material it would be 'rarefied' or depleted.

3.07

5. The shock to the nerves (or convulsion rather) is occasioned by the sudden passing of the fire through the body in its way from the top to the bottom of the bottle. The fire takes the shortest course, as Mr. Watson justly observes. But it does not appear from experiment that, in order for a person to be shocked, a communication with the floor is necessary for he that holds the bottle with one hand and touches the wire with the other, will be shocked as much, though his shoes be dry, or even standing on wax, as otherwise. And on the touch of the wire (or of the gun-barrel, which is the same thing), the fire does not proceed from the touching finger to the wire, as is supposed, but from the wire to the finger, and passes through the body to the other hand, and so into the bottom of the bottle.

Other circumstances being equal.

Franklin correctly notes that all that is required to 'restore the equilibrium' is that there be a complete circuit. The path does not HAVE to pass to the floor as some others had supposed.

Experiments confirming the above

EXPERIMENT I

3.08

Place an electrized phial on wax; a small cork ball, suspended by a dry silk thread, held in your hand and brought near to the wire, will first be attracted and then repelled; when in this state of repellency, sink your hand that the ball may be brought towards the bottom of the bottle. It will be there instantly and strongly attracted till it has parted with its fire.

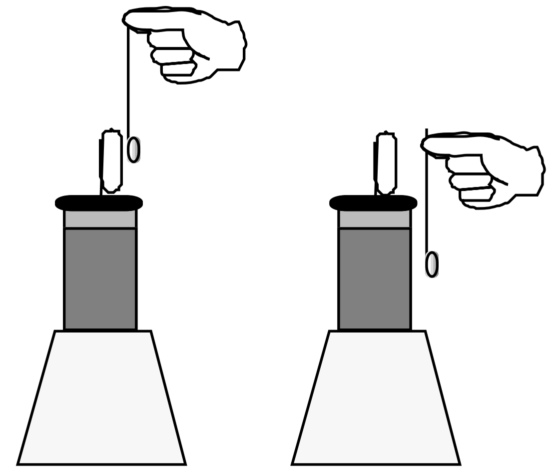
3.09

If the bottle had a *positive* electrical atmosphere, as well as the wire, an electrified cork would be repelled from one as well as from the other.

Charge the film can with the generator or with the tube.

3.08
Place the charged film can Leyden jar on a foam cup, and use the hanging foil bit to try the experiment.

What do you find?



3.09 Here, Franklin means that if both the outside coating and the inside coating have excess charge, then the foil bit would be repelled by both.

To try this stick the film can to the top of the foam cup with a bit of tape, and first 'electrify' or charge the paper clip by touching it to the positive pole of your generator (or use the tube) while holding it by the foam cup.

Then, still holding it by the foam cup, touch the coating to the generator or the tube. Set it down on the table and use the foil bit to try the experiment.

What do you find?

3.10

EXPERIMENT II

Plate III., Fig. I. From a bent wire (*a*) sticking in the table, let a small linen thread (*b*) hang down within half an inch of the electrized phial (*c*). Touch the wire or the phial repeatedly with your finger, and at every touch you will see the thread instantly attracted by the bottle. (This is best done by a vinegar cruet, or some such bellied bottle.) As soon as you draw any fire out from the upper part by touching the wire, the lower part of the bottle draws an equal quantity in by the thread.

In Franklin's day, the wood surface of a table would have acted as a conductor, an effect that was not initially recognized as important at the time, although Franklin realizes its importance. The table would have been connected to the floor and through the feet to the experimenter.

With modern plastic or plastic coated tables you need to have a conducting surface to do this experiment successfully. Set up your equipment as shown on a sheet of aluminum foil, with a tab of foil to connect the surface to the foil covered straw. You will also need to touch the foil with one hand, as your (plastic soled) shoes will also insulate you from the floor.

Use either a piece of damp sewing thread or (preferably) christmas tree tinsel for the thread. Tie it or tape it to the end of the straw.

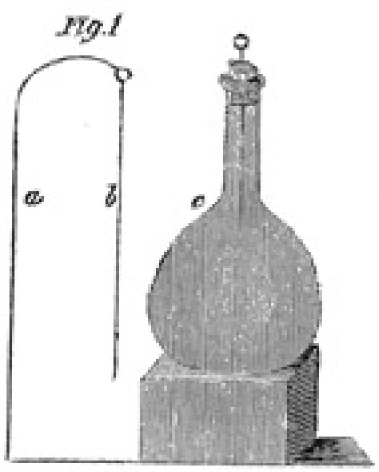
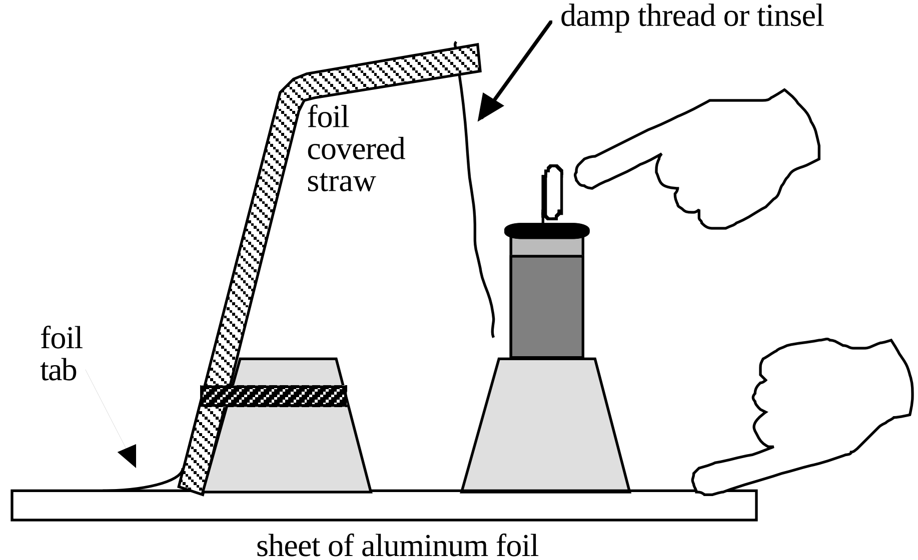


Figure 1 from J. Bigelow 1904 *Works of Benjamin Franklin* Vol II p. 200 (public domain)

Here is Franklin's illustration of this experiment reproduced from the plate in Bigelow, plate III Vol II, p. 200



3.11

EXPERIMENT III

Fig. 2.–Fix a wire in the lead, with which the bottom of the bottle is armed (*d*), so as that, bouncing upwards, its ring-end may be level with the top, or ring-end of the wire in the cork (*e*), and at three or four inches distance. Then electrize the bottle and place it on wax. If a cork, suspended by a silk thread (*f*), hang between these two wires, it will play incessantly from one to the other till the bottle is no longer electrized; that is it fetches and carries fire from the top to the bottom[1] of the bottle till the equilibrium is restored.

[1] See note on p 197 relating to *top* and *bottom*. [paragraph 3.03]

Figure 2
From Bigelow, plate III, vol II, p 200

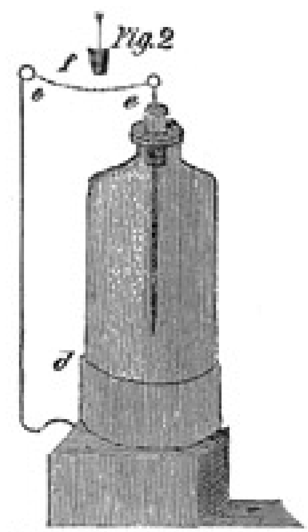
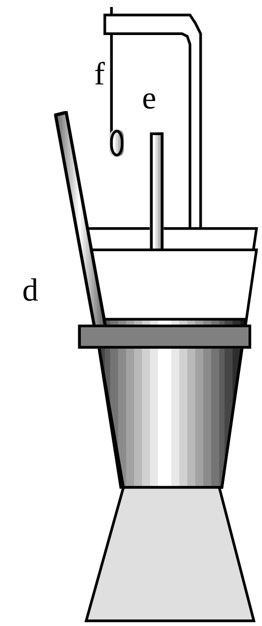


Figure 2 from J. Bigelow 1904
Works of Benjamin Franklin
Vol II p. 200 (public domain)

For this experiment, use a plastic drink cup Leyden jar. Fasten another foil coated straw to the outside with a rubber band, and fasten a bendy straw supporting a foil bit on a thread, so it can swing back and forth between the two foil coated straws.

Charge the jar with the generator, or the tube by holding onto the outer coating and touching the straw connected to the inner coating to the positive pole of the generator or to the tube. Set it on a foam base.

Carefully add the straw with the foil bit. BE CAREFUL not to touch both the foil covered straws at the same time, or you will get a shock and discharge the jar.



Cohen in *Franklin & Newton*, p 309, notes the possible importance of this experiment as showing that the electrical fluid could be transferred a small amount at a time, not just in a sudden discharge, providing evidence that some substance was being transferred, rather than merely a change from an excited to an unexcited condition of the material. Franklin repeatedly uses this technique and similar ones involving a series of small sparks to slowly transfer charge, and bolster his argument that the ‘electrical fluid’ is a conserved substance.

3.12

EXPERIMENT IV

Fig. 3.–Place an electrized phial on wax; Take a wire (*g*) in form of a *C*, the ends at such a distance, when bent, as that the upper may touch the wire of the bottle when the lower touches the bottom; stick the outer part on a stick of sealing-wax (*h*), which will serve as a handle; then apply the lower end to the bottom of the bottle, and gradually bring the upper end near the wire in the cork. The consequence is, spark follows spark till the equilibrium is restored. Touch the top first, and on approaching the bottom with the other end, you have a constant stream of fire from the wire entering the bottle. Touch the top and bottom together, and the equilibrium will instantly be restored, the crooked wire forming the communication.

A bent straw taped to a pair of foil covered bent straws makes the connection here. You may also use the neon bulb connector, bending the paper clips a little.

Touching one end to the jar, tip the other end near so that sparks jump, GRADUALLY bringing it closer. The series of small sparks shows a gradual transfer of 'electrical fluid'.

Figure 3
from Bigelow,
plate III, vol II, p
200

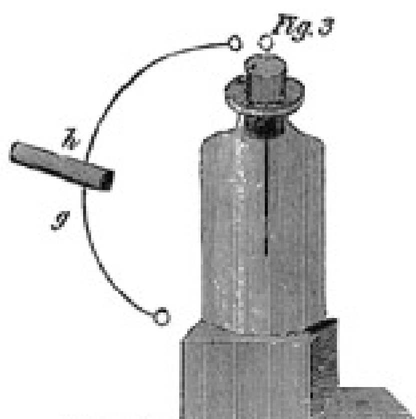
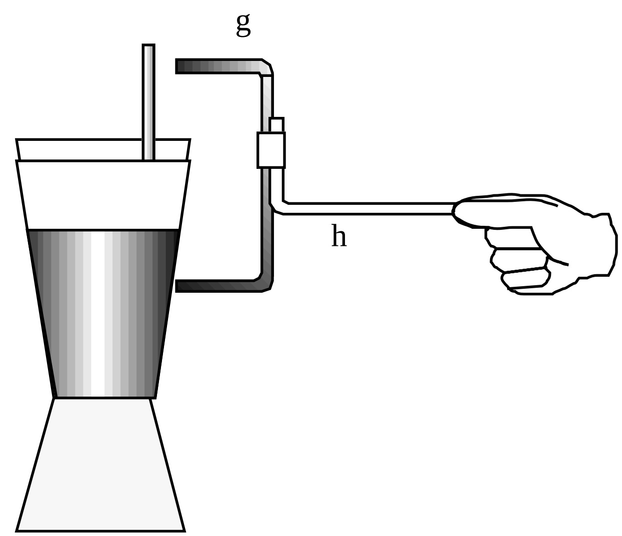


Figure 3 from J. Bigelow 1904
Works of Benjamin Franklin
Vol II. p. 200 (public domain)



3.13

EXPERIMENT V

FIG. 4–Let a ring of thin lead or paper surround a bottle (*i*) even at some distance from or above the bottom. From that ring let a wire proceed up till it touch the wire of the cork (*k*). A bottle so fixed cannot by any means be electrized; the equilibrium is never destroyed; for while the communication between the upper and lower parts of the bottle is continued by the outside wire, the fire only circulates; what is driven out at bottom is constantly supplied from the top[1]. Hence a bottle cannot be electrized that is foul or moist on the outside, if such moisture continue up to the cork or wire.

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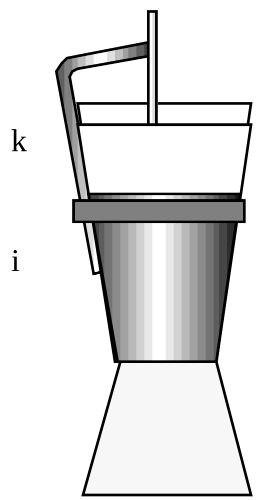
[1] see note, on p. 197, relating to *top* and *bottom*

Franklin's note is simply to clarify what he is calling the parts of the bottle.

'Top' refers to the wire connected to the inside conductor.

'Bottom' to the wire connected to the outside conductor.

Figure 4 from J. Bigelow 1904
Works of Benjamin Franklin
Vol. II p. 200 (public domain)



(See Franklin's figure 4 on previous page) In the early stages of understanding electricity, the mechanism of "storing electrical fluid" in the Leyden jar was not well understood. This experiment was actually an important one to show the conditions that could prevent charging the bottle.

Franklin simply connects the outer coating with the inner coating and attempts to charge the jar. You can do this by connecting a foil covered bendy straw to the outside of the jar with a rubber band, with its top end touching the foil covered straw that connects to the inside foil coating. Now try to charge the jar with the tube or the generator.

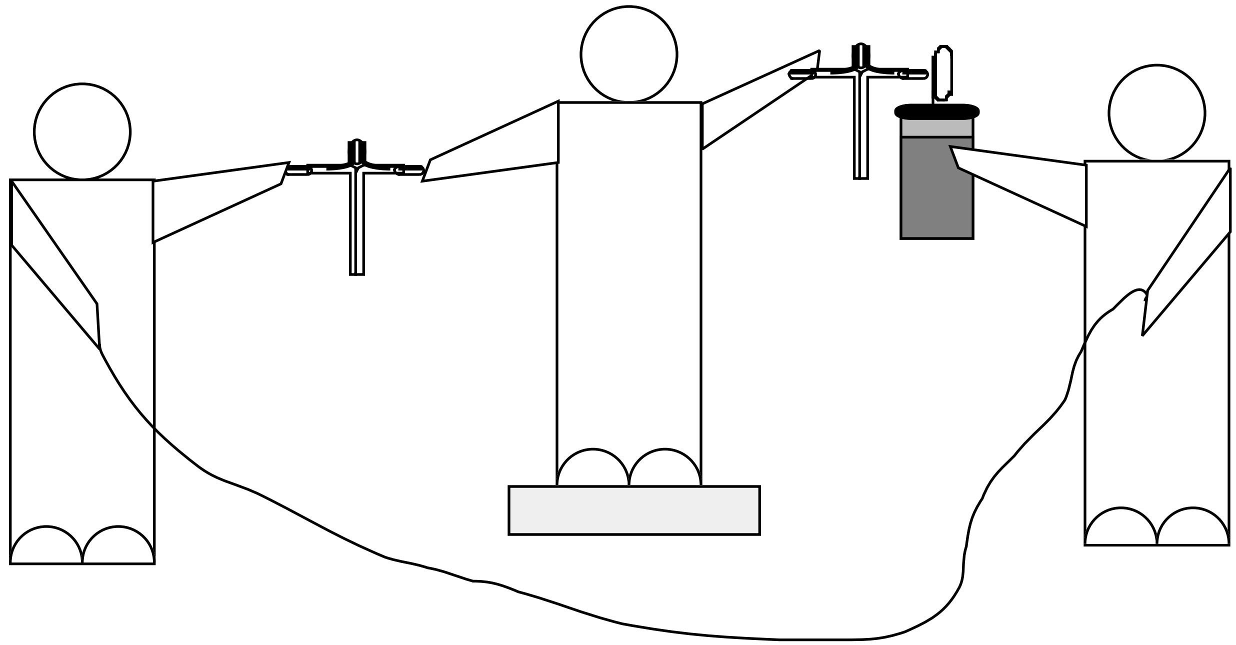
Test for a spark when you touch the outside of the jar and the straw connected to the inside foil. Is the jar charged?

What is your evidence?

3.14

EXPERIMENT VI

Place a man on a cake of wax, and present him the wire of the electrified phial to touch, you standing on the floor and holding it in your hand. As often as he touches it he will be electrified *plus*; and any one standing on the floor may draw a spark from him. The fire in this experiment passes out of the wire into him; and at the same time out of your hand into the bottom of the bottle.



Franklin used a cake of wax as a convenient insulator to stand on. A two-inch thick piece of foam insulation is a good modern substitute. You can also use thick pieces of foam packing material.

You can do this experiment full size using people, and use the neon bulbs to monitor the direction of discharge, as shown in the diagram.

Because modern shoes are usually good insulators, you will need to connect the two people who stand on the floor. I have drawn a wire, but they can simply hold hands.

You may also mock up this procedure using empty soda cans instead of people.

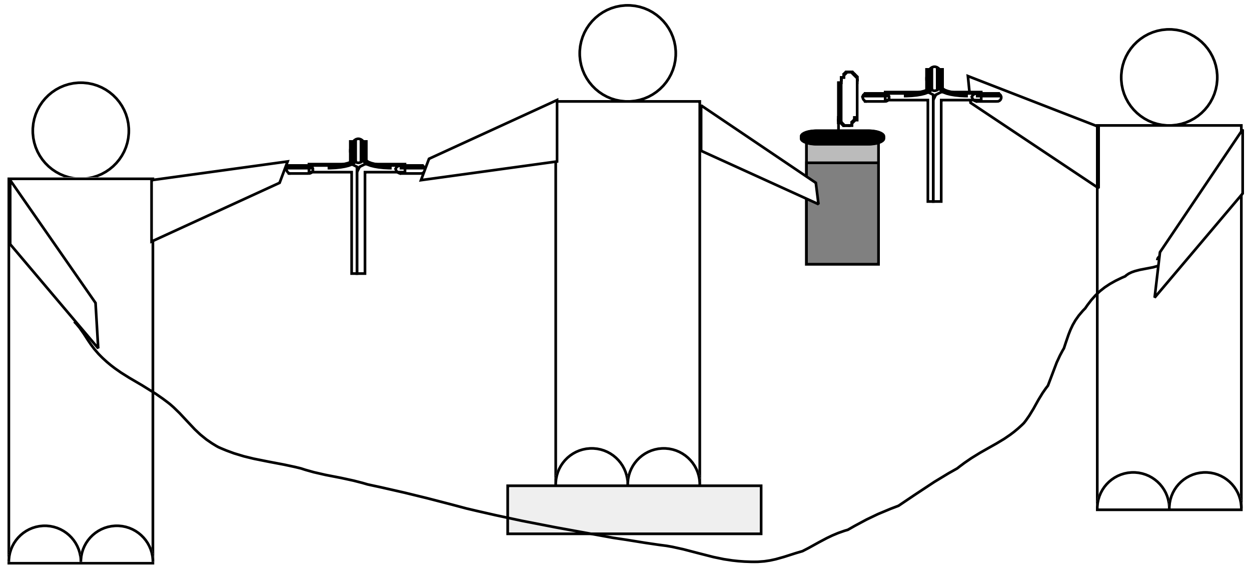
Place one soda can on a foam cup for the person in the middle.
Set a second can on a sheet of aluminum foil on the table.
Set the charged Leyden jar on a third can sitting on the foil.
Use the neon bulb to make the connections between the jar and the cans.

Note the direction of the flashes on the neon bulbs. Are your observations consistent with Franklin's predictions?

3.15

EXPERIMENT VII

Give him the electrical phial to hold, and do you touch the wire; as often as you touch it he will be electrified *minus*, and may draw a spark from any one standing on the floor. The fire now passes from the wire to you, and from him into the bottom of the bottle.



This is nearly a repeat of the previous experiment, but for Franklin it was important as some competing theories of electrification would have made a different prediction for the two cases.

As before, the outer people should hold hands to complete the circle, which would have been through their shoes and the floor in Franklin's time. Check the direction of the neon bulb flashes to test Franklin's prediction. What do you find?

3.16

EXPERIMENT VIll

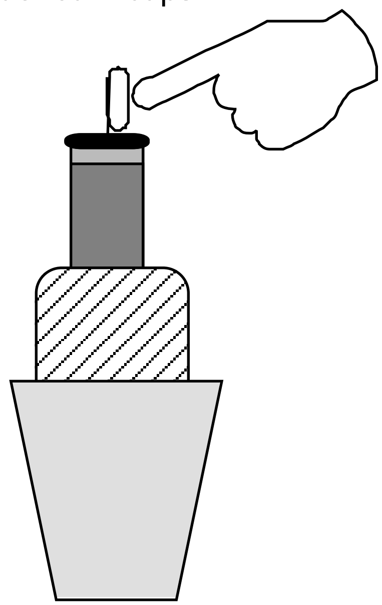
Lay two books on two glasses, back towards back, two or three inches distant.

Set the electrified phial on one, and then touch the wire; that book will be electrified *minus*, the electrical fire being drawn out of it by the bottom of the bottle.

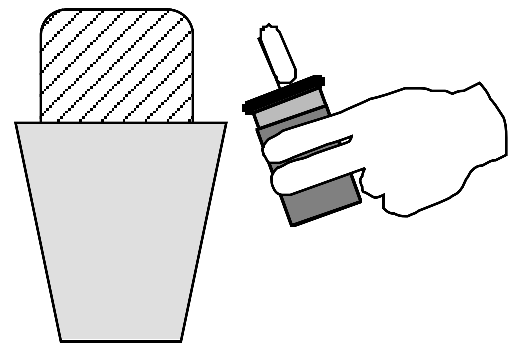
Take off the bottle, and, holding it in your hand, touch the other with the wire; that book will be electrified *plus*; the fire passing into it from the wire, and the bottle at the same time supplied from your hand.

A suspended small cork ball will play between these books till the equilibrium is restored.

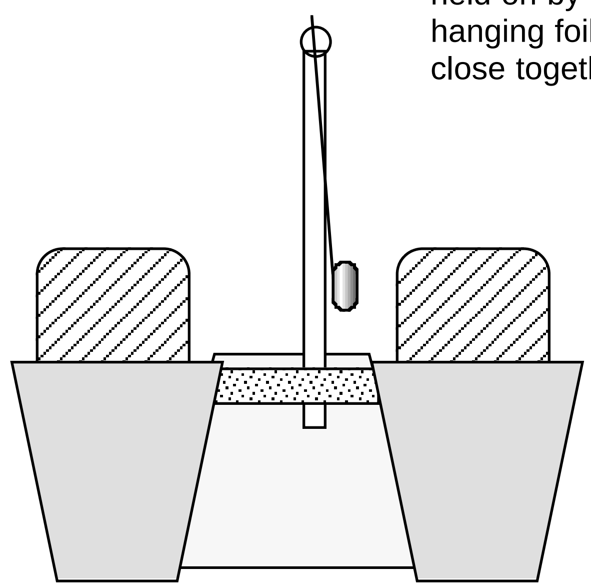
Franklin was a printer, and founder of a library. He had books ready to hand, and leather bound books of that time would have been sufficiently good conductors for this experiment. We can use empty soda cans set inside foam cups.



Set the charged Leyden jar down on the first soda can and touch the wire. Then lift it by the wire and set it on a foam cup. Pick it up by the coating and touch the wire to the other soda can.



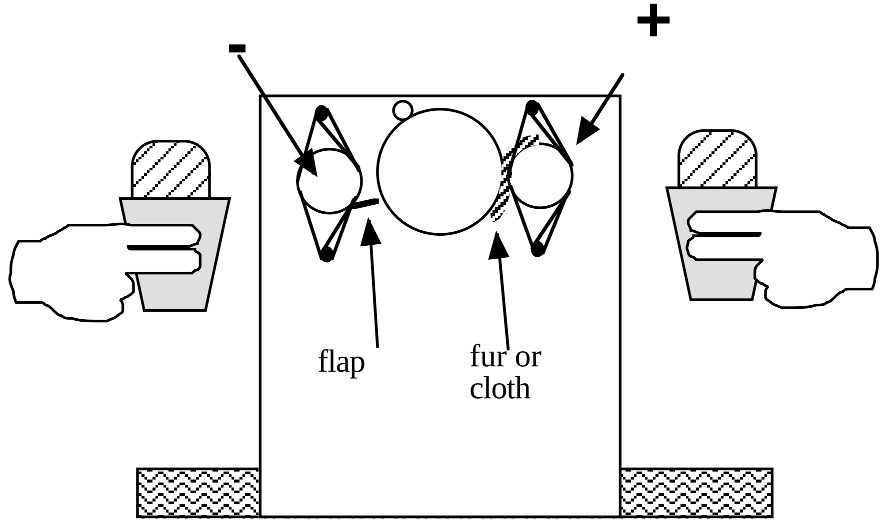
Set up a foam cup with a bendy straw held on by a rubber band and a hanging foil bit Move the soda cans close together and watch the action



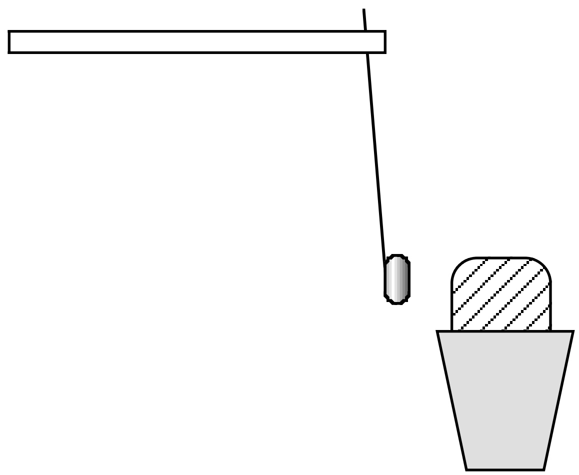
3.17

EXPERIMENT IX

When a body is electrized *plus*, it will repel a positively electrified feather or small cork ball. When *minus* (or when in the common state), it will attract them, but stronger when *minus* than when in the common state, the difference being greater.



Your generator is built to charge PLUS at the rubbing terminal and to charge MINUS at the collecting terminal. Charge two soda cans in foam cups, one plus and one minus.
Have a third soda can in a foam cup. Touch it with your finger to be sure it is neutral or in the 'common state'.



Take a foil bit hanging from a straw. Let the foil bit touch the PLUS terminal.
Bring it near the PLUS can.
Bring it near the neutral can.
(be careful not to let it touch the can)
Bring it near the MINUS can. How do your observations compare with Franklin's?

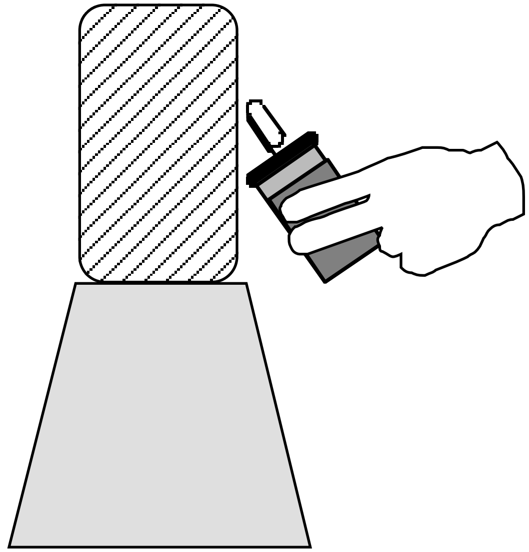
NOTE What Franklin did NOT suggest! You can repeat this experiment with the foil bit charged MINUS, and the results are symmetrical. Franklin's theory had trouble with this, as if there is too little electrical fluid, why should the objects repel? Partly because the generators of the time connected the rubber to the ground, the experimenters rarely electrized things negatively. In a later letter (Bigelow Vol III, p 377, Morse, p 165) Franklin worries about this problem. He had already accepted it as a principle, but without explanation of a mechanism. "III. Bodies electrified negatively, or deprived of their natural quantity of electricity, repel each other (or at least appear to do so by a mutual receding), as well as those electrified positively, or which have electric atmospheres."- Bigelow Vol III. p 61, Morse p 130

3.18

EXPERIMENT X

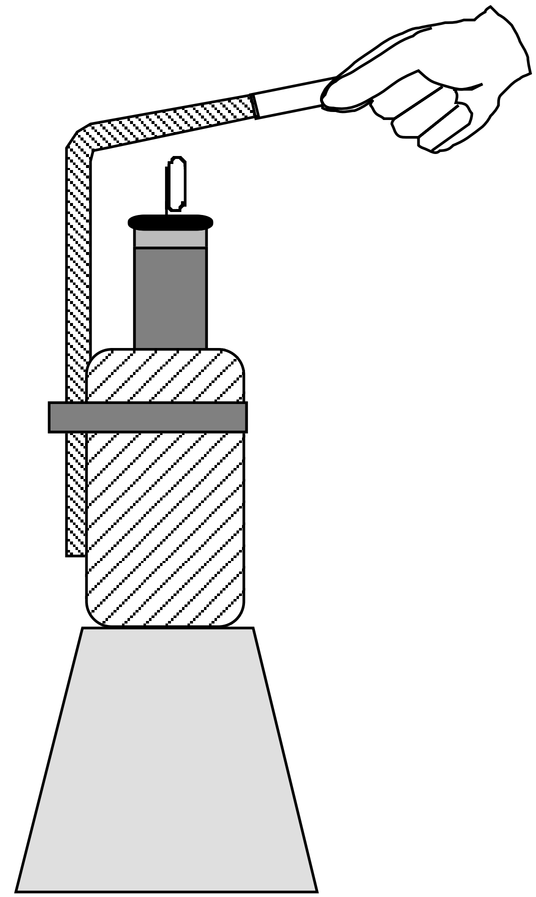
Though, as in *Experiment* VI, a man standing on wax may be electrifed a number of times by repeatedly touching the wire of an electrized bottle (held in the hand of one standing on the floor), he receiving the fire from the wire each time; yet holding it in his own hand and touching the wire, though he draws a strong spark, and is violently shocked, no electricity remains in him, the fire only passing through him from the upper to the lower part of the bottle. Observe, before the shock, to let some one on the floor touch him to restore the equilibrium of his body; for in taking hold of the bottom of the bottle he sometimes becomes a little electrized *minus*, which will continue after the shock, as would also any *plus* electricity which he might have given him before the shock. For restoring the equilibrium in the bottle does not at all affect the electricity in the man through whom the fire passes; that electricity is neither increased nor diminished.

This experiment can be done as Franklin describes it, or simulated by using a soda can on a foam cup in place of the man on wax.



The diagram above shows electrification of a soda can repeatedly from the wire of the Leyden jar. Test for charge with the neon bulb.

The diagram at right shows the attempt to electrify the soda can from the wire of the Leyden jar that rests on top of the can. Bend the foil covered straw down to touch the paper clip, holding only onto the uncovered part. Test the can for charge with the neon bulb, then test the Leyden jar for charge with the neon bulb.



3.19

EXPERIMENT XI

The passing of the electrical fire from the upper to the lower part of the bottle, to restore the equilibrium, is rendered strongly visible by the following pretty experiment. Take a book whose covering is filleted with gold; bend a wire of eight or ten inches long in the form of (*m*), Fig. 5, slip it on the end of the cover of the book, over the gold line, so as that the shoulder of it may press upon one end of the gold line, the ring up, but leaning towards the other end of the book. Lay the book on a glass or wax,[1] and on the other end of the gold line set the bottle electrized; then bend the springing wire by pressing it with a stick of wax till its ring approaches the ring of the bottle wire; instantly there is a strong spark and stroke, and the whole line of gold which completes the communication between the top and bottom of the bottle, will appear a vivid flame, like the sharpest lightning. The closer the contact between the shoulder of the wire and the gold at one end of the line, and between the bottom of the bottle and the gold at the other end, the better the experiment succeeds. The room should be darkened. If you would have the whole filleting round the cover appear in fire at once, let the bottle and wire touch the gold in the diagonally opposite corners.

I am, &c.,

B. FRANKLIN

[1] Placing the book on glass or wax is not necessary to produce the appearance; it is only to show that the visible electricity is not brought up from the common stock in the earth.

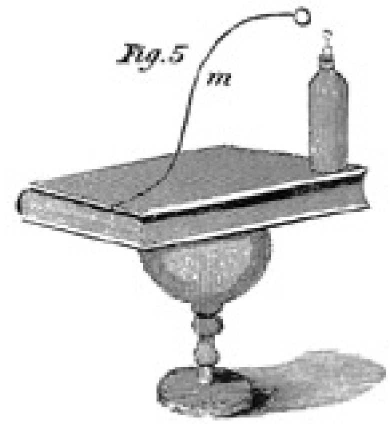


Figure 5 from J. Bigelow 1904
Works of Benjamin Franklin
Vol II. p. 200 (public domain)

The thin gilding on the cover of a book would have numerous small gaps, which sparks would jump across when the jar was discharged. You may see a similar effect by connecting neon bulbs together one after another and discharging the jar through the string of bulbs.

Alternatively, cut a thin strip of aluminum foil and place it on the sticky side of a length of tape. Use the end of a paper clip to scratch gaps in the foil, (without breaking the tape), and fasten a tab of aluminum foil at each end of the strip.Connect one end to the outside of a Leyden jar, and use a straw to touch the other end to the top of the Leyden jar. Try it in a darkened room. You could try making a similar tape using a paper punch to punch out small foil circles and sticking them on the tape with small gaps between.

Franklin apparently liked this effect for he mentions it more than once.