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
Tufts University
Medford MA 02155

by Robert A. Morse, Ph.D.

Sept. 2004

Part VI. Opinions and Conjectures concerning the properties and effects of electrical matter...

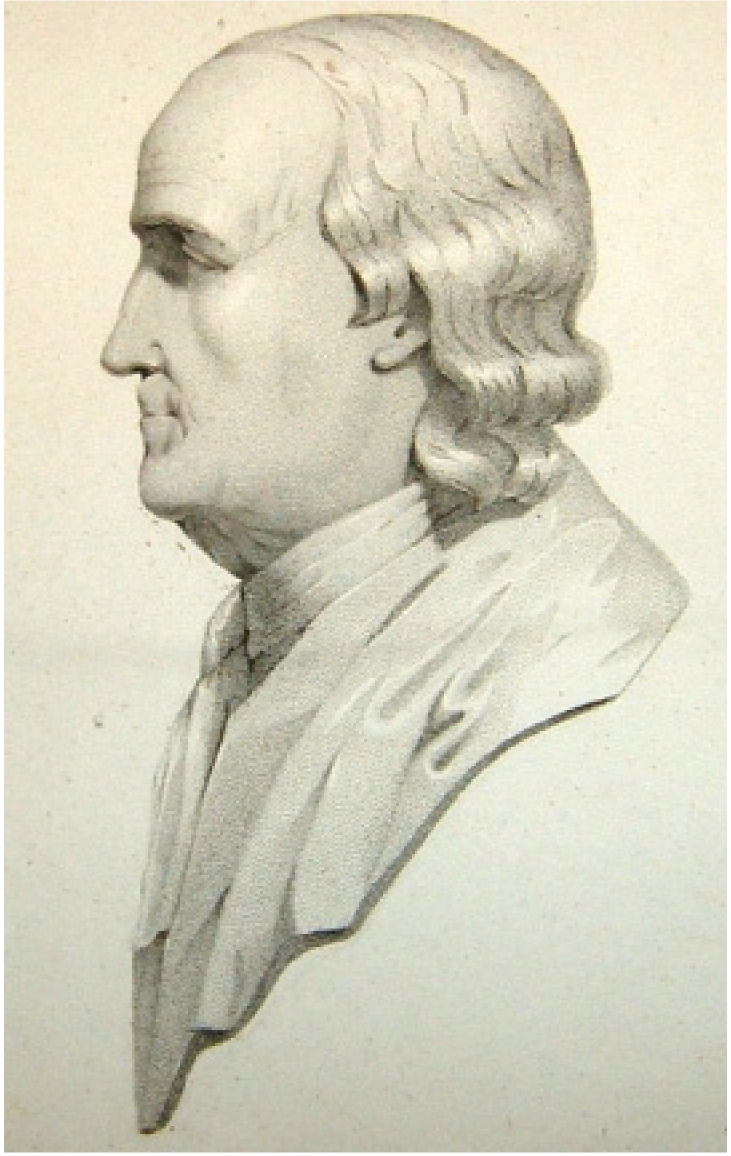
Franklin discusses his theory further, proposes the experiment with the lightning rod to test if lightning is electrical, and suggests the use of lightning rods to protect buildings and ships.

Additional Papers to Peter Collinson enclosing Opinions & Conjectures and Additional Experiment: Proving that Leyden bottle has no more electrical fire in it when charged, than before.
(July 29, 1750) *Bigelow Vol. II, p. 286-319*

Philadelphia, 29 July, 1750.

Sir:–As you first put us on electrical experiments by sending to our Library Company a tube with directions how to use it, and as our honorable proprietary enabled us to carry those experiments to a greater height by his generous present of a complete electrical apparatus, it is thus fit that both should know from time to time what progress we make. It was in this view I wrote and sent you my former papers on this subject, desiring that as I had not the honor of a direct correspondence with that bountiful benefactor to our library, they might be communicated to him through your hands. In the same view I write and send you this additional paper. If it happens to bring you nothing new (which well may be, considering the number of ingenious men in Europe continually engaged in the same researches), at least it will show that the instruments put into our hands are not neglected, and that if no valuable discoveries are made by us, whatever the cause may be, it is not want of industry and application.

I am, sir, your much obliged humble servant,
B. Franklin.



Benjamin Franklin
Engraved by
T. B. Welch
after the bust by
Houdon
Frontispiece, Vol. 4
J. Sparks,
Works of Benjamin Franklin,
1837,
Hilliard, Gray & Co., Boston
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Opinions and Conjectures concerning the Properties and Effects of the Electrical Matter, and the Means of Preserving Buildings, Ships, &c., from Lightning, arising from Experiments and Observations made at Philadelphia, 1749.

In this document, Franklin further describes his theory of how the electrical fluid behaves, describes his idea of electrical atmospheres, and attempts to explain the power of points to throw off and draw off charge in terms of his idea of the electric atmosphere. Franklin never develops a completely consistent theory, and a number of his ideas change with time. Notably, he always returns to experiment to test his ideas, and ultimately discards some of his ideas on the basis of contradicting experiments.

§1. The electrical matter consists of particles extremely subtle, since it can permeate common matter, even the densest metals, with such ease and freedom as not to receive any perceptible resistance.

2. If any one should doubt whether the electrical matter passes through the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him.

Some electrical experimenters held that the 'electrical matter' did not flow through an object, but only over its surface. Franklin here argues that the experience of the electrical shock from a large Leyden jar (of which Franklin had a number of experiences) ought to convince anyone that electrical effects deeply penetrated a person at least.

3. Electrical matter differs from common matter in this, that the parts of the latter mutually attract, those of the former mutually repel, each other. Hence the appearing divergency in a stream of electrified effluvia.

4. But, though the particles of electrical matter do repel each other, they are strongly attracted by all other matter.[1]

[1] See the ingenious essays on Electricity, in the *Transactions*, by Mr. Ellicot.–F.

Franklin suggests that ordinary objects consist of two kinds of material.

1. A matrix of 'common matter', the particles or atoms of which stick together by attraction.
2. A 'subtile electric fluid' whose (much smaller) particles repel each other, but are attracted by the particles of common matter.

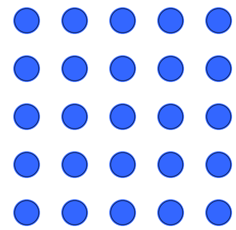
5. From these three things, the extreme subtility of the electrical matter, the mutual repulsion of its parts, and the strong attraction between them and other matter, arises this effect, that, when a quantity of electrical matter is applied to a mass of common matter, of any bigness or length, within our observation (which hath not already got its quantity), it is immediately and equally diffused through the whole.

6. Thus, common matter is a kind of sponge to the electrical fluid, And as a sponge would receive no water, if the parts of water were not smaller than the pores of the sponge; and even then but slowly, if there were not a mutual attraction between those parts and the parts of the sponge; and would still imbibe it faster, if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest, if, instead of attraction, there were a mutual repulsion among those parts, which would act in conjunction with the attraction of the sponge; so is the case between the electrical and common matter.

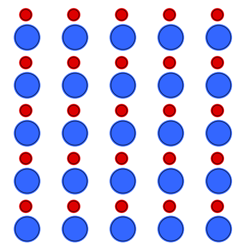
7. But in common matter there is (generally) as much of the electrical as it will contain within its substance. If more is added, it lies without upon the surface, and forms what we call an electrical atmosphere; and then the body is said to be electrified.

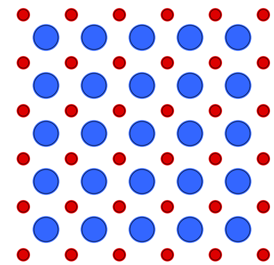
8. It is supposed, that all kinds of common matter do not attract and retain the electrical with equal strength and force, for reasons to be given hereafter. And that those called electrics *per se* [insulators], as glass, &c., attract and retain it strongest, and contain the greatest quantity.

Below left, normal matter with NO electrical fluid, representing a negatively charged object

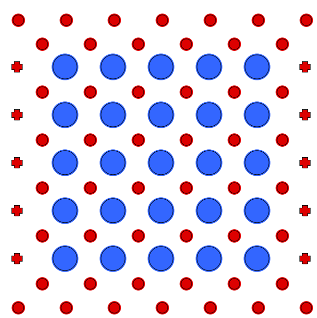


Below center, normal matter with its normal amount of electrical fluid, representing an uncharged object.





At right, normal matter with more than its normal amount of electrical fluid, representing a positively charged object.



At left, normal matter with much more than its normal amount of electrical fluid, representing a positively charged object.

Note the ‘electrical atmosphere’ of extra electrical fluid on the surface of the object, conforming to the shape of the object.

Note that at the corners the outlying particles of the electrical fluid are farthest from the normal matter.

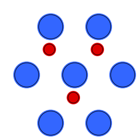
9. We know, that the electrical fluid is *in* common matter, because we can pump it *out* by the globe or tube. We know that common matter has near as much as it can contain, because, when we add a little more to any portion of it, the additional quantity does not enter, but forms an electrical atmosphere. And we know, that common matter has not (generally) more than it can contain, otherwise all loose portions of it would repel each other, as they constantly do when they have electric atmospheres.

10. The beneficial uses of this electric fluid in the creation we are not yet well acquainted with, though doubtless such there are, and those very considerable; but we may see some pernicious consequences that would attend a much greater proportion of it. For, had this globe we live on as much of it in proportion as we can give to a globe of iron, wood, or the like, the particles of dust and other light matters that get loose from it would, by virtue of their separate electrical atmospheres, not only repel each other, but be repelled from the earth, and not easily be brought to unite with it again; whence our air would continually be more and more clogged with foreign matter and grow unfit for respiration. This affords another occasion of adoring that wisdom which has made all things by weight and measure!

11. If a piece of common matter be supposed entirely free from electrical matter, and a single particle of the latter be brought nigh, it will be attracted and enter the body, and take place in the centre, or where the attraction is every way equal. If more particles enter, they take their places where the balance is equal between the attraction of the common matter and their own mutual repulsion. It is supposed that they form triangles, whose sides shorten as their common number increases, till the common matter has drawn in so many that its whole power of compressing those triangles by attraction is equal to their whole power of expanding themselves by repulsion; and then will such a piece of matter receive no more.

Franklin was not a member of any church, but he did believe in a beneficent creator, and felt that he was trying, like Newton, to understand how the world as created by God was supposed to function. Since Franklin's God is very much a rational being, Franklin is curious about the function of the various aspects of nature and how they work to benefit man.

See Edmund Morgan, *Benjamin Franklin*, Yale University Press, New Haven, 2002.
(Note – Morgan has some details of the science incorrect (Gulf Stream direction reversed, p.7, incorrect description of Leyden jar function, p. 12) but he does a good job of describing Franklin's scientific character and beliefs.



Three particles of electrical matter in a triangle within a piece of normal matter.

12. When part of this natural proportion of electrical fluid is taken out of a piece of common matter, the triangles formed by the remainder are supposed to widen, by the mutual repulsion of the parts, until they occupy the whole piece.

13. When the quantity of electrical fluid taken from a piece of common matter is restored again, it enters the expanded triangles, being again compressed till there is a room for the whole.

14. To explain this: take two apples, or two balls of wood or other matter, each having its own natural quantity of the electrical fluid. Suspend them by silk lines from the ceiling. Apply the wire of a well-charged phial, held in your hand, to one of them (*A*) Plate III., Fig. 7, and it will receive from the wire a quantity of the electrical fluid, but will not imbibe it, being already full. The fluid, therefore, will flow round its surface and form an electrical atmosphere. Bring A into contact with B, and half the electrical fluid is communicated, so that each has now an electrical atmosphere, and therefore they repel each other. Take away these atmospheres, by touching the balls, and leave them in their natural state; then, having fixed a stick of sealing-wax to the middle of the phial to hold it by, apply the wire to A, at the same time the coating touches B. Thus will a quantity of electrical fluid be drawn out of B, and thrown on A. So that A will have a redundance of this fluid, which forms an atmosphere round, and B an exactly equal deficiency. Now bring these balls again into contact, and the electrical atmosphere will not be divided between A and B, into two smaller atmospheres as before; for B will drink up the whole atmosphere of A, and both will be found again in their natural state.

Franklin illustrates the equipment for this experiment at the right.

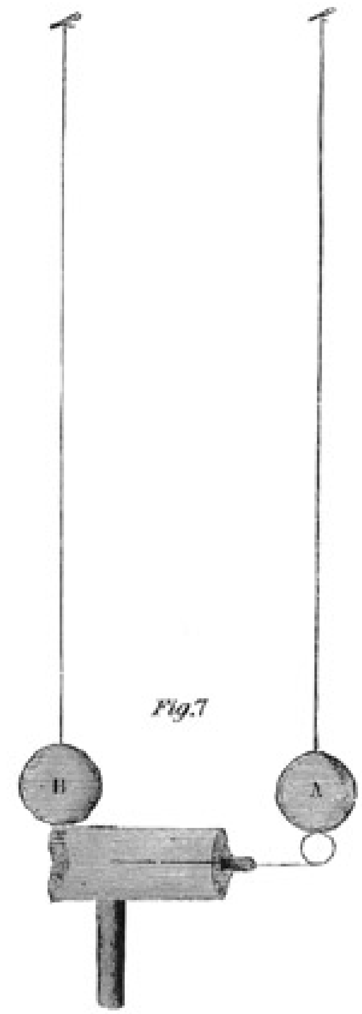


Figure 7 from J. Bigelow 1904 *Works of Benjamin Franklin* Vol. II p. 200 (public domain)

15. The form of the electrical atmosphere is that of the body it surrounds. This shape may be rendered visible in a still air, by raising a smoke from dry rosin dropt into a hot tea-spoon under the electrified body, which will be attracted, and spread itself equally on all sides, covering and concealing the body. And this form it takes, because it is attracted by all parts of the surface of the body, though it cannot enter the substance already replete. Without this attraction, it would not remain round the body, but dissipate in the air.

16. The atmosphere of electrical particles surrounding an electrified sphere is not more disposed to leave it, or more easily drawn off from any one part of the sphere than another, because it is equally attracted by every part. But that is not the case with bodies of any other figure. From a cube it is more easily drawn at the corners than at the plane sides, and so from the angles of a body of any other form, and still more easily from the angle that is most acute. Thus if a body shaped as *A, B, C, D, E,* in Plate III., Fig. 8, be electrified, or have an electrical atmosphere communicated to it, and we consider every side as a base on which the particles rest, and by which they are attracted, one may see, by imagining a line from *A* to *F,* and another from *E* to *G,* that the portion of the atmosphere included in *H, A, B, I,* has the line *A, B* for its basis. And likewise the portion included in *K, B, C, L,* has *B, C* to rest on; and so on the other side of the figure. Now, if you will draw off this atmosphere with any blunt, smooth body, and approach the middle of the side *A, B,* you must come very near, before the force of your attractor exceeds the force or power with which that side holds the atmosphere. But there is a small portion between *I, B, K,* that has less of the surface to rest on, and to be attracted by, than the neighbouring portions, while at the same time there is a mutual repulsion between its particles and the particles of those portions; therefore here you can get it with more ease, or at a greater distance. Between *F, A, H,* there is a larger portion that has yet a less surface to rest on, and to attract it; here, therefore, you can get it away still more easily. But easiest of all, between *L, C, M,* where the quantity is largest, and the surface to attract and keep it back the least. When you have drawn away one of these angular portions of the fluid, another succeeds in its place from the nature of fluidity and the mutual repulsion before mentioned; and so the atmosphere continues flowing off at such angle, like a stream, till no more is remaining. The extremities of the portions of atmosphere over these angular parts are likewise at a greater distance from the electrified body, as may be seen by the inspection of the above figure; the point of the atmosphere of the angle *C* being much farther from *C,* than any other part of the atmosphere over the lines *C, B,* or *B, A*; and besides the distance arising from the nature of the figure, where the attraction is less, the particles will naturally expand to a greater distance by their mutual repulsion. On these accounts we suppose electrified bodies discharge their atmospheres upon unelectrified bodies more easily, and at a greater distance from their angles and points than from their smooth sides. Those points will also discharge into the air, when the body has too great an electrical atmosphere, without bringing any non-electric [conductor] near to receive what is thrown off. For the air, though an electric *per se* [insulator], yet has always more or less of water and other non-electric matters mixed with it; and these attract and receive what is so discharged.

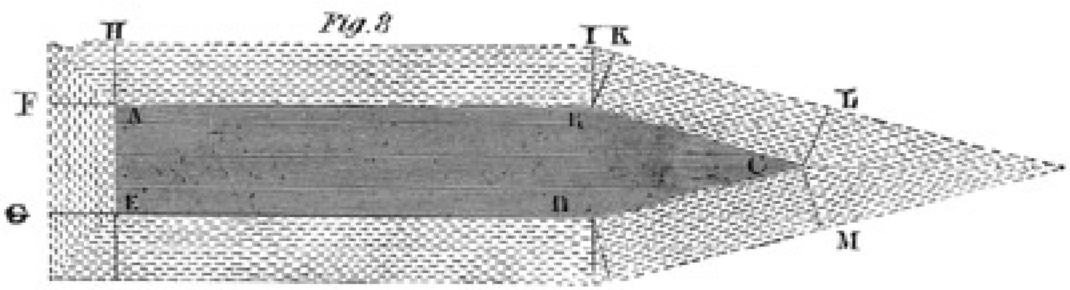


Figure 8 from J. Bigelow 1904
Works of Benjamin Franklin
Vol II. p. 200 (public domain)

The paragraph above lays out Franklin's theory of electric atmospheres, and how he accounts by it for the special characteristics of points. Later he modifies his ideas considerably, but still retains the notion of an electric atmosphere in his thinking. A detailed account of Franklin's theories, their successes, problems, and consequences is given by J. L. Heilbron (*Elements of Early Modern Physics*, Univ. of California Press, 1982, pp187-207.)

17. But points have a property, by which they *draw on* as well as *throw off* the electrical fluid, at greater distances than blunt bodies can. That is, as the pointed part of an electrified body, farther than a blunter part of the same unelectrified body will do. Thus a pin held by the head, and the point presented to an electrified body, will draw off its atmosphere at a foot distance; where, if the head were presented instead of the point, no such effect would follow. To understand this, we may consider that, if a person standing on the floor would draw off the electrical atmosphere from an electrified body, an iron crow and a blunt knitting-needle held alternately in his hand, and presented for that purpose, do not draw with different forces in proportion to their different masses. For the man, and what he holds in his hand, be it large or small, are connected with the common mass of unelectrified matter; and the force with which he draws is the same in both cases, it consisting in the different proportion of electricity in the electrified body and that common mass. But the force with which the electrified body retains its atmosphere by attracting it, is proportioned to the surface over which the particles are placed; that is, four square inches of that surface retain their atmosphere with four times the force that one square inch retains its atmosphere. And as in plucking the hairs from a horse's tail a degree of strength not sufficient to pull away a handful at once could yet easily strip it hair by hair, so a blunt body presented cannot draw off a number of particles at once, but a pointed one, with no greater force, takes them away easily, particle by particle.

18. These explanations of the power and operation of points when they first occurred to me, and while they first floated in my mind, appeared perfectly satisfactory; but now I have written them, and considered them more closely, I must own I have some doubts about them; yet, as I have at present nothing better to offer in their stead, I do not cross them out; for even a bad solution read, and its faults discovered, has often give rise to a good one, in the mind of an ingenious reader.

19. Nor is it of much importance to us to know the manner in which nature executes her laws; it is enough if we know the laws themselves. It is of real use to know that China left in the air unsupported will fall and break; but *how* it comes to fall, and *why* it breaks, are matters of speculation. It is a pleasure indeed to know them, but we can preserve our China without it.

Franklin tries to use his idea of electric atmospheres to explain how points draw charge away from a charged surface. His idea is that a blunt object has to pull a large amount of charge away from the charged surface all at once, but a point, being smaller, can pull the charge from a much smaller area and so does not need as much "pulling force" to remove the charge.

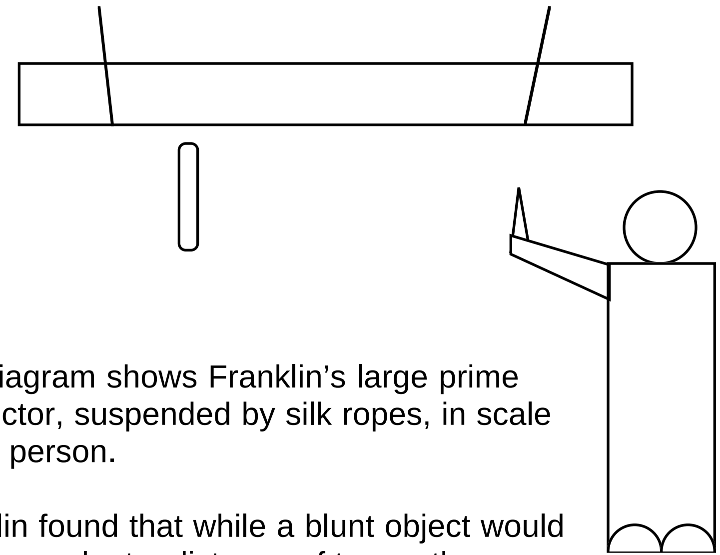
He argues by analogy with pulling hairs, but the analogy is not correct in this case. Franklin's ideas about the electric atmosphere seem to have been important to him in his reasoning, but they sometimes led him astray. Note that Franklin in paragraph 18 admits some doubts about his explanations.

In paragraph 19, he echoes Newton's "I do not feign hypotheses" when he says that we do not have to understand the mechanism of laws of nature, it is enough simply to know the laws.

20. Thus in the present case, to know this power of points may possibly be of some use to mankind, though we should never be able to explain it. The following experiments, as well as those in my first paper, show this power.

I have a large prime conductor, made of several thin sheets of clothier’s pasteboard, formed into a tube, near ten feet long and a foot diameter. It is covered with Dutch embossed paper, almost totally gilt. This large metallic surface supports a much greater electrical atmosphere than a rod or iron of fifty times the weight would do. It is suspended by silk lines, and when charged will strike, at near two inches distance, a pretty hard stroke, so as to make one’s knuckle ache.

Let a person standing on the floor present the point of a needle, at twelve or more inches distance from it, and while the needle is so presented, the conductor cannot be charged, the point drawing off the fire as fast as it is thrown on by the electrical globe. Let it be charged, and then present the point at the same distance, and it will suddenly be discharged. In the dark you may see the light on the point. when the experiment is made. And if the person holding the point stands upon wax, he will be electrified by receiving the fire at that distance. Attempt to draw off the electricity with a blunt body, as a bolt of iron round at the end, and smooth (a silversmith’s iron punch, inch thick, is what I use), and you must bring it within the distance of three inches before you can do it, and then it is done with a stroke and crack. As the pasteboard tube hangs loose on silk lines, when you approach it with the punch-iron, it likewise will move towards the punch, being attracted while it is charged; but if, at the same instant, a point be presented as before, it retires again, for the point discharges it.

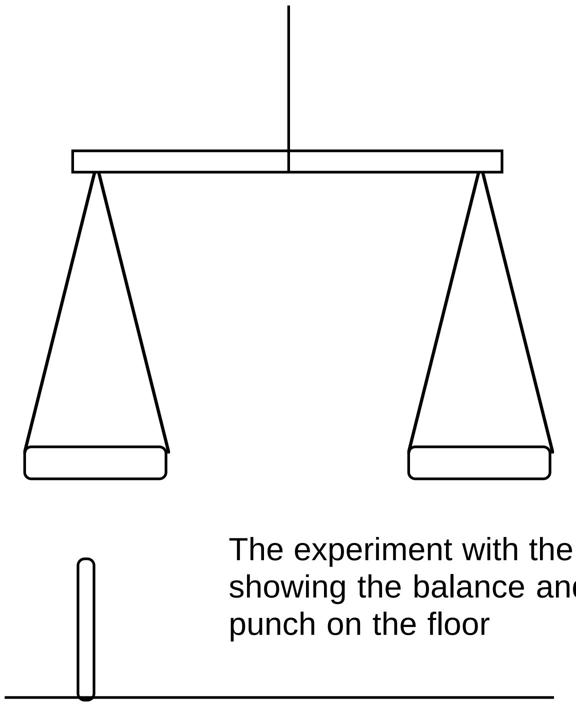


The diagram shows Franklin’s large prime conductor, suspended by silk ropes, in scale with a person.

Franklin found that while a blunt object would draw a spark at a distance of two or three inches from the conductor, a pointed object could attract charge from it at a distance of a foot, as shown in the diagram.

You may repeat the experiments by supporting your prime conductor with monofilament nylon fishing line, and connect it to the rubbing can of your generator with a paper-clip chain. Instead of the silversmith’s iron punch, use a half inch carriage bolt or the back of the bowl of a metal spoon for a blunt object, and a sewing pin or needle for a sharp point. You should be able to observe the same movement of the tube that Franklin saw.

Take a pair of large brass scales, of two or more feet beam, the cords of the scales being silk. Suspend the beam by a pack-thread from the ceiling, so that the bottom of the scales may be about a foot from the floor; the scales will move round in a circle by the untwisting of the pack-thread. Set the iron punch on the end upon the floor, in such a place as that the scales may pass over it in making their circle; then electrify one scale by applying the wire of a charged phial to it. As they move round, you see that scale draw nigher to the floor, and dip more when it comes over the punch; and if that be placed at a proper distance, the scale will snap and discharge its fire into it. But if a needle be stuck on the end of the punch, its point upward, the scale, instead of drawing nigh to the punch and snapping, discharges its fire silently through the point, and rises higher from the punch. Nay, even if the needle be placed upon the floor near the punch, its point upwards, the end of the punch, though so much higher than the needle, will not attract the scale and receive its fire, for the needle will get it and convey it away before it comes nigh enough for the punch to act. And this is constantly observable in these experiments, that the greater quantity of electricity on the pasteboard tube, the farther it strikes or discharges its fire, and the point likewise will draw it off at a still greater distance.



The experiment with the scales, showing the balance and the iron punch on the floor

To repeat this experiment, use a lightweight yardstick for the beam of the scales, monofilament nylon for three lines to support each pan, and disposable aluminum pie tins for the pans of the scales. You can fine tune the balance by adding small weights or pieces of masking tape to one of the pans. The string that supports the scales should not be monofilament, but a twisted string or cord. You may need to ‘wind up’ the apparatus first so that it will unwind slowly. A long string is best for the support.

Now if the fire of electricity and that of lightning be the same, as I have endeavoured to show at large in a former paper, this pasteboard tube and these scales may represent electrified clouds. If a tube of only ten feet long will strike and discharge its fire on the punch at two or three inches distance, an electrified cloud of perhaps ten thousand acres may strike and discharge on the earth at a proportionably greater distance. The horizontal motion of the scales over the floor may represent the motion of the clouds over the earth; and the erect iron punch, a hill or high building; and then we see how electrified clouds passing over hills or high building at too great a height to strike, may be attracted lower till within their striking distance. And lastly, if a needle fixed on the punch with its point upright, or even on the floor below the punch, will draw the fire from the scale silently at a much greater than the striking distance, and so prevent its descending towards the punch; for if in its course it would have come nigh enough to strike, yet being first deprived of its fire it cannot and the punch is thereby secured from the stroke; I say, if these things are so, may not the knowledge of this power of points be of use to mankind in preserving houses, churches, ships, &c., from the stroke of lightning, by directing us to fix on the highest parts of those edifices upright rods of iron made sharp as a needle, and gilt to prevent rusting, and from the foot of those rods, a wire down the outside of the building into the ground, or down round one of the shrouds of a ship, and down her side till it reaches the water? Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike, and thereby secure use from that most sudden and terrible mischief?

Here Franklin scales up his conclusions from these experiments to consider whether pointed metal rods would prevent lightning, (should it be electrical in nature) by discharging clouds in the same way that a needle can discharge a prime conductor without a spark. This leads up to his proposal of an experiment to test whether lighting is in fact an electrical phenomenon, which he makes in the next paragraph.

For more about lightning, see section VII of this manual.

Research done by Charles E. Moore appearing in Geophysical Research Letters suggests that Franklin's conclusion that points would be effective lightning rods to attract lightning was incorrect, and that blunt end rods are actually better at attracting lightning strokes. See the web report in EDS Journal at

<www.esdjournal.com/articles/franklin/franklin.htm>

21. To determine the question whether the clouds that contain lightning are electrified or not, I would propose an experiment to be tried where it may be done conveniently. On the top of some high tower or steeple, place a kind of sentry-box (as in Plate I., Fig. 9), big enough to contain a man and an electrical stand. From the middle of the stand let an iron rod rise and pass bending out of the door, and then upright twenty or thirty feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when such clouds are passing low might be electrified and afford sparks, the rod drawing fire to him from a cloud. If any danger to the mans should be apprehended (though I think there would be none), let him stand on the floor of his box, and now and then bring near to the rod the loop of a wire that has one end fastened to the leads, he holding it by a wax handle; so the sparks, if the rod is electrified, will strike from the rod to the wire and not affect him.

Figure 9 from J. Bigelow 1904 *Works of Benjamin Franklin* Vol. II p. 200 (public domain)

DO NOT TRY THIS AT HOME!

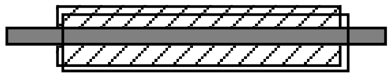
Franklin's experiment was successfully performed in France, but could easily be very dangerous. See sections VII and VIII for more about lightning.

22. Before I leave this subject of lightning, I may mention some other similarities between the effects of that and those of electricity. Lightning has often been known to strike people blind. A pigeon that we struck dead to appearance by the electrical shock, recovering life, drooped about the yard several days, ate nothing, though crumbs were thrown to it, but declined and died. We did not think of its being deprived of sight, but afterwards a pullet, struck dead in like manner, being recovered by repeatedly blowing into its lungs, when set down on the floor ran headlong against the wall, and on examination appeared perfectly blind. Hence we concluded that the pigeon also had been absolutely blinded by the shock. The biggest animal we have yet killed, or tried to kill, with the electrical stroke was a well-grown pullet.

23. Reading in the ingenious Dr. Miles's account of the thunder-storm at Stretham, the effect of the lightning in stripping off all the paint that had covered a gilt moulding of a pannel of wainscot without hurting the rest of the paint, I had a mind to lay a coat of paint over the filleting of gold on the cover of a book, and try the effect ofa strong electrical flash sent through that gold from a charged sheet of glass. But having no paint at hand, I pasted a narrow strip of paper over it, and when dry sent the flash through the gilding, by which the paper was torn off from end to end with such force that it was broken in several places, and in others brought away part of the grain of the Turkey-leather in which it was bound, and convinced me that had it been painted, the paint would have been stripped off in the same manner with that on the wainscot at Stretham.

24. Lightning melts metals, and I hinted in my paper on that subject that I suspected it to be a cold fusion; I do not mean a fusion by force of cold, but a fusion without heat. We have also melted gold, silver, and copper in small quantities by the electrical flash. The manner is this: Take leaf-gold, leaf-silver, or leaf-gilt copper, commonly called leaf-brass, or Dutch gold; cut off from the leaf long narrow strips the breadth of a straw. Place one of these strips between two strips of smooth glass that are about the width of your finger. If one strip of gold the length of the leaf be not long enough for the glass, add another to the end of it, so that you may have a little part hanging out loose at each end of the glass. Bind the pieces of glass together from end to end with strong silk thread; then place it so as to be part of an electrical circuit (the ends of gold hanging out being of use to join with the other parts of the circuit), and send the flash through it, from a large electrified jar or sheet of glass. Then, if your strips of glass remain whole, you will see that the gold is missing in several places, and instead of it a metallic stain on both glasses; the stains on the upper and under glass exactly similar in the minutest stroke, as may be seen by holding them to the light; the metal appeared to have been not only melted, but even vitrified, or otherwise so driven into the pores of the glass, as to be protected by it from the action of the strongest *aqua fortis* or *aqua regia*. I send you enclosed two little pieces of glass with these metallic stains upon them, which cannot be removed without taking part of the glass with them. Sometimes the stain spreads a little wider than the breadth of the leaf, and looks brighter at the edge, as by inspecting closely you may observe in these. Sometimes the glass breaks to pieces; once the upper glass broke into a thousand pieces, looking like coarse salt. The pieces I send you were stained with Dutch gold. True gold makes a darker stain, somewhat reddish; silver, a greenish stain. We once took two pieces of thick looking glass, as broad as a gunter's scale, and six inches long; and, placing gold-leaf between them, put them between two smoothly-plained pieces of wood, and fixed them tight in a book-binder's small press; yet, though they were so closely confined, the force of the electrical shock shivered the glass into many pieces. The gold was melted, and stained into the glass, as usual. The circumstances of the breaking of the glass differ much in making the experiment, and sometimes it does not break at all; but this is constant, that the stains in the upper and under pieces are exact counterparts of each other. And though I have taken up the pieces of glass between my fingers immediately after this melting, I never could perceive the least warmth in them.

Franklin later rejected the idea of "cold fusion" as he collected more evidence of the effects of lightning and made larger Leyden jars, giving larger sparks.

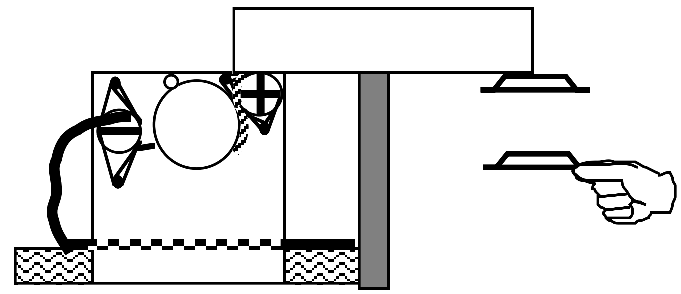


A thin strip of metal bound between two glass microscope slides would approximate Franklin's set up. The metal would have to be very thin, and a large charge would be needed to get the same effect Franklin saw. This experiment is probably not practical to safely do at home.

25a. In one of my former papers I mentioned that gilding on a book, though at first it communicated the shock perfectly well, yet failed after a few experiments, which we could not account for. We have since found, that one strong shock breaks the continuity of the gold in the filleting, and makes it look rather like dust of gold, abundance of its parts being broken and driven off; and it will seldom conduct above one strong shock. Perhaps this may be the reason; when there is not a perfect continuity in the circuit, the fire must leap over the vacancies; there is a certain distance which it is able to leap over according to its strength; if a number of small vacancies, though each be very minute, taken together exceed that distance, it cannot leap over them, and so the shock is prevented.

I have not tried this experiment successfully, not having leather bound books with gold filleting readily to hand. You can purchase thin gold leaf or brass leaf at a craft store and try to recreate this effect. You will probably need to make a Leyden jar from a one pint size plastic jar such as peanut butter comes in, and charge it vigorously on your generator to get a strong enough shock. Be careful–the shock would not be dangerous, but might be stronger than you wish to feel.

25b. From the before-mentioned law of electricity, that points, as they are more or less acute, draw on and throw off the electrical fluid with more or less power, and at greater or less distances, and in larger or smaller quantities in the same time, we may see how to account for the situation of the leaf of gold suspended between two plates, the upper one continually electrified, the under one in a person's hand standing on the floor. When the upper plate is electrified, the leaf is attracted and raised towards it, and would fly to that plate, were it not for its own points. The corner that happens to be uppermost when the leaf is rising, being a sharp point, from the extreme thinness of the gold, draws and receives at a distance a sufficient quantity of the electric fluid to give itself an electric atmosphere, by which its progress to the upper plate is stopped, and it begins to be repelled from that plate, and would be driven back to the under plate, but that its lowest corner is likewise a point, and throws off or discharges the overplus of the leaf's atmosphere as fast as the upper one draws it on. Were these two points perfectly equal in acuteness, the leaf would take place exactly in the middle space, for its weight is a trifle compared to the power acting on it; but it is generally nearest the unelectrified plate, because, when the leaf is offered to the electrified plate, at a distance, the sharpest point is commonly first affected and raised towards it; so *that* point, from its greater acuteness, receiving the fluid faster than its opposite can discharge it at equal distance, it retires from the electrified plate and draws nearer to the unelectrified plate, till it comes to a distance where the discharge can be exactly equal to the receipt, the latter being lessened and the former increased; and there it remains as long as the glove continues to supply fresh electrical matter. This will appear plain, when the difference of acuteness in the corners is made very great.



Two aluminum pie tins will serve as plates.Suspend one from the prime conductor, perhaps with masking tape, making sure a good connection is made with the conductor. Hold the other in the hand. The shape of the metal leaf is shown in Franklin's figure on the next page. Instead of gold leaf, try the thin foil peeled from a gum wrapper.

25c. Cut a piece of Dutch gold (which is fittest for these experiments on account of its great strength) into the form of Figure 10, the upper corner a right angle, the two next obtuse angles, and the lowest a very acute one; and bring this on your plate, under the electrified plate, in such a manner as that the right-angled part may be first raised (which is done by covering the acute part with the hollow of your hand), and you will see this leaf take place much nearer to the upper than the under plate; because, without being nearer, it cannot receive so fast at its right-angled point as it can discharge at its acute one. Turn this leaf with the acute part uppermost, and the it takes place nearest the unelectrified plate; because otherwise it receives faster at its acute point than it can discharge at its right-angled one. Thus the difference of distance is always proportioned to the difference of acuteness. Take care, in cutting your leaf, to leave no little ragged particles on the edges, which sometimes form points where you would not have them

25d. You may make this figure so acute below and blunt above, as to need no under plate, it discharging fast enough into the air. When it is made narrower, as the figure between the pricked lines, we call it the *golden fish*, from its manner of acting. For if you take it by the tail, and hold it at a foot or greater horizontal distance from the prime conductor, it will, when let go, fly to it with a brisk but wavering motion, like that of an eel through the water; it will then take place under the prime conductor, at perhaps a quarter or half an inch distance, and keep a continual shaking of the tail like a fish, so that it seems animated. Turn its tail towards the prime conductor, and then it flies to your finger, and seems to nibble at it. And if you hold a plate under it at six or eight inches distance, and cease turning the globe, when the electrical atmosphere of the conductor grows small, it will descend to the plate, and swim back again several times, with the same fish-like motion, greatly to the entertainment of spectators. By a little practice in blunting or sharpening the heads or tails of these figures, you may make them take place as desired, nearer or farther from the electrified plate.

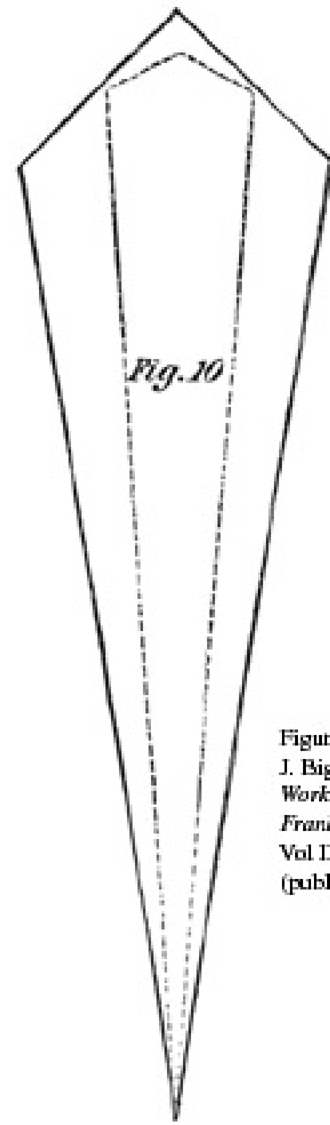


Figure 10 from
J. Bigelow 1904
Works of Benjamin Franklin
Vol II. p. 200
(public domain)

27. It is said, in section eighth of this paper, that all kinds of common matter are supposed not to attract the electrical fluid with equal strength; and that those called electrics *per se*,[non-conductors or insulators] as glass, &c., attract and retain it strongest, and contain the greatest quantity. This latter position may seem a paradox to some, being contrary to the hitherto received opinion; and therefore I shall now endeavour to explain it.

28. In order to this, let it first be considered *that we cannot, by any means we are yet acquainted with, force the electrical fluid through glass.* I know it is commonly thought that it easily pervades glass; and the experiment of a feather suspended by a thread, in a bottle hermetically sealed, yet moved by bringing a rubber tube near the outside of the bottle, is alleged to prove it. But if the electrical fluid so easily pervades glass, how does the phial become *charged* (as we term it), when we hold it in our hands? Would not the fire, thrown in by the wire, pass through to our hands , and so escape into the floor? Would not the bottle in that case be left just as we found it, uncharged, as we know a metal bottle so attempted to be charged would be? Indeed, if there be the least crack, the minutest solution of continuity in the glass, though it remains so tight that nothing else we know of will pass, yet the extremely subtile electric fluid flies through such a crack with the greatest freedom, and such a bottle we know can never be charged; what then makes the difference between such a bottle and one that is sound, but this, that the fluid can pass through the one and not through the other[1].

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[1] See the first sixteen sections of the former paper, No. LXI. [Section IV of this manual- Bigelow Vol: II: pp. 237-253; Morse pp.16-24]

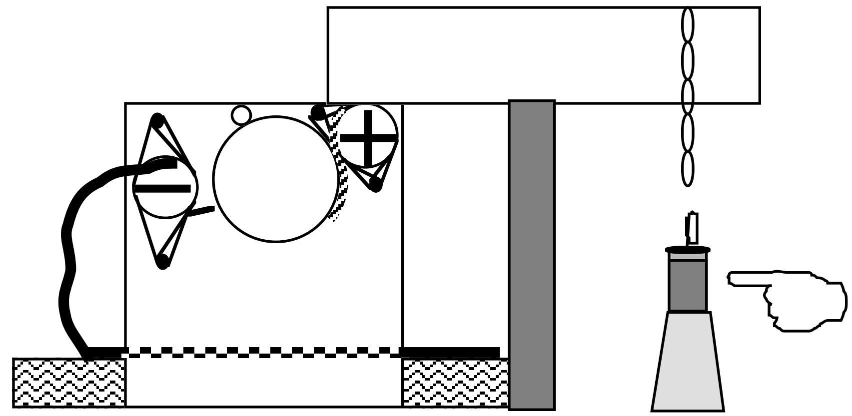
Hang a thin strip of tissue paper or toilet paper from a thread, and suspend it inside an empty bottle so that it is about an inch or less from the side of the bottle.Bring the charged tube near the outside of the bottle, and you should see the strip of tissue attracted to the inner wall of the bottle.

29. It is true there is an experiment that at first sight would be apt to satisfy a slight observer that the fire thrown into the bottle by the wire does really pass through the glass. It is this. Place the bottle on a glass stand under the prime conductor; suspend a bullet by a chain from the prime conductor till it comes within a quarter of an inch right over the wire of the bottle; place your knuckle on the glass stand at just the same distance from the coating of the bottle as the bullet is from its wire. Now let the globe be turned, and you see a spark strike from the bullet to the wire of the bottle, and the same instant you see and feel an exactly equal spark striking from the coating on your knuckle, and so on, spark for spark. This looks as if the whole received by the bottle was again discharged from it. And yet the bottle by this means is charged! And therefore the fire that thus leaves the bottle, though the same in quantity, cannot be the very same fire that entered at the wire, for if it were, the bottle would remain uncharged.

See § 10 of paper No. LXI.
[Section IV of this manual- Bigelow Vol: II: pp. 237-253; Morse pp.16-24]

30. If the fire that so leaves the bottle be not the same that is thrown in through the wire, it must be fire that subsisted in the bottle (that is, in the glass of the bottle) before the operation began.

31. If so there must be a great quantity in glass, because a great quantity is thus discharged, even from very thin glass.



The experiment can be done with the setup shown above. Use a chain of paper clips hanging from the prime conductor to come near to the clip on the film can Leyden jar. Bring your finger near the coating, while someone turns the crank of the generator.

Here Franklin is showing that charge goes into the top of the Leyden jar, and out of the side of the Leyden jar, but does not pass through the walls of the jar, an interpretation that had been proposed by other experimenters.

Franklin ascribes special properties to glass, partly because he had little easy opportunity to experiment with capacitors made of other insulators. No other insulating material at the time was capable of being made easily into a capacitor, at least in jar form. Later experiments with wax and air capacitors made by others showed that it was not a special property of glass that accounted for capacitance, but the arrangement of two conducting surfaces separated by an insulator. See Heilbron, 1982, *Elements of Early Modern Physics*, Chapter III.

32. That this electrical fluid or fire is strongly attracted by glass, we know from the quickness and violence with which it is resumed by the part that had been deprived of it when there is an opportunity. And by this, that we cannot from a mass of glass draw a quantity of electric fire, or electrify the whole mass *minus*, as we can a mass of metal. We cannot lessen or increase its whole quantity, for the quantity it has it holds, and it has as much as it can hold. Its pores are filled with it as full as the mutual repellency of the particles will admit, and what is already in refuses, or strongly repels, any additional quantity. Nor have we any way of moving the electrical fluid in glass, but one; that is, by covering part of the two surfaces of thin glass with non-electrics [conductors], and then throwing an additional quantity of this fluid on one surface, which, spreading in the non-electric[conductor], and being bound by it to that surface, acts by its repelling force on the particles of the electrical fluid contained in the other surface, and drives them out of the glass into the non-electric[conductor] on that side from whence they are discharged, and then those added on the charged side can enter. But when this is done there is no more in the glass, nor less, than before, just as much having left it on one side as it received on the other.

Franklin states that we cannot electrify a whole piece of glass with negative charge as we can a large piece of metal. This is not true, glass can be charged negatively by rubbing as well as positively, but Franklin had no experience of charging it negatively in his experiments. He is ignoring here the fact that he can charge a piece of glass, such as the glass tube, with a net positive charge by rubbing it.

33. I feel a want of terms here, and doubt much whether I shall be able to make this part intelligible. By the word *surface*, in this case, I do not mean mere length and breadth without thickness; but, when I speak of the upper or under surface of a piece of glass, the outer or inner surface of the phial, I mean length, breadth, and half the thickness, and beg the favor of being so understood.

Now I suppose that glass, in its first principles, and in the furnace, has no more of this electrical fluid than other common matter; that when it is blown, as it cools, and the particles of common fire leave it, its pores become a vacuum; that the component parts of glass are extremely small and fine, I guess from its never showing a rough face when it breaks, but always a polish; and from the smallness of its particles I suppose the pores between them must be exceedingly small, which is the reason that *aqua fortis*, nor any other other menstruum that we have, can enter to separate them and dissolve the substance; nor is any fluid we know of fine enough to enter, except common fire and the electric fluid. Now the departing fire, leaving a vacuum, as aforesaid, between these pores, which air nor water are fine enough to enter and fill, the electric fluid (which is everywhere ready in what we call the non-electrics [conductors], and in the non-electric mixtures [conducting mixtures] that are in the air) is attracted in; yet does not become fixed with the substance of the glass, but subsists there as water in a porous stone, retained only by the attraction of the fixed parts, itself still loose and a fluid.

But I suppose farther, that, in the cooling of the glass, its texture becomes closest in the middle, and forms a kind of partition, in which the pores are so narrow that the particles of the electrical fluid, which enter both surfaces at the same time, cannot go through, or pass and repass from one surface to the other, and so mix together; yet, though the particles of electric fluid imbibed by each surface cannot themselves pass through to those of the other, their repellency can, and by this means they act on one another. The particles of the electric fluid have a mutual repellency, but by the power of attraction in the glass they are condensed or forced near to each other. When the glass has received, and by its attraction forced closer together, so much of this electric fluid, as that the power of attracting and condensing in the one, is equal to the power of expansion in the other, it can imbibe no more, and that remains its constant whole quantity; but each surface would receive more, if the repellency of what is in the opposite surface did not resist its entrance. The quantities of this fluid in each surface being equal, their repelling action on each other is equal; and therefore those of one surface cannot drive out those of the other; but if a greater quantity is forced into one surface than the glass would naturally draw in, this increases the repelling power on that side, and, overpowering the attraction on the other, drives out part of the fluid that had been imbibed by that surface, if there be any non-electric ready to receive it; such there is in all cases where glass is electrified to give a shock. The surface that has been thus emptied, by having its electrical fluid driven out, resumes again an equal quantity with violence, as soon as the glass has an opportunity to discharge that over quantity more than it could retain by attraction in its other surface, by the additional repellency of which the vacuum had been occasioned. For experiments favoring (if I may not say confirming) this hypothesis, I must, to avoid repetition, beg leave to refer you back to what is said of the electrical phial in my former papers.

Franklin later abandons his idea that the atomic structure of glass is different in the middle of the glass than near the surfaces. The paragraph above is a fairly clear statement of the mechanism he proposes for charge added to one surface driving out charge from the opposite surface, and is essentially a mechanism for electrostatic induction. Franklin is implicitly using action at a distance but never states that explicitly in this passage

34. Let us now see how it will account for several other appearances.

Glass, a body extremely elastic (and perhaps its elasticity may be owing in some degree to the subsisting of so great a quantity of this repelling fluid in its pores), must, when rubbed, have its rubbed surface somewhat stretched, or its solid parts drawn a little farther asunder, so that the vacancies, in which the electrical fluid resides, become larger, affording room for more of that fluid, which is immediately attracted into it from the cushion or handrubbing, they being supplied from the common stock. But the instant the parts of the glass so opened and filled have passed the friction, they close again, and force the additional quantity out upon the surface, where it must rest till that part comes round to the cushion again, unless some non-electric [conductor] (as the prime conductor) first present to receive it.[1]

But if the inside of the globe be lined with a non-electric [conductor], the additional repellency of the electrical fluid thus collected by friction on the rugged part of the globe's outer surface drives an equal quantity out of the inner surface into that non-electric [conducting] lining, which, receiving it and carrying it away from the rubbed part into the common mass through the axis of the globe and frame of the machine, the new-collected electrical fluid can enter and remain in the outer surface, and none of it (or a very little) will be received by the prime conductor. As this charged part of the globe comes round to the cushion again, the outer surface delivers its overplus fire into the cushion, the opposite inner surface receiving at the same time an equal quantity from the floor. Every electrician knows that a globe wet within will afford little or no fire; but the reason has not before been attempted to be given, that I know of.

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[1] In the dark the electric fluid may be seen on the cushion in two semi-circles or half-moons, one on the fore part, the other on the back part of the cushion, just where the globe and cushion separate. In the fore crescent the fire is passing out of the cushion into the glass; in the other it is leaving the glass and returning into the back part of the cushion. When the prime conductor is applied to take it off the glass, the back crescent disappears.–F.

35a So, If a tube lined with a non-electric [conductor] be rubbed[1], little or no fire is obtained from it; what is collected from the hand in the downward rubbing stroke entering the pores of the glass, and driving an equal quantity out of the inner surface into the non-electric lining; and the hand, in passing up to take a second stroke, takes out again what had been thrown into the outer surface, and then the inner surface receives back again what it had given to the non-electric [conducting] lining. Thus the particles of electrical fluid belonging to the inside surface go in and out of their pores every stroke given to the tube.

35b. Put a wire into the tube, the inward end in contact with the non-electric lining, so it will represent the Leyden bottle. Let a second person touch the wire while you rub, and the fire, driven out of the inward surface when you give the stroke, will pass through him into the common mass, and return through him when the inner surface resumes its quantity, and therefore this new kind of Leyden bottle cannot be so charged.

35c. But thus it may: after every stroke, before you pass your hand up to make another, let a second person apply his hand to the wire, take the spark, and then withdraw his finger; and so on till he has drawn a number of sparks; thus will the inner surface be exhausted, and the outer surface charged; then wrap a sheet of gilt paper close round the outer surface, and grasping it in your hand you may receive a shock by applying the finger of the other hand to the wire; for now the vacant pores in the inner surface resume their quantity, and the overcharged pores in the outer surface discharge their overplus; the equilibrium being restored through your body, which could not be restored through the glass.[2]

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[1] Gilt paper, with the gilt face next the glass, does well.

[2] See paper No. LXI., § 15.[Section IV of this manual or Bigelow Vol: II: pp. 237-253; in Morse pp.16-24]

A tube lined with a conductor would appear to be less charged by a single stroke because an opposite charge would be induced on the part of the conductor that is immediately under the rubbed part of the tube, which would reduce the apparent electrification of the surface of the tube. Franklin then shows that this behaves like a Leyden jar, and can be discharged by wrapping the outer surface with a conductor and touching both the inner and outer surfaces.

To try this in a small version, you could line a plastic drink cup with foil, rub its outer surface with fur or on dry hair, and then wrap a second piece of foil around it and attempt to get a discharge.

35d. If the tube be exhausted of air, a non-electric [conducting] lining in contact with the wire is not necessary; for *in vacuo* the electrical fire will fly freely from the inner surface without a non-electric conductor; but air resists its motion; for being itself an electric *per se* [insulator], it does not attract it, having already its quantity. So the air never draws off an electric atmosphere from any body, but in proportion to the non-electrics [conductors] mixed with it; it rather keeps such an atmosphere confined, which, from the mutual repulsion of its particles, tends to dissipation, and would immediately dissipate *in vacuo*.

And thus the experiment of the feather enclosed in a glass vessel hermetically sealed, but moving on the approach of the rubbed tube, is explained. When an additional quantity of the electrical fluid is applied to the side of the vessel by the atmosphere of the tube, a quantity is repelled and driven out of the inner surface of that side into the vessel, and there affects the feather, returning again into its pores when the tube with its atmosphere is withdrawn; not that the particles of that atmosphere did themselves pass through the glass to the feather. And every other appearance I have yet seen, in which glass and electricity are concerned, are, I think, explained with equal ease by the same hypothesis. Yet perhaps it may not be a true one, and I shall be obliged to him that affords me a better.

Hauksbee (see Section I of this manual) had experimented with electrical charging of evacuated glass globes. The physics of electricity at low pressures is interesting and complex. At the voltages Franklin was using, he would have ionized the gas inside the tube which would then act as a conducting lining.

Franklin's explanation uses his idea of electric atmospheres and a less definite idea of action at a distance to explain the induction of charge on the inside surface of the glass tube, which then affects the feather.

36 Thus I take the difference between non-electrics [conductors] and glass, an electric *per se* [insulator], to consist in these two particulars.

1st, that a non-electric [conductor] easily suffers a change in the quantity of the electric fluid it contains. You may lessen it whole quantity by drawing out a part, which the whole body will again resume; but of glass you can only lessen the quantity contained in one of its surfaces; and not that, but by supplying an equal quantity at the same time to the other surface; so that the whole glass may always have the same quantity in the two surfaces, their two different quantities being added together. And this can only be done in glass that is thin; beyond a certain thickness we have yet no power than can make this change.

And 2dly, that the electric fire freely moves from place to place in and through the substance of a non-electric [conductor], but not so through the substance of glass. If you offer a quantity to one end of a long rod of metal it receives it, and when it enters every particle that was before in the rod pushes its neighbour quite to the farther end, where the overplus is discharged; and this instantaneously, where the rod if part of the circle in the experiment of the shock. But glass, from the smallness of its pores, or stronger attraction of what it contains, refuses to admit so free a motion; a glass rod will not conduct a shock, nor will the thinnest glass suffer any particle entering one of its surfaces to pass through to the other.

Franklin is not correct in stating that glass cannot have a net charge, but he is correctly distinguishing the behavior of conductors from insulators in this paragraph.

37. Hence we see the impossibility of success in the experiments proposed to draw out the effluvial virtues of a non-electric [conductor], as cinnamon, for instance, and mixing them with the electric fluid, to convey them with that into the body by including it in the globe, and then applying friction, &c. For, though the effluvia of cinnamon and the electric fluid should mix within the globe, they would never come out together through the pores of the glass, and so go to the prime conductor, for the electric fluid itself cannot come through, and the prime conductor is always supplied from the cushion, and that from the floor. And besides, when the globe is filled with cinnamon, or other non-electric, no electric fluid can be obtained from its outer surface, for the reason before mentioned. I have tried another way, which I thought more likely to obtain a mixture of the electric and other effluvia together, if such a mixture had been possible. I placed a glass plate under my cushion, to cut off the communication between the cushion and the floor, then brought a small chain from the cushion into a glass of oil of turpentine, and carried another chain from the oil of turpentine to the floor, taking care that the chain from the cushion to the glass should touch no part of the frame of the machine. Another chain was fixed to the prime conductor, and held in the hand of a person to be electrified. The ends of the two chains in the glass were near an inch distant from each other, the oil of turpentine between. Now the globe being turned could draw no fire from the floor through the machine, the communication that way being cut off by the thick glass plate under the cushion; it must then draw it through the chains whose ends were dipped in the oil of turpentine. And as the oil of turpentine, being an electric *per se* [insulator], would not conduct, what came up from the floor was obliged to jump from the end of one chain to the end of the other, through the substance of that oil, which we could see in large sparks, and so it had a fair opportunity of seizing some of the finest particles of the oil in its passage, and carrying them off with it; but no such effect followed, nor could I perceived the least difference in the smell of the electric effluvia thus collected, from what it has when collected otherwise nor does it otherwise affect the body of a person electrized. I likewise put into a phial, instead of water, a strong purgative liquid, and then charged the phial, and took repeated shocks from it, in which case every particle of the electrical fluid must, before it went through my body, have first gone through the liquid when the phial is charging, and returned through it when discharging, yet no other effect followed than if it had been charged with water. I have also smelled the electric fire when drawn through gold, silver, copper, lead, iron, wood, and the human body, and could perceive no difference; the odor is always the same, where the spark does not burn what it strikes; and therefore I imagine it does not take that smell from any quality of the bodies it passes through. And indeed, as that smell so readily leaves the electric matter, and adheres to the knuckle receiving the sparks, and to other things, I suspect that it never was connected with it, but arises instantaneously from something in the air acted upon by it. For if it was fine enough to come with the electric fluid through the body of one person, why should it stop on the skin of another?

Spark discharges in air are accompanied by a smell due to the production of ozone when an oxygen molecule is ionized by the spark and the ions combine with other oxygen molecules.

Since people thought that the electrical fluid was a material substance, the supposition was that the smell was that of loose particles of the electrical fluid.

Since other gases and liquids can pick up flavors and odors, for instance vanilla dissolved in alcohol, it was thought that the electrical fluid might be able to pick up an odor from a substance and carry it along through wires, etc.

Franklin’s experiment with the turpentine showed no sign that any odor or flavor of turpentine accompanied the passage of electricity through the turpentine and into other bodies.

Franklin finally suspects (correctly) that the odor associated with electricity is due to some action in the air acted on by the spark.

38. But I shall never have done, if I tell you all my conjectures, thoughts, and imaginations on the nature and operations of this electric fluid, and relate the variety of little experiments we have tried. I have already made this paper too long, for which I must crave pardon, not having now time to abridge it. I shall only add that, as it has been observed here that spirits will fire by the electric spark in the summer-time without heating them, when Fahrenheit's thermometer is above seventy; so, when colder, if the operator puts a small flat bottle of spirits in his bosom, or a close pocket, with the spoon, some little time before he uses them, the heat of his body will communicate warmth more than sufficient for the purpose.

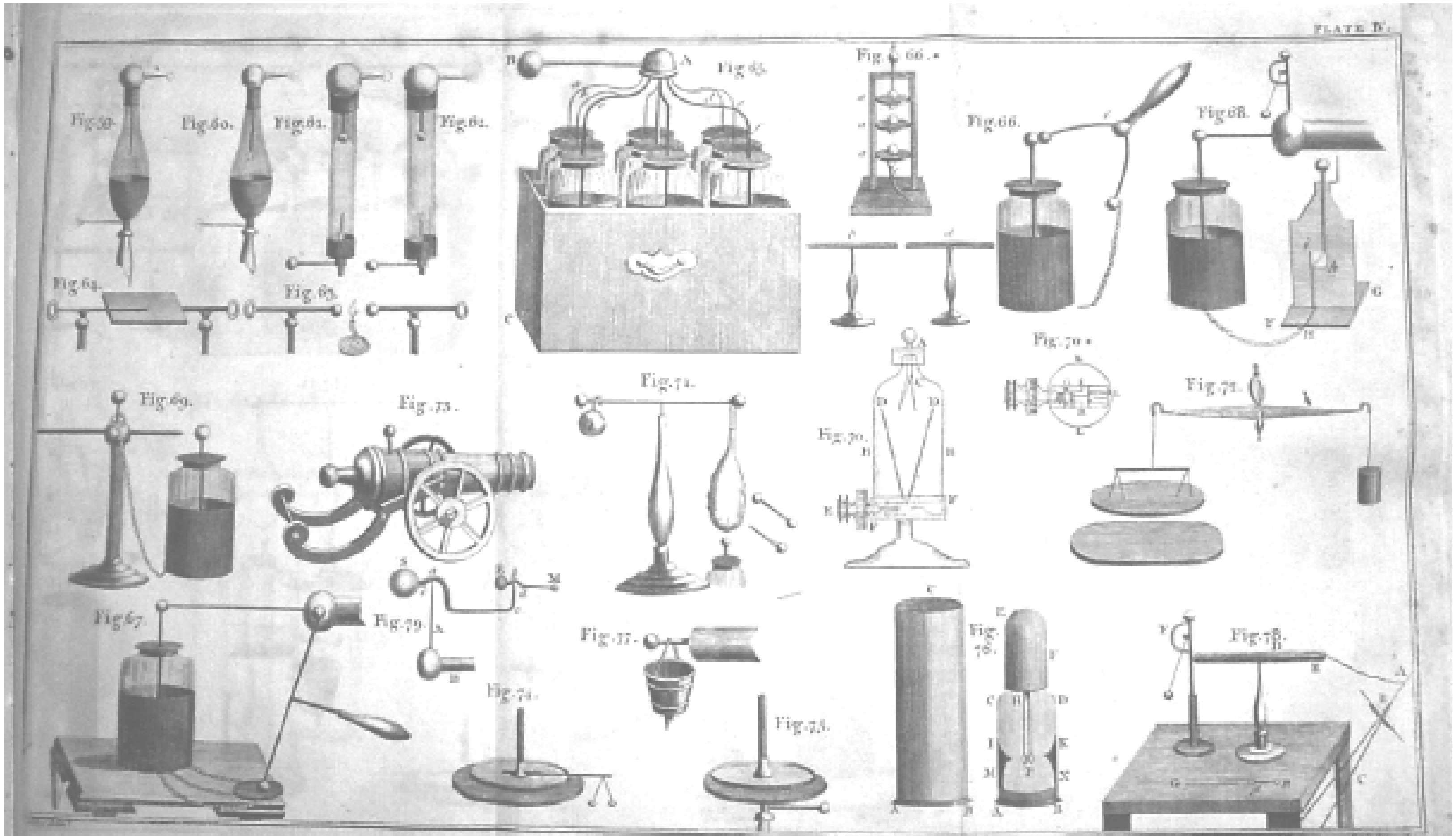


Plate V from George Adams, *Lectures on Natural Philosophy*, 2nd ed. J. Dillon & Co. London, 1799
Courtesy of The Burndy Library, Dibner Institute for the History of Science & Technology, Cambridge, Massachusetts

Many variations of electrical experiments were developed and tried by those following Franklin, and published in books of electrical experiments for people to try for themselves by purchasing the equipment listed in catalogs of electrical instruments. The plate at left shows only a few of the hundreds of experiments that could be purchased, and explained using the Franklinian system.

Franklin concludes his long theoretical discussion with a short set of experiments again illustrating his ideas about the Leyden jar and what we would now call the conservation of charge.

39.

ADDITIONAL EXPERIMENTS

Proving that the Leyden Bottle has no more Electrical Fire in it when charged than before, nor less when discharged; that, in discharging , the Fire does not issue from the Wire and the Coating at the same Time, as some have thought, but that the Coating always receives what is discharged by the Wire, or an equal Quantity; the outer Surface being always in a Negative State of Electricity, when the inner Surface is in a positive State.

40.
Place a thick plate of glass under the rubbing cushion, to cut off the communication of electrical fire from the floor to the cushion; then, if there be no fine points or hairy threads sticking out from the cushion, or from the parts of the machine opposite to the cushion (of which you must be careful), you can get but a few sparks from the prime conductor, which are all the cushion will part with.

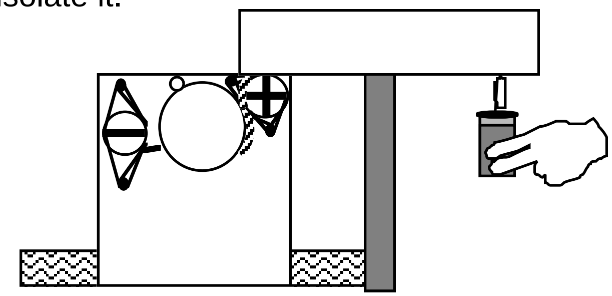
Hang a phial then on the prime conductor , and it will not charge, though you hold it by the coating.

But–
Form a communication by a chain from the coating to the cushion, and the phial will charge.

For the globe then draws the electric fire out of the outside surface of the phial, and forces it through the prime conductor and wire of the phial into the inside surface.

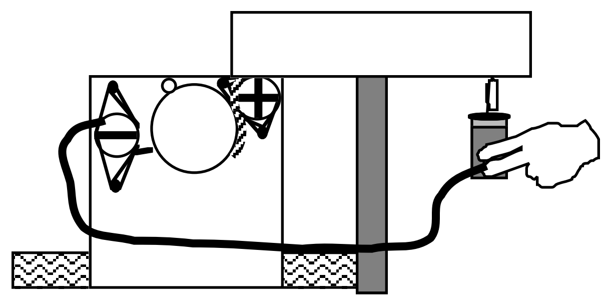
Thus the bottle is charged with it's own fire, no other being to be had while the glass plate is under the cushion.

Franklin had to insulate the cushion of his generator from the floor with a plate of glass. You can simply remove the long strip of foil that connected the negative can to the base of your generator in order to isolate it.

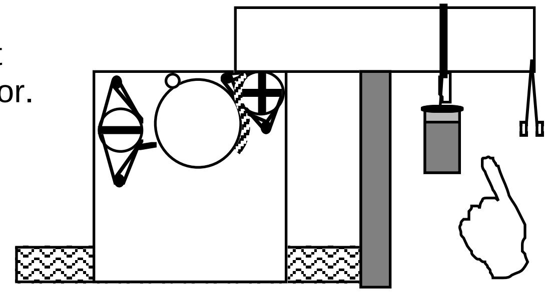


If you now try to charge the prime conductor, you will only get a few sparks as Franklin says.

Try to charge the Leyden jar without grounding the negative can and again there will be little charge accumulated in the jar.
Connect the coating to the negative can with a wire, chain or foil, and it will charge as usual



In the following experiments Franklin shows that positive and negative charges on a charged Leyden jar exactly cancel and that they do not change the overall charged state of the prime conductor.



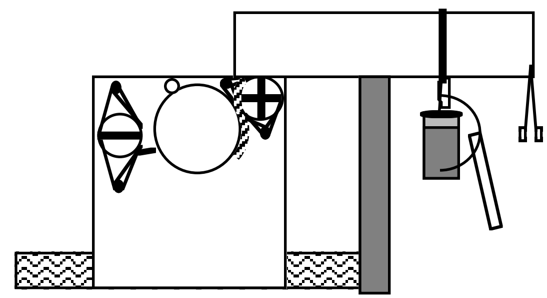
Hang the Leyden jar from the prime conductor with a strip of foil, and attach a pair of hanging foil bits on tinsel.
With no connection to the negative can, touch the coating of the bottle while cranking the generator.

Hang two cork balls by flaxen threads to the prime conductor; then touch the coating of the bottle, and they will be electrified and recede from each other.

For, just as much fire as you give the coating, so much is discharged through the wire upon the prime conductor, whence the cork balls receive an electrical atmosphere. But–

Take a wire bent in the form of a C, with a stick of wax fixed to the outside of the curve to hold it by; an apply one end of this wire to the coating, and the other at the same time to the prime conductor, the phial will be discharged; and if the balls are not electrified before the discharge, neither will they appear to be so after the discharge, for they will not repel each other.

Hang a charged Leyden jar from the prime conductor with a strip of foil, and attach a pair of hanging foil bits on tinsel. With no connection to the coating, touch the prime conductor with a finger to neutralize it.



If the phial really exploded at both ends, and discharged fire from both coating and wire, the balls would be *more* electrified, and recede *farther*; for none of the fire can escape, the wax handle preventing.

A partially straightened large paper clip attached to a plastic straw can be used to touch both the coating and hook of the Leyden jar. This should not change the condition of the hanging foil bits.

But if the fire with which the inside surface is surcharged be so much precisely as is wanted by the outside surface, it will pass round through the wire fixed to the wax handle, restore the equilibrium in the glass, and make no alteration in the state of the prime conductor.

Repeat the experiment, but this time leave the prime conductor charged with the charged jar hanging from it. Again discharge the jar with the straw and paper clip. This time the foil bits should remain apart.

Accordingly we find that if the prime conductor be electrified, and the cork balls in a state of repellency before the bottle is discharged, they continue so afterwards. If not, they are not electrified by that discharge.