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.

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Part V. Franklin's theory of atmospheric electrification and the possibility that lightning is electric.

Franklin describes his theory on how clouds might become electrified.

Letter V. Benjamin Franklin to Peter Collinson

(April 29, 1749) *Bigelow Vol. II, p. 253-266*
(Date from Cohen from Bowdoin MS)

In this letter Franklin sets forth his theory of atmospheric electricity, extrapolating from his experiments and the accepted science of the time, he formulates a theory as to how clouds become electrically charged, and puts forward his idea that lightning is in fact an electrical discharge.

5.01
To: Peter Collinson

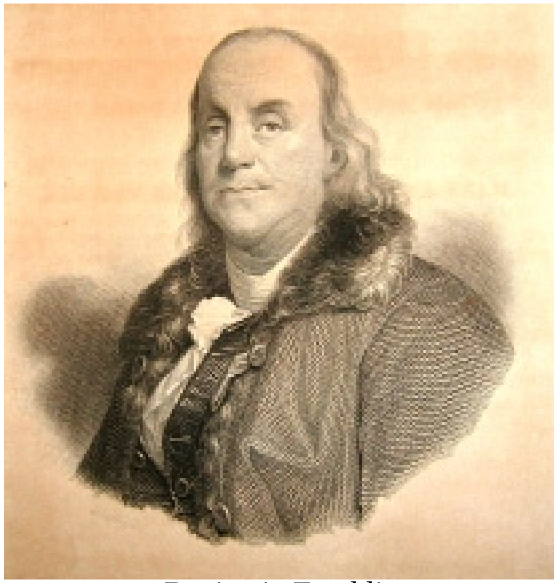
Sir: – Non-electric bodies [conductors], that have electric fire thrown into them. will retain it till other electrics [insulators], that have less, approach; and then it is communicated by a snap, and becomes equally divided.

5.02
2. Electrical fire loves water, is strongly attracted by it, and they can subsist together.

5.03
3. Air is an electric *per se* [insulator], and when dry will not conduct the electrical fire; it will neither receive it, nor give it to other bodies; otherwise no body surrounded by air could be electrified positively and negatively; for, should it be attempted positively, the air would immediately take away the overplus; or negatively, the air would supply what was wanting.

5.04
4. Water being electrified, the vapors arising from it will be equally electrified, and floating in the air, in the form of clouds, or other wise, will retain that quantity of electrical fire, till they meet with other clouds or bodies not so much electrified, and then will communicate as before mentioned.

5.05
5. Every particle of matter electrified is repelled by every other particle equally electrified. Thus the stream of a fountain, naturally dense and continual, when electrified, will separate and spread in the form of a brush, every drop endeavouring to recede from every other drop. But on taking out the electrical fire they close again.



Benjamin Franklin
Frontispiece, Vol. 3
from original picture by Duplessis in the possession of Mrs. Barnett of Paris
J. Sparks, *Works of Benjamin Franklin*, 1837
Hilliard, Gray & Co. Boston
(public domain)

Try this by bringing a charged comb or PVC pipe near a thin stream of water trickling from a faucet.

5.06

6. Water being strongly electrified (as well as when heated by common fire), rises in vapors more copiously; the attraction of cohesion among its particles being greatly weakened by the opposite power of repulsion introduced with the electrical fire; and, when any particle is by any means disengaged, it is immediately repelled, and so flies into the air.

Franklin supposes that electrically charged water should evaporate more rapidly than uncharged water. Water particles such as A and B at the surface of the liquid are not held as strongly to the rest of the water particles and therefore can escape from the surface.

5.07

7. Particles happening to be situated as A and B (Pl. III. *Fig. 6, representing the profile of a vessel of water)* are more easily disengaged than *C* and *D*, as each is held by contact with three only, whereas *C* and *D* are each in contact with nine. When the surface of the water has the least motion, particles are continually pushed into the situation represented by *A* and *B*.

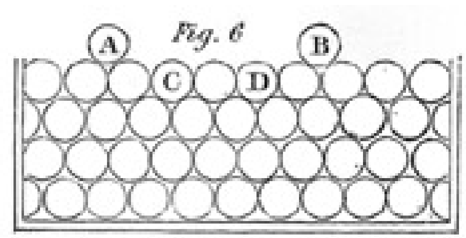


Figure 6 from J. Bigelow 1904
Works of Benjamin Franklin
Vol. II p. 200 (public domain)

5.08

8. Friction between a non-electric [conductor] and an electric *per se* [insulator] will produce electrical fire, not by *creating*, but *collecting* it, for it is equally diffused in our walls, floors, earth, and the whole mass of common matter. Thus the whirling glass globe, during its friction against the cushion, draws fire from the cushion, the cushion is supplied from the frame of the machine, that from the floor on which it stands. Cut off the communication by thick glass or wax, placed under the cushion, and no fire can be *produced*, because it cannot be *collected*.

5.09

9. The ocean is a compound of water–a nonelectric [conductor], and salt–an electric *per se* [insulator].

5.10

10. When there is a friction among the parts near its surface the electrical fire is collected from the parts below. It is plainly visible in the night; it appears in the stern and in the wake of every sailing vessel; every dash of an oar shows it, and every surf and spray; in storms the whole sea seems on fire. The detached particles of water then repelled from the electrified surface continually carry off the fire as it is collected; they arise and form clouds, and those clouds are highly electrified and retain the fire till they have an opportunity of communicating it.

Franklin is trying to build an explanation of how thunderclouds get charged. Here he suggests that water particles rubbing against salt particles acquire excess charge, and then, at the surface of the ocean, evaporate. As evidence, he cites the observation that at night, agitated seawater glows.

Franklin's friend James Bowdoin later explains this phenomena as due to small phosphorescent sea creatures- plankton- rather than to electrical discharges.

5.11

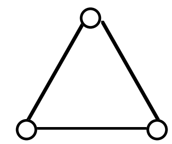
11. The particles of water, rising in vapors, attach themselves to particles of air.

An electrified water particle will now be attracted to a neutral particle of air, and attach itself to the air particle.

5.12

12. The particles of air are said to be hard, round, separate, and distant from each other, every particle strongly repelling every other particle, whereby they recede from each other as fast as common gravity will permit.

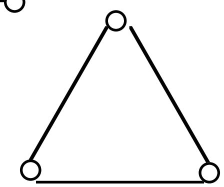
3 air particles in compressed air



5.13

13. The space between any three particles equally repelling each other will be an equilateral triangle.

3 air particles in rarefied air



5.14

14. In air compressed these triangles are smaller, in rarified air they are larger.

5.15

15. Common fire joined with air increases the repulsion, enlarges the triangles, and thereby makes the air specifically lighter. Such air among denser air will rise.

Franklin supposes (12) that air particles repel each other, which is why they stay apart from each other, although held near the earth by gravity. Heated air (15) is less dense and rises.

5.16

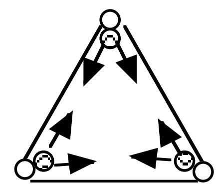
16. Common fire as well as electrical fire gives repulsion to the particles of water, and destroys their attraction of cohesion; hence common fire as well as electrical fire assists in raising vapors.

Water vapor can be made less dense by heat (common fire) or by electrical repulsion (16)

5.17

17. Particles of water having no fire in them mutually attract each other. Three particles of water, then, being attached to the three particles of a triangle of air, would, by their mutual attraction operating against the air's repulsion, shorten the sides and lessen the triangle, whereby that portion of air made denser would sink to the earth with its water and not rise to the formation of a cloud.

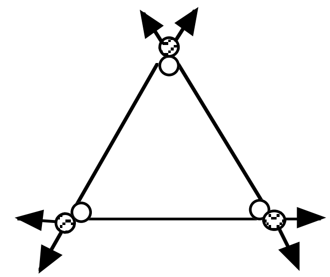
3 water particles attached to 3 air particles and shrinking triangle by their mutual attraction, making the air denser (17)



5.18

18. But if every particle of water attaching itself to air brings with it a particle of common fire, the repulsion of the air being assisted and strengthened by the fire more than obstructed by the mutual attraction of the particles of water, the triangle dilates, and that portion of air, becoming rarer and specifically lighter, rises.

3 water particles which carry common fire (heat) or electrical fire attached to 3 air particles and enlarging triangle by their mutual repulsion, making the air less dense (17)



5.19

19. If the particles of water bring electrical fire when they attach themselves to air, the repulsion between the particles of water electrified, joins with the natural repulsion of the air to force its particles to a greater distance, whereby the triangles are dilated, and the air rises, carrying up with it the water.

5.20

20. If the particles of water bring with them portions of *both sorts* of fire, the repulsion of the particles of air is still more strengthened and increased and the triangles farther enlarged.

5.21

21. One particle of air may be surrounded by twelve particles of water of equal size with itself, all in contact with it, and by more added to those.

5.22

22. Particles of air thus loaded would be drawn together by the mutual attraction of the particles of water, did not the fire, common or electrical, assist their repulsion.

5.23

23. If air thus loaded be compressed by adverse winds or by being driven against mountains, &c., or condensed by taking away the fire that assisted it in expanding, the triangles contract, the air with its water will descend as a dew; or if the water surrounding one particle of air comes in contact with the water surrounding another, they coalesce and form a drop, and we have rain.

(23) Air that is saturated (loaded) with water particles will release drops of water if the air is squeezed, somewhat like squeezing water out of a sponge.

5.24

24. The sun supplies (or seems to supply) common fire to vapors, whether raised from the earth or sea.

5.25

25. Those vapors, which have both common and electrical fire in them are better supported than those which have only common fire in them; for when vapors rise into the coldest region above the earth, the cold will not diminish the electrical fire, if it doth the common.

5.26

26. Hence clouds, formed by vapors raised from fresh waters within land, from growing vegetables, moist earth, &c., more speedily and easily deposit their water, having but little electrical fire to repel and keep the particles separate. So that the greatest part of the water raised from the land is let fall on the land again; and winds blowing from the land to the sea are dry, there being little use for rain on the sea, and to rob the land of its moisture, in order to rain on the sea would not appear reasonable.

5.27

27. But clouds formed by vapors raised from the sea, having both fires, and particularly a great quantity of the electrical, support their water strongly, raise it high, and being moved by winds, may bring it over the middle of the broadest continent from the middle of the widest ocean.

Franklin supposes that clouds from fresh water contain only common fire to keep the particles repelled, while clouds formed from saltwater contain both common fire and electrical fire

5.28

28. How these ocean clouds, so strongly supporting their water, are made to deposit it on the land where it is wanted, is next to be considered.

5.29

29. If they are driven by winds against mountains, those mountains, being less electrified, attract them, and on contact take away their electrical fire, (and, being cold, the common fire also); hence the particles close towards the mountains and towards each other. If the air was not much loaded, it only falls in dews on the mountain tops and sides, forms springs, and descends to the vales in rivulets, which, united, make larger streams and rivers. If much loaded, the electrical fire is at once taken from the whole cloud; and, in leaving it, flashes brightly and cracks loudly, the particles instantly coalescing for want of that fire, and falling in a heavy shower.

5.30

30. When a ridge of mountains thus dams the clouds and draws the electrical fire from the cloud first approaching it, that which next follows, when it comes near the first cloud, now deprived of its fire, flashes into it, and begins to deposit its own water, the first cloud again flashing into the mountains; the third approaching cloud, and all succeeding ones, acting in the same manner as far back as they extend, which may be over many hundred miles of country.

5.31

31. Hence the continual storms of rain, thunder, and lightning on the east side of the Andes, which, running north and south, and being vastly high, intercept all the clouds brought against them from the Atlantic ocean by the trade winds, and oblige them to deposit their waters, by which the vast rivers Amazons, La Plata, and Oroonoko are formed, which return the water into the same sea, after having fertilized a country of very great extent.

5.32

32. If a country be plain, having no mountains to intercept the electrified clouds, yet it is not without means to make them deposit their water. For if an electrified cloud coming from the sea, meets in the air a cloud raised from the land, and therefore not electrified, the first will flash its fire into the latter, and thereby both clouds shall be made suddenly to deposit water.

5.33

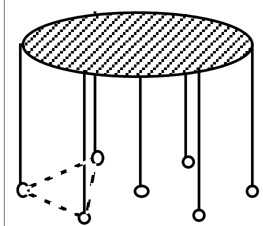
33. The electrified particles of the first cloud close when they lose their fire; the particles of the other clouds close in receiving it; in both, they have thereby an opportunity of coalescing into drops. The concussion or jerk given to the air contributes also to shake down the water, not only from those two clouds, but from others near them. Hence the sudden fall of rain immediately after flashes of lightning.

Franklin is arguing that his mechanism for creating clouds accounts for a variety of meterological observations, including both ordinary rainstorms and thunderstorms.

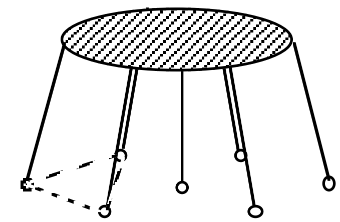
5.34

34. To show this by an easy experiment; take two round pieces of pasteboard, two inches diameter; from the centre and circumference of each of them suspend, by fine silk threads eighteen inches long, seven small balls of wood, or seven peas equal in goodness; so with the balls, appending to each pasteboard, form equal equilateral triangles, one ball being in the center, and six at equal distances from that and from each other; and thus they represent particles of air. Dip both sets in water, and some adhering to each ball, they will represent air loaded. Dexterously electrify one set, and its balls will repel each other to a greater distance, enlarging the triangles. Could the water supported by seven balls come into contact, it would form a drop or drops so heavy as to break the adhesion it had with the balls, and so fall. Let the two sets then represent two clouds, the one a sea cloud electrified, the other a land cloud. Bring them within the sphere of attraction, and they will draw towards each other, and you will see the separated balls close thus: the first electrified ball that comes near an unelectrified ball by attraction, joins it, and gives it fire; instantly they separate, and each flies to another ball of its own party, one to give, the other to receive fire; and so it proceeds through both sets, but so quick as to be in a manner instantaneous. In the cohesion they shake off and drop their water, which represents rain.

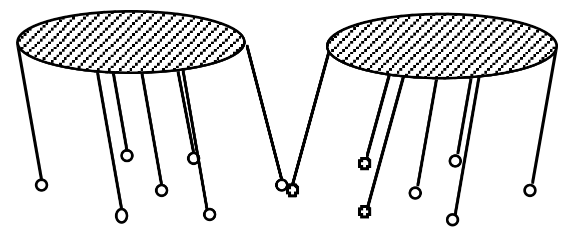
Here Franklin proposes a demonstration experiment to show how flashes of lightning might trigger heavy rain. The diagrams below indicate his demonstration- but are not to scale.



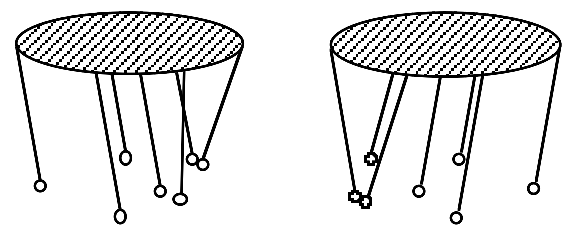
Unelectrified cloud



Electrified cloud



initial contact of two clouds



charge being transferred from one particle to the next, with water drops released at contact.

5.35

35. Thus, when the sea and land clouds would pass at too great a distance for the flash, they are attracted towards each other till within that distance: for the sphere of electrical attraction is far beyond the distance of flashing.

5.36

36. When a great number of clouds from the sea meet a number of clouds raised from the land, the electrical flashes appear to strike in different parts; and as the clouds are jostled and mixed by the winds, or brought near by the electrical attraction, they continue to give and receive flash after flash, till the electrical fire is equally diffused.

5.37

37. When the gun-barrel (in electrical experiments) has but little electrical fire in it, you must approach it very near with your knuckle before you can draw a spark. Give it more fire, and it will give a spark at a greater distance. Two gun-barrels united, and as highly electrified, will give a spark at a still greater distance. But if two gun-barrels electrified will strike at two inches distance, and make a loud snap, to what a great distance may ten thousand acres of electrified cloud strike and give its fire, and how loud must be that crack?

During electrical experiments with generators, Franklin and others had seen that the larger the metal surface that was used to collect the ‘electrical fluid’, the longer and stronger the sparks were. Franklin argues, essentially correctly, that scaling the volume of the charged object up would much increase the strength of the spark, leading him to suggest that lightning is simply a very large electrical spark.

5.38

38. It is a common thing to see clouds at different heights passing different ways, which shows different currents of air, one under the other. As the air between the tropics is rarefied by the sun, it rises, the denser northern and southern air pressing into its place. The air, so rarefied and forced up, passes northward and southward, and must descend into the polar regions, if it has no opportunity before, that the circulation may be carried on.

Martinus van Marum, in the Netherlands, built a very large generator with huge Leyden jars and could obtain sparks about two feet long.

5.39

39. As currents of air, with the clouds therein, pass different ways, it is easy to conceive how the clouds, passing over each other, may attract each other, and so come near enough for the electrical stroke. And also how electrical clouds may be carried within land very far from the sea, before they have an opportunity to strike.

Van Marum later visited Franklin shortly before he left France, to meet him and to tell Franklin of his experiments.

5.40a

40. When the air, with its vapors raised from the ocean between the tropics, comes to descend in the polar regions, and to be in contact with the vapors arising there, the electrical fire they brought begins to be communicated, and is seen in clear nights, being first visible where it is first in motion–that is, where the contact begins, or in the most northern part; from thence the streams of light seem to shoot southerly, even up to the zenith of northern countries. But though the light seems to shoot from the north southerly, the progress of the fire is really from the south northerly, its motion beginning in the north being the reason that it is there seen first.

5.40b

For the electrical fire is never visible but when in motion and leaping from body to body, or from particle to particle, through the air. When it passes through dense bodies it is unseen. When a wire makes part of the circle in the explosion of the electrical phial, the fire, though in great quantity, passes in the wire invisibly; but in passing along a chain, it becomes visible as it leaps from link to link. In passing along leaf gilding it is visible, for the leaf gold is full of pores; hold a leaf to the light, and it appears like a net, and the fire is seen in its leaping over the vacancies. And as when a long canal filled with still water is opened at one end, in order to be discharged the motion of the water begins first near the opened end, and proceeds towards the close end, though the water itself moves from the close toward the opened end, so the electrical fire discharged into the polar regions, perhaps from a thousand leagues length of vaporized air, appears first where it is first in motion–that is, in the most northern part, and the appearance proceeds southward, though the fire really moves northward. This is supposed to account for the *aurora borealis.*

Franklin here suggests that electrified clouds entering the polar regions and giving up their ‘electrical fire’ there might be the source of the Northern Lights.

5.41

41. When there is great heat on the land in a particular region (the sun having shone on it perhaps several days, while the surrounding countries have been screened by clouds), the lower air is rarefied, and rises; the cooler denser air above descends; the clouds in that air meet from all sides, and join over the heated place; and if some are electrified, others not, lightning and thunder succeed, and showers fall. Hence, thunder-gusts after heats, and cool air after gusts; the water and the clouds that bring it coming from a higher and therefore a cooler region.

5.42

42. An electrical spark drawn from an irregular body at some distance is scarcely ever straight, but shows crooked and waving in the air. So do the flashes of lightning, the clouds being very irregular bodies.

5.43

43. As electrified clouds pass over a country, high hills and high trees, lofty towers, spires, masts of ships, chimneys, &c., as so many prominences and points draw the electrical fire, and the whole cloud discharges there.

5.44

44. Dangerous, therefore, is it to take shelter under a tree during a thunder-gust. It has been fatal to many, both men and beasts.

5.45a

45. It is safer to be in the open field for another reason. When the clothes are wet, if a flash in its way to the ground should strike your head, it may run in the water over the surface of your body; whereas, if your clothes were dry, it would go through the body, because the blood and other humors, containing so much water, are more ready conductors.

Franklin is not far off the mark here. Inside a closed metal car, which is a conducting shell, is a safe place to be in a thunderstorm.

5.45b

Hence a wet rat cannot be killed by the exploding electrical bottle, when a dry rat may.[1]

[1] This was tried with a bottle containing about a quart. It is since thought that one of the large glass jars mentioned in these papers might have killed him, though wet.–F.

5.46

46. Common fire is in all bodies, more or less, as well as electrical fire. Perhaps they may be different modifications of the same element; or they may be different elements. The latter is by some suspected.

5.47

47. If they are different things, yet they may and do subsist together in the same body.

5.48

48. When electrical fire strikes through a body, it acts upon the common fire contained in it, and puts that fire in motion; and if there be a sufficient quantity of each kind of fire, the body will be inflamed.

5.49

49. When the quantity of common fire in the body is small, the quantity of the electrical fire (or the electrical stroke) should be greater; if the quantity of common fire be great, less electrical fire suffices to produce the effect.

Here Franklin suggests that the 'electrical fire' passing through an object starts the 'common fire' or heat moving. At the time, heat was considered to be a substance, rather than a state of activation, and it was thought that bodies that ignite and burn easily do so because they have a large amount of inactive 'common fire.'

5.50

50. Thus spirits must be heated before we can fire them by the electrical spark.[1] If they are much heated, a small spark will do; if not, the spark must be greater.

[1] We have since fired spirits without heating them, when the weather is warm. A little, poured into the palm of the hand, will be warmed sufficiently by the hand, if the spirit be well rectified. Ether takes fire most readily.–F.

5.51

51. Till lately, we could only fire warm vapors; but now we can burn hard, dry rosin. And when we can procure greater electrical sparks, we may be able to fire, not only unwarmed spirits, as lightning does, but even wood, by giving sufficient agitation to the common fire contained in it, as friction we know will do.

5.52

52. Sulphureous and inflammable vapors arising from the earth are easily kindled by lightning. Besides what arise from the earth, such vapors are sent out by stacks of moist hay, corn, or other vegetables, which heat and reek. Wood, rotting in old trees or buildings, does the same. Such are therefore easily and often fired.

5.53

53. Metals are often melted by lightning, though perhaps not from heat in the lightning, nor altogether from agitated fire in the metals. For, as whatever body can insinuate itself between the particles of metal, and overcome the attraction by which they cohere (as sundry *menstrua* can), will make the solid become a fluid, as well as fire, yet without heating it; so the electrical fire, or lightning, creating a violent repulsion between the particles of the metal it passes through, the metal is fused.

5.54

54. If you would, by a violent fire, melt off the end of a nail which is half driven into a door, the heat given the whole nail, before a part would melt, must burn the board it sticks in; and the melted part would burn the floor it dropped on. But if a sword can be melted in the scabbard, and money in a man's pocket by lightning, without burning either, it must be a cold fusion.[1]

[1] These facts, though related in several accounts, are now doubted;since it has been observed that the parts of a bell-wire which fell on the floor, being broken and partly melted by lightning, did actually burn into the boards. (See *Philosophical Transactions*, vol. li., Part I.) And Mr. Kinnersley has found that a fine iron wire, melted by electricity had the same effect.–F.

5. 55

55. Lightning rends some bodies. The electrical spark will strike a hole through a quire of strong paper.

5.56

56. If the source of lightning assigned in this paper be the true one, there should be little thunder heard at sea far from land. And accordingly some old sea-captains, of whom inquiry has been made, do affirm, that the fact agrees perfectly with the hypothesis; for that, in crossing the great ocean, they seldom meet with thunder till they come into soundings; and that the islands far from the continent have very little of it. And a curious observer, who lived thirteen years at Bermudas, says there was less thunder there in that time than he has sometimes heard in a month at Carolina.

The beginnings of modern chemistry from alchemy were only slowly emerging at this time. By '*menstrua'* Franklin means what we would presently call solvents or acids. Based on a number of reports of lightning having melted metals without heating them, Franklin is suggesting that the 'electrical fluid' might act like an acid. In the footnote to paragraph 54, he renounces this opinion, as he has come to doubt the reports of this phenomena. One of Franklin's strengths as a scientist is his willingness to give up one of his ideas when confronted with clear experimental evidence, a trait not always observed in some of his contemporaries.