The next major legislation in 1852 required the use of fusible metal safety guards without specifying any particular type. Shortly after this law passed, Evans published *A Statement of Experiments Upon the Temperature of Steam, the Operations of the Common Safety Valve, and Upon Government Alloys: with a Description of a Newly Invented Safety Valve, &c.* (Pittsburgh, 1854). He apparently died before he could promote his safety guard further. According to Bathe, op. cit., p. 271, only one of Oliver Evans's children, a daughter, lived beyond 1854. His wife, Jane B. Evans, appears as a widow in the 1856–1857 Pittsburgh City Directory.

For the history of attempts to prevent steamboat accidents, which involved not only technological solutions but also the education and professionalization of engineers, inspection, licensing, penalties, etc., see Louis C. Hunter, op. cit., chapter 13: "The Movement for Steamboat Regulation." See also John G. Burke, "Bursting Boilers and the Federal Power," *Technology and Culture*, 1966, 7:1–23.

"RECORD OF EXPERIMENTS"[1]

Henry Papers, Smithsonian Archives

July 15th 1841[2]

{Effects of Lightning Mrs Hamiltons
{House struck

Last evening we were visited by a very severe thunder storm. Princeton of late years has been remarkably exempt from lightning near by—the storms generally come from the south west and seperate into two parts before reaching us. One part passes along Rocky hill the other along the canal. The one of last evening was the second severe storm of the kind we have had since I have resided in Princeton. It has been conjectured that the canal and rail road on one side and the hill on the other protect us and that a

[1] This entry was Henry's first extended account of observations on thunderstorms, but certainly not his last. Though his primary work was in the laboratory, Henry always maintained an active interest in terrestrial physics, and when this subject had a bearing on his experimental work, the interest increased to a passion.

Henry had had some interest in atmospheric electricity and electrical storms before this. He participated in a kite experiment in Philadelphia in 1836, which eventually found its way into "Contributions III" (*Henry Papers*, 3:77–80; "Contributions III: Electro-Dynamic Induction," paragraph 124). He saw Peltier experiment on atmospheric electricity in France in 1837, and observed St. Elmo's fire on his return trip from Europe ("Atmospheric Electricity," Part V of "Meteorology in Its Connection with Agriculture," *Report of the Commissioner of Patents for 1859: Agriculture* [Washington, 1860], p. 493; *Henry Papers*, 3: 514–515). He had variously noted the effects of induction and lateral discharge from lightning and lightning rods (ibid., 3:63, 4:57). Finally, he noted in some detail in his commonplace book the effects of an April 12, 1840, thunderstorm in Princeton (ibid., 4:345–346). But the present long entry, and the next, marked his largest investment of time and effort to date, and started his lifelong concern with explaining storms on physical principles.

In this volume of the *Henry Papers* appears much of his additional work on the phenomena of atmospheric electricity and lightning. Henry twice took note of similar storms in Princeton: July 22, 1842, and May 8, 1843 (see the "Record of Experiments" entries, below). On at least two other occasions he referred to this entry in explaining other electrical effects: entries for October 12 and 28, 1843, below. Henry also became interested in atmo-

spheric electricity, proposing (May 28, 1842) and constructing (June 10) a detector, and considering an automated registering system as well ("Record of Experiments" entries for those dates, and Lefroy to Sabine, October 25, 1842, all below). Finally, his commonplace book for the period is full of references to theory and phenomena of lightning, from Becquerel's "De l'électricité atmosphérique" (*Traité de l'électricité et du magnétisme*, 7 vols. [Paris, 1834–1840], 6:117–222), Peltier's *Météorologie* (Brussels, 1841), Arago's "Sur la tonnerre," *Annuaire du Bureau des Longitudes, 1838* (Paris, 1839), pp. 221–618, and articles from eighteenth-century volumes of the *Phil. Trans.* (Henry Commonplace Book [10615], pp. 10–32, passim, Henry Papers, Smithsonian Archives).

Henry's interest continued. He brought up the subject of lightning in remarks to the American Philosophical Society in 1843 (APS *Proceedings*, 1843–1847, 4:23), 1845 (ibid., pp. 179–180), and 1846 (ibid., pp. 260–268), and to the 1850 meeting of the American Association for the Advancement of Science, in New Haven (AAAS *Proceedings*, 1850, 4:7, 10, 39–42). His large-scale work, "Meteorology in Its Connection with Agriculture," published in five parts by the Commissioner of Patents from 1855 to 1859, was essentially a physics text, and its fifth part (1859), "Atmospheric Electricity," dealt extensively with storms and lightning. In it Henry collected and discussed almost all his observations and thoughts to this time. Even in the year of his death Henry had a letter published on the best and most scientific way of observing thunderstorms (*Journal of the American Electrical Society*, 1878, 2:1–8).

Henry's theoretical speculations on the nature of storms centered on the less generally discussed electrical effects. He considered it well established from experiments of Volta and Peltier that the earth as a whole was negatively charged—a conclusion he saw as no stranger than that it should be magnetic. Thunderclouds, then, being vertical objects of ascending warm vapor and descending condensate—partially conducting—are acted on by static induction by the earth. The portion of the cloud closest to the earth is positively charged, the portion farthest away is negative. As the electrical condition of the cloud changes through condensation, lightning can then travel between the upper and lower portions of the cloud, or between the lower portion and the earth.

In discussing lightning bolts, Henry highlighted three effects. When lightning passes, it gives "a sudden and violent repulsive energy" to the air and other objects, especially in the direction of its passage. Thus lightning can form holes in walls and splinter trees. Second, the storm cloud, prior to emitting its lightning, strongly induces static charges in the area under it. This explained the apparent attraction of lightning to tall metallic objects. Similarly, the discharge of the lightning releases the inductive effect explosively, giving shocks to all that had formerly been subject to it. Finally, Henry always pointed to the process of lateral discharge, which is the giving off of sparks from a wire discharging a capacitor. Since Henry considered the discharge not to be a simple process, but actually a double wave of deficiency and redundancy of electrical fluid traveling down the rod, sparks could always be drawn from the lightning rod, no matter how large and well-grounded it might be. All three effects appear in Henry's account of this July storm. For the theories in full form, see his "Atmospheric Electricity," especially pp. 478–505.

Henry was often asked for advice about the selection and positioning of lightning rods. See, for example, the letter of Jacobus to Henry, July 18, 1843, and Henry's reply of the following day, both below.

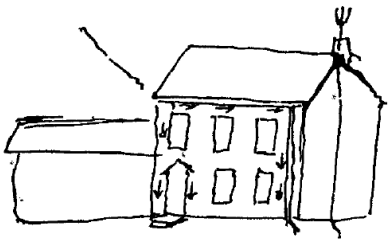
Material from this entry was used in a November 5, 1841, presentation to the APS, published in the *Proceedings*, 1841–1843, 2:111–116. The account of the last two paragraphs, beginning "Between Princeton and Mr Philips . . . ," was omitted; another paragraph, relating to the "Record of Experiments" entry of September 2, 1841, was included.

[2] The dates on this document provide insight into Henry's procedures. The entire entry refers to the effects of a severe storm that swept through the Princeton area on the fourteenth. Henry's narrative of his survey of houses hit by lightning is continuous through the nine-page entry. The entire entry clearly refers to his activities on the fifteenth, and the first three pages are so dated. The next two pages, originally dated the fifteenth, were later changed to the sixteenth, and a small note in the upper margin of the first of these states "Written 16th." The last four pages of this entry lack date and heading. Distinctly separated from this one, the next entry is dated the sixteenth, and refers to activities of that day.

change has been produced since the construction of the canal.[3] Be this as it may, the storm of the 14th was very unusual and nothing like it, it is said, has occurred here in the course of 20 years. The clouds had an unusual direction, there appeared to be two storms, one in the norwest and the other in the south. The clouds came together over Princeton and deluged us with rain. The lighting was almost incessant but the thunder was not very loud except on one or two occassions when it appeared to be very near and then the intensity was not as great as I have heard it in Albany. The storm lasted about 3 hours but not in full force during the whole time.

Several places in the vicinity of Princeton were struck and one in the village namely Mrs Hamiltons[4] house, situated on the main street, about 30 rods to the south west of the college on the opposite side of the street. It appears somewhat strange that this house should have been struck, since it is one of the lowest on that side of the street in the vicinity and on the west of it are a number of high trees. The house is also furnished with a lightning rod but not of very perfect construction or arrangement.

The house stands parallel to the street in a north east and south west direction. It is of br[i]ck covered with a shingle roof two stories high—has a door and an entrance hall on the west and two rooms one front and the other rear above and below with a small room in front over the hall. In the upper storey there are three windows in front and two below—the front door being under the 1st window. There is a wooden gutter which runs horrizontally along the front of the house under the eaves and at the nor<*west*>east side this is furnished with a tin pipe of about <*4*>3 inches indiameter connecting it with the ground. Both the gutter and the pipe must have been filled or nearly filled with water at the time. The lightning rod is attached to the N-W gable of the house and was probably placed there, rather than on the east on account of the support which the chim-

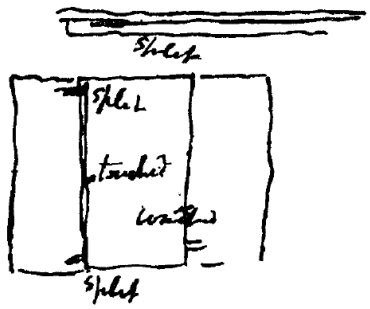


[3] The Delaware and Raritan Canal was constructed through Princeton in 1834. In 1839, a branch of the Camden and Amboy Railroad, running from Trenton to New Brunswick, was constructed along the bank of the canal. This connected Princeton directly with New York and Philadelphia. *Hageman*, 1:252–253.

[4] The reference was to Phebe Hamilton, the widow of James Hamilton (painter and chairmaker, d. 1815) and mother of two sons and five daughters. All the daughters but one married clergymen, including one Reverend Mr. Huntington, from which comes the textual reference to Mrs. Huntington. One daughter remained unmarried, the Miss Hamilton of the entry. One son survived to adulthood, James Hamilton, Professor of Mathematics and Natural Philosophy at the University of Nashville. He appears below in the "Record of Experiments" entry of May 8, 1843. *Hageman*, 1:192–193.

ney would give it.[5] It is made of round iron 3/8th of an inch in diameter and in 5 pieces joined by hook and eye joint. It is terminated above by 3 points which are very blunt but do not exhibit signs of fusion and at the lower end its connection with the earth is very imperfect—it appears to be merely stuck into the ground to the depth of perhaps 2 or three feet. It rises to the hight of about [. . .][6] feet above the roof

The lightning appears to have come from the South perhaps a little to the West and first to have struck the S.W end of the horrizontal gutter. It then appears to have divided into two parts—the one passing along the gutter which was in all probability filled with water as the rain was falling almost in torrents, and then down the pipe to the ground the pipe was also probably gorged with water at the time. The other part passed immediatly down from the gutter—where the stroke was first made—to the casing of the window and then to the jambs of the door beneath to the pavement. Traces of it were observed on each side of the window frame the S W upright was split at the top where the hinge of the window shutter was fastened and below also on the opposite upright of the frame near the lower hing[e] of the shutter the casing was marked. The gutter was split where the lightning passed down to the window. It made its appearance principally where the nails were inserted. In some case the discharge appeared merely to have touched the <*part*> wood and gouged out a groove of about the 8th of an inch in diameter. The channel appeared rough but regular in width. After passing down from the window, it is next seen on the jams of the door the casing on each side is marked—that on the SW is split and that on the opposite side marked in several places. The course of the lightning along the gutter was probably principally through the water its course hower is shown by a long splinter <*on*> near the S end of the gutter and also two splinters thrown off from the wash board or architrave under the gutter at the other end near the tin pipe. No marks of the discharge were observed along the tin pipe <*or*> at the ground where the electricity was probably discharged. The lightning rod was also examined but no markes about it could be seen which would lead us to supose than any part of the discharge had gone down this



[5] In this sentence, Henry has mistakenly switched west and east; the lightning rod is on the northeast gable, where the chimney is. Compare with the correct account in the APS *Proceedings* (see note 1), and the diagram.

[6] Henry left this blank, but his published account gives the height as six feet.

During the storm there were several females in the house three of these Old Mrs Hamilton and her two daughters were in the front room in the secohd story. The Old Lady was lying on <*the*> a bead placed near the partition wall between the two rooms her daughter Miss Hamilton was sitting on the be<*a*>d and her Daughter Mrs Huntington was on the floor about 8 feet from the front wall of the house with her face to the same. A[t] the moment of the discharge Old Mrs Hamilton who was looking towars Mrs Huntington as she stood on the floor saw her surrounded with light. Mrs H. herself felt a sensation on her right ear which was nearest the point where the lightning first struck as if it had been touched with a live coal of fire. She also felt a "rushing sensation" down her left side and perceived a brilliant discharge of light at her foot. At the same time a flash or <*long*> forked spark, 8 inches long, appeared between her body and the nearest window. The other two persons in the room felt nothing unusual, or if any effect was produced it was merged in the succeeding alarm. No mark on the ear or the foot was perceptible next day. The shoe was also examined but nothing could be seen. Mrs H at the time was standing on a grass carpet which covered the floor of the room. The window shutter nearest Mrs H. was shut and also the <*windo*> shutter of the window over the door was closed. One valve of the window next the pipe was open. The shutters were of the open kind with slanting slats. Three pains of glass were broken in the window over the door and the glass thrown inward. This window it must be observed was in the little room over the hall and therefore was seperated from the room in which the females were by a partition wall.

These phenomena do not appear difficult of explanation—the long horizontal gutter and the perpendicular pipe, both filled with water, formed a continuous conductor from the place where the lightning struck to the ground at the farther corner of the front of the house. This conductor would be acted on by the approaching discharge and by induction become highly charged if the cloud was + the <*upper area*> end of the gutter would be minus <*the*> its natural electricity would be repelled towards the earth through the pipe and therefore the whole would be in the most favourable condition to attract the lightning, which came in a direction somewhat coinsiding with the direction of the gutter. The effects observed by Mrs H and her mother in the room, were probably owing to induction. If electricity be suddenlly thrown on a pain of glass on one side, electricity will be thrown off on the other by induction and when a powerful discharge passed along the front of the house as in this case the natural electricity of the interior we would suppose would be disturbed and all the effects described by Mrs H produced. She says that an explosion like that of

a pistol took place apparently at her foot—the light of which appeared like a ball of about an inch and a half in diameter. I am inclined to believe however that this was the explosion of the part of the discharge from the cloud which struck the house since a similar noise was heard at Dr Macleans[7]

The discharge came from the South and passed over the houses on the opposite side of the street. In one of these two persons were affected with the discharge—one a servant girl of Mr Warner[8] was thrown into convulsions, either by the immediate effects of the lightning or by the fright produced by the thunder—the other Mrs Warner felt at the moment a prickling sensation in her limbs particularly in her arms, which to use her own expression went out at her fingers. A girl in the room below, with the windows closed, thought she saw the lightning on the floor. Much of these effects may have been produced by immagination but still there is a sufficient cause in the principle of induction to account for all these appearances.

On the same day I visited Mr. Henry Philip's[9] house, situated about 3 miles from Princeton on the road to Trenton. This was also struck by the same storm. The house has a lightning rod on the end fartherest from Princeton but it is in a very bad condition the top and for or five feet of the stem is broken off or rather bent down so that no part of the rod rises above the top of the house. The lightning struck the farth[er] gable from the rod on the east end of the house passed down the chimney into the fire of the cellar kitchen scattered the ashes through the room and filled all below with smoke—a strong odour of sulphure was perceptible and this was also the case at Mrs Hamiltons. The smell was so strong around the front door that Mrs H thought the house was on fire. But to return to Mr. Philip's case. A large quantity of suit was thrown down the chimney—the whole charge however did not go down <*the*> into the fire—a part of it passed out through the thick stone wall which formed the back of the fire place and came out opposite the upper iron hoop of a Ley cask which was placed against the wall. It then passed down the cask which was moisted with the ley and burst off three or four wooden hoops which alternated with those

[7] Henry retrospectively added here a reference to the next entry in the "Record of Experiments," July 16.

[8] The 1840 census lists five Warner households in Mercer County. Only one of these, however, that of John Warner, was located in Princeton township. Ronald Vern Jackson and Gary Ronald Teeples, eds., *New Jersey 1840 Census Index* (Bountiful, Utah, 1978).

[9] Henry D. Phillips (1793–1873) of Maidenhead Plantation located near Lawrenceville, New Jersey, halfway between Princeton and Trenton. Phillips was a prosperous landowner from a family prominent in central New Jersey. In addition to his stock farm and stable of thoroughbred horses, Phillips owned and operated the Lawrenceville Female Seminary. Francis Bazley Lee, ed., *Genealogical and Personal Memorial of Mercer County, New Jersey*, 2 vols. (New York, 1907), 1:79.

of iron. The hole in the wall was made between the stone of a triangular form the plaster was thrown out and the angles of the stone broken. No sines of fusion were observed—other cases of a passage through a thick wall were observed in the discharges of the same storm[10]

Inductive effects were also noticed in this discharge. Mr P his wife and little son were seated on the edge of <*the*> a bed at the distance of about 20 feet <*from*> or more from the chimney where the discharge passed down. They each felt a shock in the legs. Mr P felt it in his right leg, which was thrown over the other and did not touch the floor. Mrs P felt the shock in both legs and said it resembled precisely that which She had felt from an electrical jar. The boy felt it in his knees also Mr P felt it most sensibly in the same joint. The house was about 60 feet long and from the bad condition of the rod it is not surprising that the farther end of the house should have been struck particularly since it <*came*> there was a fire in the chimney[11]

Between Princeton and Mr Philips at Stony brook we inspected a tree which was struck at nearly the same time. It stood before the door of the house on the <*left*> right hand as you pass over the bridge going from Princeton. The tree was of the kind called Balm of Gilead about 50 feet high—it showed signs of the descharge at the distance of about 15 feet from the ground but the principal effect was produced at about 5 feet above this, where the first larger branches came out. The splitting and scathing appeared to be confined to a length of 5 or six feet—the upper branches were not affected and the lower part of the trunk showed no sines of the passage of the discharge. The <*effect*> action however was so intense on the part about the projection of the lower branches that the tree was nearly severed in two and was unable to withstand the wind which followed the storm. It fell in the wind and had been cut up that is all the upper part before I saw it. The high stump however was standing

The woman was in the entrance hall almost immediatly opposite the tree and about 25 or 30 feet distance from it. She experienced no effect except fright. Her husband was in the garden immediately behind the house and complained of being very sensibly affected by the shock—had a pain in his head all the next day. The tree showed no indications of ignition, the part struck was much splintered and the slivers thrown off as if by an explosive force. The tree was green and quite succulent and this was probably the cause of its not being splintered below perhaps it was hollow

[10] Another reference to the July 16 entry, added later.

[11] In light of the fact that heated air, being less dense, conducted electricity better. *Henry Papers*, 3:66.