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The Enigma of Volta's "Contact Tension" and the Development of the "Dry Pile"

1. Prologue

The collection of the Clarendon Laboratory in Oxford possesses a remarkable instrument that has been ringing almost continuously since it was purchased from Watkins & Hill of London in 1840 (figure 1).[1] A tiny brass clapper suspended by a silk fibre moves to and fro between the bells attached to the base of two vertical pillars, known as "dry piles". These are connected in series, sealed in a coating of sulphur, and housed under a glass dome to keep out the dust. Its fame has secured it a place in the *Guinness Book of Records*. This device closely resembles the one described by George John Singer in his textbook of 1814 (figure 3).[2] The dry pile, although it became to be regarded as a novelty, also had its brief moment of glory in the debate concerning the relationship between "classical" high-tension electrostatic experiments and Volta's low-tension experiments with the voltaic pile. The debate over the dry pile highlights the *nature* of scientific evidence and the key role of instruments in this debate.

2. The Origins of the Dry Pile

The dry pile grew out of the debate between those that ascribed the electrical behaviour of the "wet" voltaic pile either to "contact tension" (the "Volta effect") or "chemical action". Helge Kragh and Nahum Kipnis have described in detail this lengthy controversy with its ramifications in the first[3] and in the present volume of the *Nuova Voltiana* series. Instrumental evidence figured largely in this debate, as it did in Volta's original discovery of his pile. A key aspect that made the contact theory popular was that it kept the explanation of the pile in familiar territory, that is, in terms of the high-tension static electricity of the phenomena associated with the frictional electrical machine. In these

[1] CROFT (1984). See also SANDERS (1997).
[2] SINGER (1814), pp. 454-5, plate IV, fig. 46. According to Singer this electric chime was invented by a Mr B.M. Forster.
[3] KRAGH (2000).

terms the property of the pile was sought in the behaviour of a "perpetual" Leyden jar, although the purest form of this explanation did not survive for long. The electrical tests conducted on the nature of electricity produced by the voltaic pile were those well known in the laboratory for establishing the authenticity of electrical (read "static electrical") phenomena.

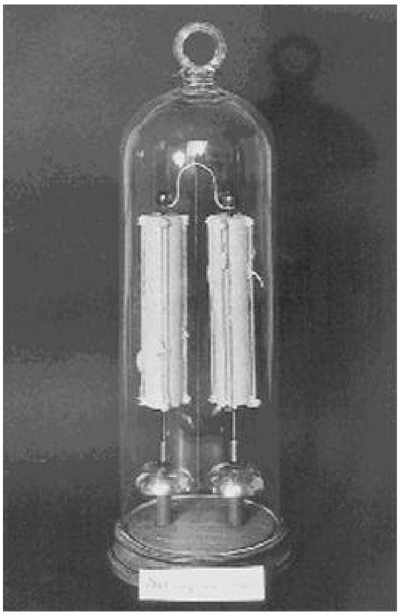

Figure 1 The Oxford Dry Pile, purchased from Watkins & Hill of London in 1840. Courtesy Clarendon Laboratory, University of Oxford.

This "mind set" of electrical behaviour established over more than a hundred years of laboratory routines was being challenged by some of the "peculiar" phenomena produced by the new device. Thus both the contact tension and the chemical action protagonists had to develop new techniques for elucidating these phenomena. Certainly as far as the contact tension school was concerned, most acceptable would be to develop laboratory routines that tied these "new" electrical properties to those associated with the "package" of properties that had been established for high tension static electricity. In this way, it could be argued that there was less resistance to accepting a contact tension form of hypothesis than one based on chemical action, as the latter came from another realm of laboratory practice. In time, chemical action would become more associated with explanatory frameworks surrounding low-tension dynamical electricity of the voltaic pile.

3. The Discovery and Early Development

A number of high-tension dry piles were invented between the early 1800s and the 1830s in an attempt to determine the source of electricity of the wet voltaic pile, and specifically to support Volta's hypothesis of contact tension.[4] Indeed Volta himself experimented with a pile whose cardboard discs had dried out, probably accidentally. Wilhelm Ostwald makes two claims in his discursive history of electrochemistry.[5] Firstly, that the discoverer of the dry pile was Johann Wilhelm Ritter (1776-1810), and secondly that over the next decade it was announced again and again as a new discovery. This is certainly a curious aspect of this story. The early experimenters were attempting to replace the wet conductor in order to demonstrate that moisture had no role in the electroscopic effect.

Ritter described his experiments in an obscure publication in 1802.[6] He recounted what happened as follows. Living in reduced circumstances in Jena, he was invited by the Duke, Ernst von Sachsen-Gotha, to Gotha in 1802 to continue his galvanic experiments. He decided to follow up his observation that the voltaic pile continued to exhibit the "electroscopic effect" (that is, would diverge a gold-leaf electroscope) even after its moist conductor had almost completely dried out. He deliberately set out to construct a dry pile made up of 600 pieces of zinc, copper and white sheep's leather which appeared to be free of moisture. This pile charged a Leyden jar to the same degree as a wet pile of the same size, and the spark and shocks produced by this jar were of the same size. The main differences were that such a pile took much longer to charge the jar and showed no chemical action for short-duration shocks. He concluded that it was the moisture of the cardboard, leather or any other intermediate substance that made the pile electrically active, and that only the smallest degree of moisture was required. The electricity of such a pile obeyed the same laws as the kind produced by the electrical machine.[7]

Dyckhoff tried to construct a real dry pile in 1804 in order to refute Ritter's claim that a voltaic pile had to have *some* moisture for it to be electrically active.[8] He:

> constructed a pile with discs of copper and zinc, and little bits of green glass, about the size of a lentil, three of which I placed triangularly in the intervals that separated the metallic plates. Thus between each pair of metals I had a thin stratum of air instead of a wet substance […] A pile of ten pairs, tried by the condenser, affected the electrometer as powerfully as a common pile of five pairs.[9]

[4] For an early historical account of this intriguing device, see GAY-LUSSAC (1816).
[5] OSTWALD (1980), pp. 346-53.
[6] *Riechsangeiger*, 1802 (n. 66), p. 813.
[7] ØRSTED (1804). Taken from *Journal de physique*, 57 (1803), pp. 401-4.
[8] MOTTELAY (1922), p. 387. See DYCKHOFF (1804). Taken from Voigt's *Magazin fuer den neuesten Zustand der Naturkunde*, 4 (1804), pp. 791-2. Dyckhoff read of Ritter's experiments in the *Intelligenzblatt der allgemeinen Literaturzeitung*, 1802 (n. 193).
[9] DYCKHOFF (1804), p. 305.

The challenge was now taken up by a number of natural philosophers. Among the first wave were Peter Ludwig Maréchaux (1764-?), Jean Nicholas Pierre Hachette (1769-1834), Charles-Bernard Desormes (1777-1862), Thomas George Bernhard Behrens (1775-1813) and Paul Erman (1764-1851).

Maréchaux of Wesel was generally given the credit in nineteenth-century textbooks for having invented the dry pile.[10] He was noted at this time for his sensitive micro-electrometer for measuring and investigating both atmospheric electricity and Volta's contact potential between metal pairs,[11] and his experiments on the dry pile have to be seen in this context. In 1805 he described his "colonne pendule" to the Galvanic Society in Paris. This consisted of pairs of oven-dried cardboard, pasteboard, or blotting paper, and copper and zinc discs, suspended and held in position by three silk cords.[12] His experiments were confirmed for the Galvanic Society by Veau Delaunay.[13]

Hachette, professor at the Paris École Polytechnique, and Desormes, a manufacturer of chemical products, replaced the wet discs with a compound of common starch and either salts, varnishes or gums. These discs were dried and placed alternately between the copper and zinc pairs, but were found to be too affected by moisture for the experiment to be convincing.[14] Probably the most exotic pile constructed at this time, albeit hardly a "dry" one, was the one made entirely of vegetable matter by Giuseppe Baronio of Milan. The discs, two inches in diameter, were of beet root and walnut wood from which the resin had been removed by a solution of vinegar and cream of tartar. A pile of sixty pairs produced convulsions in a frog when excited with a leaf of *cochleria* (spoon wort or scurvy-grass). It was observed that no convulsions were obtained with a Maréchaux pile of the same size, even though it showed a strong electroscopic effect on the micro-electrometer.[15]

Baronio's pile is of no consequence in our story. Behrens' work, although much more relevant in the debate about the part played by moisture in either the voltaic or the dry pile, initially attracted little attention. He completed most of his experimental work in the summer of 1803, continued in the winter of 1804 and sent his paper to Gilbert's *Annalen der Physik* before April 1805, where it was mislaid and not published until the following year.[16] If he was not actually claiming priority over Maréchaux (nowhere in his paper did he mention *that* author), by laying stress on this sequence of events he must have been implying that his work was done independently. His quest was to find a "completely dry" non-metallic conductor that could take over the function of the wet conductor in the voltaic pile without causing

[10] STURGEON (1842), p. 234. That is of the common form using dry paper.
[11] HACKMANN (1978), pp. 24-5.
[12] MOTTELAY (1922), pp. 394-5. See MARÉCHAUX (1806). Taken from *Annales de chimie*, 57 (1805), pp. 61 and ff.
[13] MOTTELAY (1922), p. 394. Reported in the *Journal de Physique*, Messidor (an XIV), pp. 48 and ff.
[14] Reported in *The Journal of Science and the Arts*, 2 (1817), pp. 161-2, and 3 (1817), p. 177. See also TOMMASI (1889), p. 529.
[15] HACKMANN (1978), pp. 24-5, and MARÉCHAUX (1806).
[16] BEHRENS (1806), plate 1, fig. 8.

any chemical action, thus siding with the contact tension school. His first passive conductor was dry flint (stone) placed between copper and zinc plates, and although the pile performed satisfactorily he found it impractical to have to go outdoors in search for suitable material. He discovered that gold paper worked well and when immersed in a weak salt solution and then thoroughly dried ("in order to increase its conductivity") produced an even more active pile when placed between pairs of copper and zinc plates. He was only able to reproduce the electroscopic effects. Water could not be decomposed, the colour of litmus solution changed, or even the smallest shocks felt. More significantly for him, he could not observe any corrosion to the metal plates even after three months of electrical activity.

The story now has to return briefly to Maréchaux. He believed that in his dry pile he had discovered a new delicate meteorological instrument for determining changes in atmospheric electricity. His micro-electrometer indicated that his dry pile was electrically very unstable, which Maréchaux now tried to relate to changes of electricity in the atmosphere.[17] Erman in a detailed paper published in 1807 demonstrated that this electrical instability had quite a different origin. It came from variations in the moisture content of the so-called dry cardboard caused by changes in both the temperature and vapour of the air. Thus, the dry pile could be regarded as a special kind of hygrometer in which electrical activity was related to moisture. Unfortunately, although the dry pile was said to be more sensitive than any known hygrometer, there was no way of making direct comparisons of humidity with this device.[18]

By 1807 the main properties of the dry pile had been established. It was noted that both the voltaic and the dry pile produced electricity, but there were differences in the electrical effects. In the case of the dry pile the phenomena were more akin to the high-tension electricity produced by the common electrical machine, but it was electricity nevertheless. The importance of moisture on the electrical activity of the dry pile was observed. In the next wave of experimental activity, in particular by de Luc and Zamboni, little more of value about the general behaviour of this device would be discovered. However, the hope continued to be expressed that the dry pile would help with elucidating the source of the electricity in the voltaic pile. Did the substance (such as water) between the bi-metallic voltaic pairs simply behave as a conductor for the electric fluid generated by the metals in contact (*vide* the contact tension school), or was it chemically involved in generating the charge (*vide* the chemical school)? It seemed to the experimenters that the dry pile might be a good vehicle for determining the processes that were taking place, as it appeared to slow down the electrical activity taking place inside the voltaic pile.

[17] MARÉCHAUX (1805).
[18] ERMAN (1807).

4. De Luc

Extensive dry pile experiments were performed in England between 1806 and 1811 by J.A. de Luc (1727-1817), a natural philosopher of Swiss extraction. Appointed reader to Queen Charlotte, the consort of George III, he had had a long career as an experimenter and had travelled widely. Apart from having been for a time professor of philosophy and geology at Göttingen, he lived in Berlin, Hanover and Brunswick, before finally settling at an advanced age in London. The results of his experiments communicated to the Royal Society were not published in their *Philosophical Transactions.* He expanded his account and added some new results for papers to be printed in *A Journal of Natural Philosophy, Chemistry, and the Arts* [*Nicholson's Journal*] in 1810. The reason why his papers were not printed in the journal of the Royal Society de Luc makes clear in a letter he addressed to the editor.[19] In 1806 he deposited in the library of the Royal Society two papers written in Berlin and printed in Paris. Only the second one entitled *Traité élémentaire sur le Fluide électro-galvanique* is of concern here as it deals with de Luc's ideas on the properties of the voltaic pile.[20] His analysis was left unfinished because of geological studies undertaken in various parts of Germany, so he took the pile up again on his return to England. What spurred him on was Humphrey Davy's Bakerian lecture on "some chemical agencies of electricity" which contained observations already disproved by de Luc in his paper deposited in the Society's library. This resulted in a new paper being presented to the Royal Society on May 30 1808. On being told that his paper was too long to be read at a meeting, he asked Joseph Banks for its return in early 1809 so that he could shorten it. By suppressing in his new account all the experiments that contradicted Davy, he managed to reduce it by twenty-three pages, but his less controversial version, presented to the Society on February 25, 1809, fared no better. On March 7, de Luc presented a new paper "On the Electric Column, and Aerial Electroscope", but the door remained firmly closed. The following summer he received a letter signed by Davy that "the Committee of Papers, although they did not think it proper to publish my papers at present, had directed that they be deposited in the Archives of the Society".[21] De Luc must have felt that the intention was to suppress his results that seemed to be contrary to Davy. A request by de Luc for the return of his drawings, so that he could get them engraved for papers to be published elsewhere, elicited no response. At the same time he felt that his "electric column" was no longer a novelty as he had shown it to Davy and many other "experienced philosophers" from July 1808. Nicholson responded in a footnote to de Luc's letter that "he will print the learned author's

[19] De Luc's letter [Windsor, March 22, 1810] is reported in *Journal of Natural Philosophy, Chemistry and the Arts*, 26 (1810), pp. 69-72.
[20] DE LUC (1810).
[21] See de Luc's letter quoted in note 19, p. 71.

communications which my duty as a Journalist, and the nature and importance of those writings, may demand".[22]

In the first two papers in this series he described his "dissection" of the "galvanic pile".[23] Small tripods of thin brass wire were interposed between the units of the pile in three different ways. They were either placed between the zinc and silver plates (first dissection), between the silver plate and the wet cloth (second dissection), and finally between the zinc plate and the wet cloth (third dissection). Only in the case of the 'uninterrupted' pile (that is when de Luc did not separate the units or pairs by brass tripods) and in the first dissection were shocks felt and did chemical action take place (such as a litmus solution changing colour). The second dissection produced electrical but no chemical effects and the third neither effect. He furthermore observed that only in the first dissection did the zinc plates show signs of corrosion ("oxidation"). De Luc concluded that it was through the process of oxidation that the electric fluid[24] experienced a change in nature, and it was this change that made the electric fluid capable of bringing about further chemical action (as shown by the effects exhibited).[25]

In order to ascertain if a liquid was essential, de Luc made up a pile with pieces of cloth not moistened, and he found the electrical effects still present but in a weaker state. This induced him to conduct a series of experiments, trying out different animal and vegetable substances between the metal pairs instead of the moistened cloth. His preferred method was writing paper.[26] His pile was made up of discs of sheet zinc and Dutch gilt metal separated by paper in such a way that the gilt side of the paper was in contact with the zinc. The discs were pressed together in a glass tube by a brass cap and screw connected at each end to a wire. He found that his apparatus had the same "electrical indications" as the common voltaic pile, but that it produced no chemical effects, nor was any oxidation of the zinc observed, even after protracted action. He concluded that what he had constructed was a "kind of perpetual electrical machine" in which the opposite electrical states perpetually

[22] *Ibid*., p. 72.
[23] DE LUC (1810), part I, plate III and IV, figs. 1 and 2. For a contemporary commentary see also FORSTER (1811), in which the author has an intriguing illustration of a dry pile in the guise of an electric eel.
[24] De Luc's use of the concept of an electric fluid is of interest here. In this context he attacks Davy's never considering this fluid as a substance and "speaks only of *electricity* or *electric energies*, which are empty words in themselves, when supposed to imply the idea of causes; while all the meteorological phenomena proclaim a *fluid*, the *chemical affinities* of which, already manifested, open the road to the most important inquiries", see DE LUC (1810), part I, p. 115.
[25] *Ibid*. See also OSTWALD (1980), pp. 421-6. Several of de Luc's claims were refuted by MAYCOCK (1816).
[26] See DE LUC (1810), part II, pp. 241-3.

exist, without any new excitement. To distinguish it from the conventional voltaic pile, he proposed to call it the "Electric Column".[27]

The column de Luc presented to the Royal Society was made up of 300 pairs. It showed identical effects to those produced by the frictional electrical machine, by applying all the standard tests for determining electricity. The dry pile's intensity was measured with a gold leaf electroscope. When the intensity was sufficiently high, the gold leaf struck the side of the electroscope and then immediately collapsed as its charge was neutralized (earthed). The gold leaf was quickly recharged by the column and would thus strike the sides of the electroscope more or less continuously. De Luc found that the speed of striking depended on several factors: the number of pairs in a column, the number of columns connected in the circuit, temperature and humidity. This led to his "aerial electroscope" (figures 2 and 3) arranged in such a way that a pith ball covered with gold leaf and suspended from a silk thread was made to oscillate between two spheres connected to the poles of the pile.[28] In another version (similar to the specimen still active in the Clarendon Laboratory) he replaced the spheres by two brass bells, so that the rate of striking could be heard. This modification (figure 3) was probably suggested by B.M. Forster (1764-1829), whose inspiration could well have been the "electric chimes", a popular eighteenth century didactic device sold as an accessory in the electrostatic kits.[29] De Luc observed that the variations in the rate of striking of the dangling bob were according to the state of the atmosphere. It was reported that with a column of 20,000 pairs of silver, zinc and double discs of paper, a continuous ringing was maintained for more than two years. With this version he obtained sparks, and a Leyden jar was charged in ten minutes with sufficient electricity to produce shocks and to fuse an inch of thin platinum wire.

Over the next few years there was a flurry of activity repeating de Luc's observations, in particular those relating to the apparent influence of the weather on the activity of the dry pile.[30] Notable among these minor players were B.M. Forster,[31] his unrelated namesake Thomas Foster[32] and Thomas Howldy.[33] A Mr J. Tatum

[27] SINGER (1814) summarises de Luc's experiments. The problem with this text is that it is difficult to identify which of the experiments are Singer's, although this becomes clear when comparing the text with de Luc's letter cited in note 19.

[28] DE LUC (1810a), plate III; DE LUC (1810b). There is also an additional third part, DE LUC (1810c).

[29] FORSTER (1810), plate VI, figs. 1-7.

[30] Notes on the variable oscillations of the dry pile's clapper depending on the weather – slower in humid conditions and ceasing altogether for brief periods in excessive humidity, are found in *Philosophical Magazine*, 35 (1810), pp. 317-8, 468; and 36 (1810), p. 472. See also DE LUC (1810a), DE LUC (1810b), DE LUC (1810c) and FORSTER (1810).

[31] FORSTER (1815). See also the earlier volumes.

[32] FOSTER (1811).

[33] HOWLDY (1814), based on the dry pile described in *Journal of Natural Philosophy, Chemistry, and the Arts*, 35 (1813), p. 84.

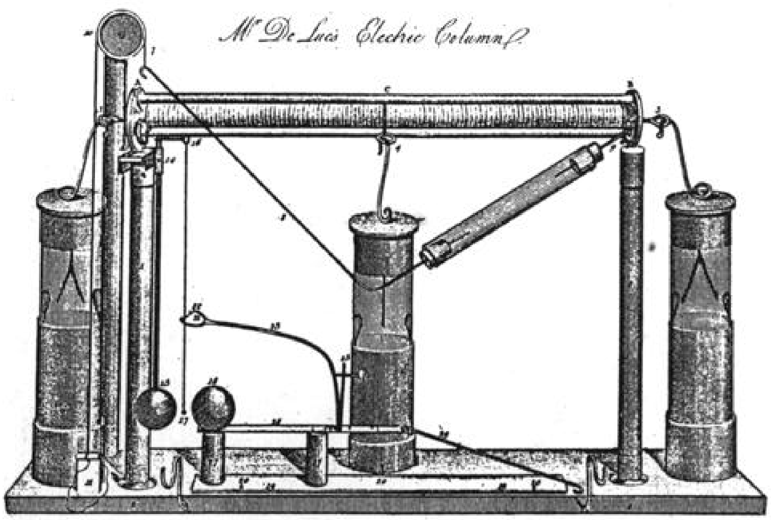

Figure 2 De Luc's column and "aerial electroscope". From *A Journal of Natural Philosophy, Chemistry, and the Arts* [Nicholson's], 27 (1810), plate III.

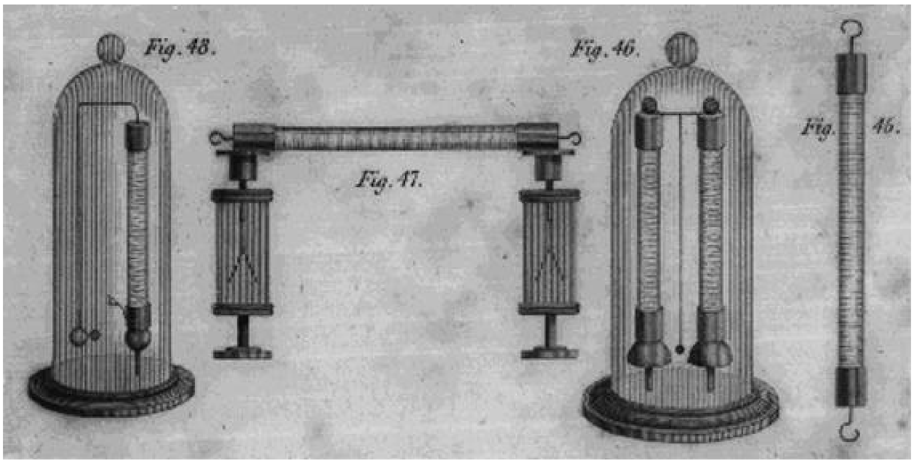

Figure 3 Dry piles in Singer's *Elements of Electricity and Electro-Chemistry* of 1814. Figure 45 is Singer's version of de Luc's "electric column". Figure 46 shows the perpetual chimes invented by B.M. Forster; figure 47 the pile arranged with a gold-leaf electroscope at each pole; figure 48 a version of de Luc's "aerial electroscope".

suggested that the chief cause for variations in the ball's oscillations was not moisture but owing to the increased temperature of the atmosphere.[34]

There was also a brief exchange of papers between de Luc and Francis Ronalds (1788-1873) on this matter in 1814, which appeared to have been based on a misunderstanding. As it happened, both identified two different sources of the effect of humidity on the pile. Firstly, a certain degree of moisture was needed inside the column (that is of the "conducting" material interposed between the metals) for the pile to work. Variations in this moisture content affected the pile's degree of activity. Secondly, the pile was affected by another source of moisture as indicated by the behaviour of the electrometer connected to the pile. Moisture deposited onto the outer glass tube, containing the column of the dry pile, reduced its electrical tension, as part of this was leaked away by the conducting film of moisture.[35] The exchange was terminated by Ronalds with a rhetorical question about the cause of the dry pile's electrical action:

> Mr De Luc's valuable experiments and observations lead to the conclusion that the presence of water, or some conducting fluid, in the substances which have been hitherto interposed between the metals, is necessary to the accumulation of electricity. Whether this effect is occasioned by the presence of water only, because a conducting fluid is essential? Which I take to be the opinion; whether water acts merely as a conductor, offering in some unknown electric relation from the metals? Which I imagine to be that of Mr Singer; or, Whether any kind of decomposition is necessary are questioned not yet determined; but I have no doubt the researches of those intelligent gentlemen will contribute very materially to elucidate the subject.[36]

George John Singer (1786-1817) in an admirable summary on the dry pile in his *Elements of Electricity and Electro-Chemistry*, published in 1814, reached the same conclusions as de Luc about the difference in action between the voltaic and the dry pile:

> It therefore appears indispensably necessary to the chemical power of the Voltaic apparatus, that a *liquid* be interposed between each pair of its plates, whilst for the pure electrical effects, the only condition appears to be the association of the two metals; and the connexion of the different pairs, by some conductor that does not interfere with the electro-motive power.[37]

Singer's intention was to test this by means of a very powerful dry pile consisting of 60,000 pairs, but this was not ready when his book was published.[38]

[34] TATUM (1816). Another correspondent to this journal devises a new meteorological instrument, "Combination of the Electric Column, the Thermometer, Barometer, and Hygrometer in one Instrument, for Electro-atmospherical Researches", *Philosophical Magazine or Annals of Chemistry, Mathematics, Astronomy, Natural History*, 49 (1817), p. 55, plate I, fig. 6. I have never seen such an instrument in contemporary trade catalogues.

[35] RONALDS (1814). Response by DE LUC (1814). Replied to by RONALDS (1814a).

[36] RONALDS (1814a), p. 444.

[37] SINGER (1814), p. 462. This is at variance with what Ronald's opinion is of what Singer believes to be the seat of electrical activity. See the previous quotation.

[38] *Ibid*., p. 462. He refers to a 50,000-element pile.

5. Zamboni

Probably the most efficient dry pile was constructed by Giuseppe Zamboni (1776-1846), professor of physics at Verona.[39] He dispensed entirely with the zinc plates of de Luc and used only discs of paper previously soaked in zinc sulphate solution and then dried. The paper was coated on one side with very thin tinfoil (of the purest tin) and on the other with (black) manganese dioxide (to replace de Luc's Dutch gilt paper). This was pulverised in a mixture of flour of milk, and a little honey so that the substance would stay stuck to the paper.[40] The paper was then cut into discs and by means of a special tool the pairs (cells) were stacked to form the pile, inserted into a glass tube, into which molten wax and turpentine or gum was poured to fill all the interstices, to prevent electrical leakage. His pile terminated in metallic plates, compressing the paper discs by means of silk ligatures. Next the outside of the glass tube was coated with wax, gum, bitumen, or sulphur to produce a good seal against influences from the atmosphere. The tinned surface was the positive pole and the manganese dioxide the negative pole.[41]

Zamboni was particularly keen to devise a pile that could move a light pendulum for a very long time. The pendulum was mounted between the oppositely charged poles of two piles placed side by side, and went into oscillation because of the alternating attraction and repulsion it experienced. The description of his "electrical perpetuum mobile" was published extensively after it appeared in Brugnatelli's *Giornale di fisica* in December 1812 and the following January.[42] Zamboni proudly presented his device to the Royal Society.[43]

6. Volta and the Dry Pile

In his letter of January 10, 1803 to Christian Heinrich Pfaff (1773-1852), Volta not only contrasted the behaviour of a pile whose cardboard discs were soaked in clean water from one whose discs were soaked in salty water, but also observed that the pile still functioned, albeit much more slowly, when the discs had dried out.[44] He would return to this point in 1811,[45] and also in his subsequent brief

[39] ZAMBONI (1812).
[40] According to Zamboni in his later piles he did not use the honey, presumably because he was told by the chemical school camp that this substance contained water.
[41] In the later forms of Zamboni's pile the discs were formed of gilt and silver paper pasted back to back. See MOTTELAY (1922), p. 420.
[42] ZAMBONI (1812a) and ZAMBONI (1812b). Fully described in GILBERT (1815), plate I. See also ZAMBONI (1820-22).
[43] ZAMBONI (1815). A striking example of such a perpetual motion machine is in the Dal Negro Collection in the Department of Physics of Padua University, see SALANDIN (1991).
[44] See *VO*, IV, pp. 236-41 and *VE*, IV, 1320, p. 254.
[45] VOLTA (1811), p. 282. The pile with the dried discs produced no shocks but did move his electrometer.

correspondence with Zamboni in the following year. By now he was in his late sixties, but he was kept abreast of electrical developments by his correspondents. For instance, in a letter dated March 20, 1807, Gilbert, the editor of the *Annalen der Physik*, described some of the latest electrical experiments including Maréchaux's delicate work with his dry pile from which he had concluded that this device did not require moisture to function.[46] Zamboni described his dry pile to Volta in a letter dated August 24, 1812. He also asked Volta whether he could dedicate his discourse on the dry pile to him,[47] to which Volta replied in the affirmative on September 8, 1812. Volta took this opportunity to discuss the work that had been done on the dry pile by himself, Zamboni and de Luc. He described his observations of the pile under different conditions that led him to disagree with de Luc that the pile could be used to indicate the electrical state of the air or the earth. It was the humidity in the air on the cardboard discs of the pile that caused the changes in the pile's electrical behaviour. In that sense it was not very rigorous to call this device a "dry pile". It might serve better as an hygrometer than as an indicator of "meteorological electricity".[48] Zamboni, in turn, responded on September 12, 1812, proposing that to Volta should go the honour of having constructed the first dry pile, and ended by reiterating de Luc's observations made with his aerial electroscope and the effects of humidity.[49]

7. Conclusions

Both the contact tension and the chemical action schools took up the pile to prove their case. Initially the dry pile appeared to prove Volta's ideas on contact electricity, but it became increasingly apparent that this was not the case. Zamboni found that the discs in his pile, unlike those in Volta's, showed no sign of tarnish even after 24 years of activity, and yet had retained full electrical tension, so there appeared to be no chemical activity.[50] Karl Christopher Friederich von Jäger of Würtenberg observed that when the temperature of the Zamboni pile was raised to quite a high level it began to work as well as ever.[51]

[46] *VE*, V, 1556, pp. 109-12, on p. 112. The reference to the Maréchaux work about which Gilbert is referring to Volta is given in MARÉCHAUX (1805).
[47] *VE*, V, 1667, pp. 241-2.
[48] *VE*, V, 1668, p. 242 and VOLTA (1812). Actually, de Luc was well aware of his problems with his "aerial electroscope" and fully appreciated the influence of humidity on his device.
[49] *VE*, V, 1669, pp. 242-4.
[50] ZAMBONI (1836), p. 387. Zamboni's original letters to Fusinieri were published in *Annali delle scienze del Regno Lombardo Veneto* [Jan.-Febr., 1836].
[51] JÄGER (1815). The author conducted a series of experiments based on Volta's condenser plate experiments. Jäger's pile consisted of metal plates and very thin intermediate layers of shellac varnish. He observed indications of electricity. Similar experiments were carried out in 1824 by Bischof and von Münchow in Bonn, but fall outside the scope of this paper. The observation that a heated pile improved its action could be used to argue for the contact tension hypothesis, but Dr Thomas Thomson held a different opinion, for according to him Dr Jäger's observations that the

These observations appeared to be in favour of the contact tension hypothesis. On the other hand Georg Friedrich Parrot (1767-1852) demonstrated in 1817[52] what Ritter had already shown in 1802: that these piles were not really dry, and like the voltaic pile required moisture to be active. Thus, after prolonged heating, the pile lost all electrical energy yet without showing any visible change in its structure. It would resume electrical activity when a little moisture was added. These observations strengthened the view of the supporters of the chemical hypothesis such as Arthur-Auguste de La Rive (1801-1873). Volta retired from scientific work in 1819, so his views remained those expressed in his brief correspondence with Zamboni.

As is often the case with instrumental evidence, this was inconclusive and ambiguous. Both the contact tension and the chemical action schools could point to aspects that appeared to prove their case and discount those that favoured the other side. By the 1830s the dry pile had effectively dropped out of this debate. This was partly because a new startling phenomenon, Seebeck's "thermoelectricity" and the thermopile, overshadowed it, and partly because experimenters had become more refined in handling such laboratory devices as the electrometer and the galvanometer, when measuring the low-tension electricity of the voltaic pile and the high-tension electricity of the dry pile.

The device became the motive power of an electrostatic clock utilising the oscillating bob between the poles. Such clocks were devised by Ronalds[53] and Zamboni,[54] but these never went beyond being scientific curiosities. A few incomplete Zamboni clocks have survived.[55] The dry piles were also used in a small group of highly sensitive single gold leaf electroscopes. Behrens suspended a single gold leaf of his electroscope between the positive and negative poles of a voltaic pile in 1806. This device indicated both the magnitude and the polarity of the charge, as the electrified gold leaf would be deflected towards the pole of the opposite charge. In 1814, J.G.F. Bohnenberger (1763-1831) replaced the voltaic pile with a dry one which increased the electroscope's sensitivity. Thus, even after the dry pile was sidelined in the debate about the source of the electrical energy of the voltaic pile, it remained for some time a useful laboratory instrument.

Perhaps the last word should be given to Singer:

electrical activity of the Zamboni pile improved when it was raised to a high temperature indicated that dry paper, when cold, is a non-conductor of electricity, but that it again becomes a conductor when heated to 104 degrees, or as high as 140 degrees (presumably ^{o}F). See MOTTELAY (1922), p. 364. Count Léo Henckel of Donnersmarck in a short letter to Volta dated 24 February 1816 cited Jäger's dry pile experiments without going into details. See *VE*, V, 1727, p. 314.

[52] PARROT (1817).

[53] AKED (1973).

[54] AKED and RIZZARDI (1975).

[55] *Ibid.*, pp. 530-7. See also HACKMANN (1995), p. 198, entry 291.

The discoveries of Franklin displayed the influence of electricity in the production of the most magnificent phenomena of nature. That of Volta led to the rapid development of its connexion with her more silent, but important processes. Like the power of gravitation, it seems to apply more extensively, the farther its investigation is pursued. Like that power too, its nature may for ever escape our cognizance; but the contemplation of its effects may supply new facts calculated to extend the resources of art, and enlighten our conception of the infinite variety, and harmony, of natural phenomena. Such pursuits are amongst the best sources of intellectual improvement, for they call into action the highest powers of the mind, and present a constant succession of interesting objects for their exercise.[56]

[56] SINGER (1814), p. 463.

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