Volta’s Invention of the Electrophorus: Research Highlights

Summary

Alessandro Volta’s invention of the electrophorus (1775) advanced the scientific consensus regarding attraction, repulsion, and the location of the electricity in a charged body. This happened even though: (1) there was no grand theory of the electrophorus,—in fact, Volta initially provided no theory of the device at all; and (2) the phenomena the device displayed were not novel; they were demonstrated and precisely analyzed by others including Johan Carl Wilcke (1762) and Giambatista Beccaria (1772), two of the best-known electricians of the era, years before Volta’s invention. The obvious, yet unanswered, question is how the scientific consensus changed and why it was the electrophorus that advanced the consensus.

The case study, The Reception of Volta’s Electrophorus Among Eighteenth-Century Electricians, provides a detailed account of how the scientific consensus changed between Benjamin Franklin’s widely-accepted theory of electricity (1747-55) and the end of the eighteenth century. We combine contemporary accounts of the electrophorus and experimentation with the device itself to determine the theoretically relevant phenomena the device displayed. These phenomena are then compared to step-by-step analyses of Beccaria’s double-pane experiment and Wilcke’s dissectible condenser to determine that these prior experiments demonstrated the same phenomena. Finally, we explain the greater renown afforded the electrophorus in terms of several design features that allowed it to achieve wider distribution and demonstrate key phenomena more clearly than prior experiments.

Provided below is a brief background section on the Leyden jar and a collection of highlights from the larger case study.

Background: The Leyden Jar

The case study itself and the research highlights below assume some familiarity with the history of electricity, especially the discovery of the Leyden jar in 1746. The story of the Leyden jar’s discovery is fascinating and warrants a case study of its own in the future. However, for our present purposes, a brief account primarily based on Heilbron, *Electricity*, 309–33 may provide useful background for the research highlights below and for the case study itself.

A Leyden jar consists of a glass jar coated on the inside and outside with a conductor, typically metal, and partially filled with water. Into the water is set a conductor, often a metal chain, which is connected to a metal ball that protrudes from the top of the device.

Figure 1. Drawing of a Leyden jar[1]

The Leyden jar's typical operation involves first attaching the jar's external surface to ground, either by holding the jar itself or through a conducting wire attached to the jar. Some source of static electricity is then applied to the knob of the device. After the device is charged, the experimenter connects the knob and the metal coating outside of the jar either by touching both simultaneously or by connecting them with a conductor to produce a terrific spark.

The device was discovered independently by Ewald Jürgen von Kleist and Pieter van Musschenbroek, both entirely by accident. The equipment involved—a source of electricity, a wire, and a water-filled vessel—were commonplace in research on electricity at that time, but existing electrical theory would have suggested precisely the wrong arrangement to anyone interested in producing substantial sparks. The story of Musschenbroek's discovery is both entertaining and illustrative of this point.

Musschenbroek was pursuing research aimed at drawing electricity out of water electrified in a glass jar. The standard procedure for doing this was to place the glass jar on an insulated stand and then run a wire into the jar from a static electric generator. This allowed the electricity to collect in the glass jar, and the insulated stand prevented the electricity from dissipating. According to established electrical theory, it was important that the external surface of the glass

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[1] Robert Alexander Houstoun, *Elements of Physics* (London: Longmans, Green and Co., 1919), 176, Google Books.

not be touched or otherwise connected to ground while charging as this would allow the collected electricity to escape the jar, resulting in a faint spark when the knob is touched.

The established theory was unknown to Andreas Cunaeus, a lawyer who occasionally enjoyed visiting Musschenbroek's laboratory and observing his experiments. After one such visit, Cunaeus tried to replicate Musschenbroek's experiment. He was alone, and for the sake of convenience, he electrified the jar by holding it up to the electrostatic generator. After charging the jar, he then took his free hand to touch the knob of the device and draw the modest spark that Musschenbroek had experienced. Instead, he discovered the terrible Leyden jar.

Upon reporting the discovery to Musschenbroek and his assistant Allamand, both tried the experiment. Allamand reported that the shock was so powerful that it knocked the wind out of him for several minutes. When Musschenbroek tried it, he said the shock was so terrific that he thought he might die. In his descriptions of the experiment to others, he was quite clear that no one else should try it and that he would not try the experiment again "for all the kingdom of France."[2]

Musschenbroek's initial letters on the discovery contained the frank statement that he "now understood nothing and could explain nothing"[3] about electricity. The sentiment was widely shared. The Leyden jar's sparks were so powerful, unexpected, and contrary to established electrical theory that electricians reacted with fear and bewilderment. If a simple modification of an entirely ordinary experiment could create such a powerful spark, maybe the next discovery by an electrician would prove to be their last. It was against this backdrop of tumult in electrical theory that Benjamin Franklin began his research.

Research highlights

Below are some highlights from the case study. Each highlight includes a set of references to either the case study itself or to external sources for more detailed discussions of the relevant topics. References that include only page numbers are references to the case study. External references have corresponding bibliography entries on pages 48–54 of the case study.

Benjamin Franklin's theory of electricity explained the Leyden jar's powerful sparks sufficiently well that the theory's deficiencies in explaining attraction and repulsion were largely overlooked.

Explanation

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[2] Heilbron, *Electricity*, 313.
[3] Heilbron, *Electricity*, 315.

The unexpected discovery of the Leyden jar (1746) both overturned all established electrical theory and shifted the focus of electricians away from the historical focus on the attraction and repulsion of light objects to attempting to explain the unprecedentedly powerful sparks the Leyden jar could produce. Franklin's theory of electricity (1747–55) successfully explained the Leyden jar's sparks and was widely adopted by electricians for that reason. This happened even though Franklin's attempt to extend his theory to explain attraction and repulsion was brief, internally inconsistent, and sufficiently unclear that his followers frequently misunderstood it.

References

— On Franklin's focus on the Leyden jar, see 3–4. See also Home, "Franklin's Electrical Atmospheres," 132–135.
— On the internal inconsistencies in Franklin's explanation of attraction and repulsion, see 5–7.
— On the misunderstandings of Franklin's views among his contemporaries, see 8–9 and 8n. See also 7–10 for how Franklin's followers attempted to explain attraction and repulsion in accordance with Franklin's theory.

Franklin's followers attempted to rectify Franklin's theory with the known facts regarding attraction and repulsion by adopting several plausible-seeming, though ultimately inaccurate notions about the nature of attraction and repulsion.

Explanation

Two notions were central to the attempts by Franklin's followers to explain attraction and repulsion. The first was the notion of an electrical atmosphere, a supposed layer of electrical fluid that surrounded bodies with more electricity than normal. The second notion—popular with Franklin's followers but rejected by Franklin himself—was that attraction and repulsion involved a transfer of electricity between the bodies or their atmospheres. While electricians would eventually abandon these notions—largely due to the influence of the electrophorus—by the end of the eighteenth century, both notions were quite plausible at the time. The notion of an electrical atmosphere was thought to be directly apparent to the senses through the "electric spider web phenomenon" wherein moving one's face or arms near an electrified body causes a distinct sensation similar to the feeling of a spider's web touching the skin. The notion that attraction and repulsion involve the movement of electricity was a natural extension of the widely accepted view that sparks occur when electricity moves from a body with a greater amount of electricity to a body with less. If the movement of fluid was involved in sparks, it seems natural to assume that it might be involved in other electrical phenomena like attraction and repulsion.

References

— On Franklin's explanation of attraction and repulsion, see 3–7.

— For how Franklin's followers attempted to explain attraction and repulsion, and how their views differed from Franklin's, see 7–11.
— On the electric spider web phenomenon, see 4.
— On Franklin's notion of an electrical atmosphere, see 3–4. For a discussion of the different ways eighteenth-century electricians used the term, see 7–8.
— For differences between Franklin's explanation of attraction and repulsion and those of his followers, see 8–11.
— For a discussion of how views on attraction and repulsion changed after the electrophorus, see 15–21, particularly the summary on 20–21.

The changes to electrical theory that occurred after the electrophorus's invention were proposed by leading theorists as early as 1759. Yet, the scientific consensus did not change until after Volta introduced the electrophorus.

Explanation
In 1759, Franz Aepinus published *Tentamen*, his insightful but largely overlooked treatise on electricity and magnetism. In it, he proposed a theory of electricity which did away with both the notion of electrical atmospheres consisting of a layer of excess electric fluid surrounding charged bodies and with the idea that attraction and repulsion required a transfer of electricity. In 1771, Henry Cavendish independently proposed a similarly insightful and similarly overlooked electrical theory that likewise required neither electrical atmospheres nor a transfer of electricity in attraction or repulsion. John Canton and Giambatista Beccaria, two of Franklin's most influential supporters, both initially proposed theories involving electrical atmospheres and transfers of electricity, and both abandoned these views in well-read works in 1767 and 1772 respectively. Despite the progress made by these leading theorists, the scientific consensus on the topic did not change, and most electricians continued to view attraction and repulsion as involving a transfer of electric fluid between electrical atmospheres.

References
— For the changes to electrical theory that occurred after the electrophorus's invention, see 15–21 and the summary on 20–21.
— For a discussion of the views of theorists before 1775, see 10 (Aepinus and Cavendish) and 8–11 (Canton and Beccaria).

Alessandro Volta's electrophorus received widespread acclaim and significantly impacted electrical theory even though the phenomena the device displayed were demonstrated by much better-known electricians years before Volta's invention.

Explanation
Volta's contemporaries regarded the electrophorus (1775) as "the most surprising device hitherto invented" and "marking a new epoch" in electrical theory. The device displayed two theoretically relevant phenomena: the production of sparks between two seemingly neutrally-electrified bodies and the ability to generate repeated sparks without rerubbing the resin. However, both of these phenomena were displayed and precisely analyzed in experiments by Giambatista Beccaria and Johan Carl Wilcke, two of the best-known electricians of the era, years before Volta's invention.

References
— For an account of Volta's design for the electrophorus and how it works, see 13–14 and appendix A (55–63).
— On the reaction of Volta's contemporaries to the electrophorus, see 15–16.
— On the renown afforded to Volta, Beccaria, and Wilcke as of 1775, see 11–12 (Volta); 8–9, 9n, and 22 (Beccaria); and 28 (Wilcke).
— On the theoretically relevant phenomena displayed by the electrophorus and the device's impact on electrical theory, see 16–21.
— For an analysis of the phenomena displayed by Beccaria and Wilcke's experiments, see 22–27 (Beccaria) and 28–34 (Wilcke).

Volta designed the electrophorus to demonstrate the phenomenon of repeated sparks as clearly as possible.

Explanation
In designing the electrophorus, Volta went to considerable lengths to ensure that the device could display the phenomenon of repeated sparks as clearly as possible. For example, instead of using more common materials like glass for the non-conductor, Volta spent considerable time perfecting a special resin cake made of three parts turpentine, two of rosin, and one of wax. Volta had to boil this mixture for hours and pay special attention to ensure that it did not crack during the cooling process. Volta knew that the procedure could be performed with glass alone—he was quite familiar with Beccaria's double-pane experiment that used glass, yet he found it essential to identify a substance that would demonstrate the phenomena even more clearly than glass. Even the name Volta attached to the device, the *electtroforo perpetuo*, or "perpetual purveyor of electricity," was designed to highlight this attribute. The device was ultimately successful in demonstrating the relevant phenomena more clearly than prior experiments.

References
— For a discussion of Volta's design for the electrophorus, see 13–14.

— For a discussion of how other elements of Volta's design contributed to clearly demonstrating its core phenomena, see 42–43.
— On the differences between Volta's electrophorus and the experiments by Beccaria and Wilcke, compare the descriptions of Volta's device (13–14) to those of Beccaria (22–23) and Wilcke (28–29).
— On how electricians tried to explain the electrophorus's repeated sparks, see 43–44.
— For a discussion of how Volta's original design for the device influenced the design of imitation electrophoruses, see 44–45.

Volta's design for the electrophorus allowed it to gain widespread distribution among both natural philosophers and amateurs.

Explanation
The electrophorus spread quickly in European scientific circles. By 1776, reports and analyses of the device appeared in Italy, Paris, London, Berlin, Vienna, Prague, and elsewhere. Volta's design for the device allowed it to gain widespread distribution for three reasons: (a) it was practically useful for electrical research; (b) it was intriguing to amateurs and could attract customers for popular courses on electricity; (c) imitations of the device were cheap and easy to build. The device's widespread availability meant many electricians were personally familiar with the device and the phenomena it displayed.

References
— For a brief discussion of the importance of distribution, see 36–37.
— On the distribution of the electrophorus circa 1775–76, see 37–38 and Pancaldi, *Volta*, 105–7.
— On the device's practical usefulness, see 34–35, 38–39, and 39n.
— On the device's use in popular courses on electricity, see 39–40, particularly figure 16.
— On the ability of the device to be imitated, see 13–14 and 41.

While Volta received substantial acclaim after the invention of the electrophorus, some of Volta's contemporaries regarded him as merely an inventor of "electrical amusements" and not as a substantive natural philosopher. Yet it was the invention of electrical devices, especially the electrophorus and the Voltaic pile, that cemented Volta's legacy.

Explanation
After Volta invented the electrophorus, he found himself in an unusual social position among natural philosophers. While some rated him among the most important electricians of the era, the "Newton of electricity," others were less taken with the up-and-coming Italian. Most electricians acknowledged Volta's merit in designing a useful electrical apparatus that clearly displayed the

relevant phenomena and attributed articulation of the underlying principles involved to others. For some of Volta's contemporaries, however, the question of who first discovered the underlying principles involved was the question that mattered most. To them, Volta was an inventor of "electrical amusements," not a substantive natural philosopher. Yet, what finally cemented Volta's legacy as one of the most important electricians of the late eighteenth century—the person after whom the volt is named—was his invention of another "electrical amusement," the Voltaic pile, the precursor to the modern battery. Volta had a lasting impact on the history of electricity by designing instruments that could capture the attention of natural philosophers, demand explanation, and illustrate important theoretical concepts without needing to provide the theory himself.

References

— For a brief discussion of how natural philosophers reacted to the electrophorus, see 15–16.
— For a concluding discussion on the nature and significance of Volta's accomplishment, see 46–47.