

Volta's Invention of the Electrophorus: Research Highlights

Summary

In 1775, Alessandro Volta announced the invention of the electrophorus, a device which could produce a seemingly endless supply of electricity through the repetition of a simple series of operations. The device could not be easily explained on some of the common theories of electricity and thus led to a shift in the scientific consensus regarding the causes of electrical attraction and repulsion. Prior scholarship on the topic has noted that both Johan Carl Wilcke (1762) and Giambatista Beccaria (1772) demonstrated the phenomenon of repeated sparks before Volta, but has not attempted to explain why the electrophorus was substantially more famous than these earlier experiments nor why the scientific consensus did not change until after the electrophorus's invention.

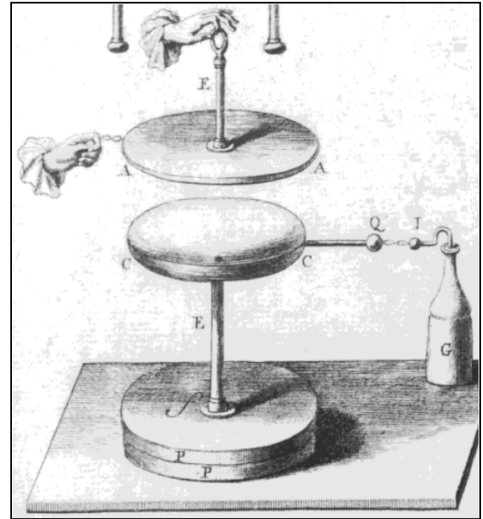


Figure 1. Volta's electrophorus with Leyden jar.¹

The case study, [The Reception of Volta's Electrophorus Among Eighteenth-Century Electricians](#), aims to answer these questions. It 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. I 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, I 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.

¹ Volta, "Lettera al Signor Priestley," 91–107. Also available in Volta, *Le Opere*, 3:93–108.

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 Evan Pence's "The Discovery and Impact of the Leyden Jar" (forthcoming) 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.

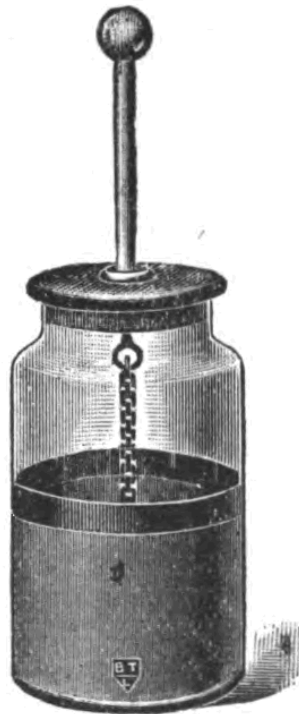


Figure 2. Drawing of a Leyden jar²

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.³ 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.

² Robert Alexander Houstoun, *Elements of Physics* (London: Longmans, Green and Co., 1919), 176, [Google Books](#).

³ It is also possible to charge the device by connecting the external surface of the jar to the electrostatic generator used to charge the jar's inner surface. Indeed, this appears to be the arrangement that allowed Kleist to make his discovery.

The device was discovered independently by Ewald Jürgen von Kleist and Pieter van Musschenbroek during their research on increasing the charge produced by electrostatic generators. The equipment involved—an electrostatic generator, a wire, and a water-filled vessel—had recently become commonplace in research on electricity at that time, but the electricians had not yet discovered the charging arrangement required to go from mild sparks to the powerful shock of the Leyden jar. The story of Musschenbroek’s discovery provides one particularly entertaining illustration of how the discovery was made.

Musschenbroek was pursuing research aimed at drawing electricity out of water electrified in a glass jar. The common practice for doing this was to ensure that the jar was insulated either by placing it on a glass stand or by having the assistant stand on glass or silk while holding the jar up to the source of electricity. After the jar was charged, the experimenter could touch the knob of the jar and produce a faint spark.

The common practice 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 standing on the ground and 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 associate 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.”⁴

The jar spread like wildfire, becoming famed and admired well before its first presentation to the public and giving rise to enough experiments that by the end of the year, Winkler could publish an entire treatise on “the Strength of the Electric Power of Water in Glass Vessels.”⁵ As often as not, experiments were undertaken primarily for the enjoyment of doing so or a simple desire to see what happens and many electricians made a living by giving public lectures on the latest electrical experiments, often centering on the jar itself. It was against this backdrop that Benjamin Franklin began his research into electricity.

⁴ Heilbron, *Electricity*, 313.

⁵ Winkler, *Die Stärke der Electricischen Kraft des Wassers in gläsernen Gefäßen*, 49.

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.

1) 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

The unexpected discovery of the Leyden jar (1745) shifted the focus of electricians away from the historical concern with attraction, repulsion, and conduction 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.

2) 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 by the end of the eighteenth century,—largely due to the influence of the electrophorus—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.

3) The improvements to Franklinist accounts of attraction and repulsion that occurred after the electrophorus's widespread adoption were proposed by leading theorists as early as 1759. Yet, the scientific consensus did not change until after Volta's invention.

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 Giambattista 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).

4) Alessandro Volta’s electrophorus received widespread acclaim and significantly impacted electrical theory even though the basic 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).

5) 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 *electroforo 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.

6) Volta designed the electrophorus to encourage adoption among electricians.

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. The device’s initial spread was often in the form of public demonstrations. In the eighteenth century, it was fashionable for amateurs to be up to date on the latest scientific developments. Electricians met this demand by charging for lectures that explained the latest developments in the field and included impressive experiments with the latest electrical apparatus. Volta encouraged electricians to acquire their own electrophorus by designing the device to be well-suited to these public demonstrations. For example, in his initial announcement of the device, Volta pays specific attention to describing the series of experiments one can perform with it, and he includes a detailed diagram of these experiments. Additionally, Volta designed the device to be portable, even including a hollow base which can be used to carry all the equipment needed for demonstrations.

The spread of the electrophorus was also aided by two other features of its design. First, it was practically useful for electrical research as a convenient way of producing the electricity required to perform experiments. Second, the device was easy and cheap to imitate which meant that many electricians were able to make their own version of the device with materials already available to them.

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 use in popular courses on electricity, see 39–40, particularly figure 16.
- On the device’s practical usefulness, see 34–35, 38–39, and 39n.
- On the ability of the device to be imitated, see 13–14 and 41.

7) Volta’s design for the electrophorus helped electricians see the inadequacies in existing electrical theory.

Explanation

Even though many electricians were familiar with the earlier and similar experiments by Beccaria and Wilcke, the electrophorus succeeded in causing a quite different reaction. Volta’s efforts to clearly demonstrate the phenomenon of repeated sparks, combined with his decision to name the device the *electtroforo perpetuo*, or “perpetual purveyor of electricity,” focused the attention of electricians on the mystery of how the device’s sparks were produced and caused many electricians realized for the first time that this was a phenomenon they could not explain. The reaction was a mixture of concern and excitement; concern that the electrophorus appeared to be directly contradictory to Franklin’s electrical theory and thus, might overturn it entirely and excitement that the electrophorus might unleash a wave of highly productive research into electricity just as the Leyden jar had decades earlier.

Ultimately, the electrophorus did not overturn Franklin’s theory of electricity. It did, however, contribute to several important changes in the theory, including changes in the understanding of attraction and repulsion, where the electricity in a charged body resides and how the electricity in a body can be affected by the electricity of other bodies.

References

- On the similarities between Volta’s electrophorus and prior experiments by Beccaria and Wilcke, see 16–21 (electrophorus), 22–27 (Beccaria), and 28–34 (Wilcke).
- On initial reactions to the electrophorus, see 15–16.
- On the impact of the electrophorus on electrical theory, see 16–20, especially the summary on 20–21.

8) 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.