

The Discovery and Impact of the Leyden Jar: Research Highlights

Summary

The 1745 invention of the Leyden jar is widely recognized as a revolutionary event in the history of electricity. By simply electrifying a glass of water, experimenters found that they could produce remarkably powerful shocks, increasing the output of their generators many times over and allowing the creation of a panoply of exciting new displays. Traditionally, the events leading to and following from the discovery have been viewed through the lens of theory. The jar has been presented as an anomaly strange enough to require amateur error to discover and significant enough to throw the community into crisis. In examining the matter more closely, however, it becomes clear that theory was less central to the practice of mid-eighteenth-century electricity than is often assumed and that the discovery of the capacitor is at least as much a story of technical refinement and practical ends as it is one of theoretical innovation.

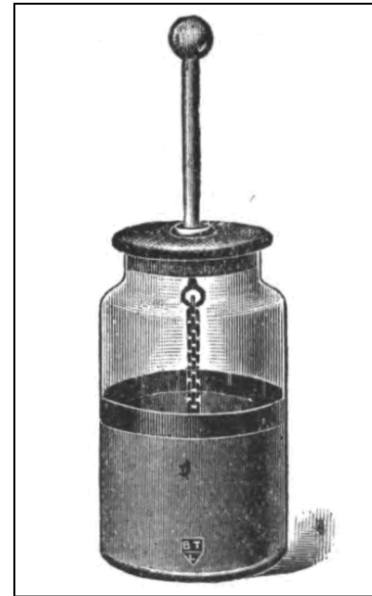


Figure 1. Drawing of a Leyden jar¹

In “[The Discovery and Impact of the Leyden Jar](#),” I present an account focused on the device’s technical development and application. I begin with a discussion of the technological requirements for constructing the Leyden jar and show how each was met in the years leading up to the discovery. I then outline how the jar was discovered, first by Ewald von Kleist in October 1745 and then by Pieter Musschenbroek, Jean-Nicolas-Sébastien Allamand, and Andreas Cunaeus shortly thereafter. Though historians have often framed the discoveries as lucky missteps, I show that this was not the case for Kleist, that theory itself played a more heuristic role at the time, and that the device’s violation of theory ultimately posed little barrier to its discovery. Turning to the jar’s development and reception, I show how exploratory methods played a critical role in the device’s refinement and discuss the importance of entertainment and practical ends in its long-term impacts. Though it may have represented a crisis for some, the jar’s myriad applications far outshined any problems it posed, revolutionizing the field less by undermining experimenters’ confidence in their beliefs than by radically extending the range of powers at their disposal.

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

Background: How the Jar Works

Taken abstractly, the jar, like all capacitors, consists of a pair of conductive materials, or electrodes, separated by a non-conductive material, or insulator. In the simplest case, this can be little more than two sheets of metal separated by dry air, though early experimenters tended to use glass as their insulator. When current flows into a capacitor, electrons accumulate along one of the plates, creating a net positive charge and, because similarly charged particles repel one another, driving free electrons away from the opposite plate, creating a net positive charge there (see figure 1 for a simple schematic). With time, the increasingly negative charge of one plate and counterbalanced positive charge of the other creates a large store of potential energy, like water filling the inside of a balloon. When a suitable connection is established between them, this stored energy is released in a process that may be drawn out or nigh instantaneous, depending on the channel (the latter being characteristic of the jar's infamous blow).

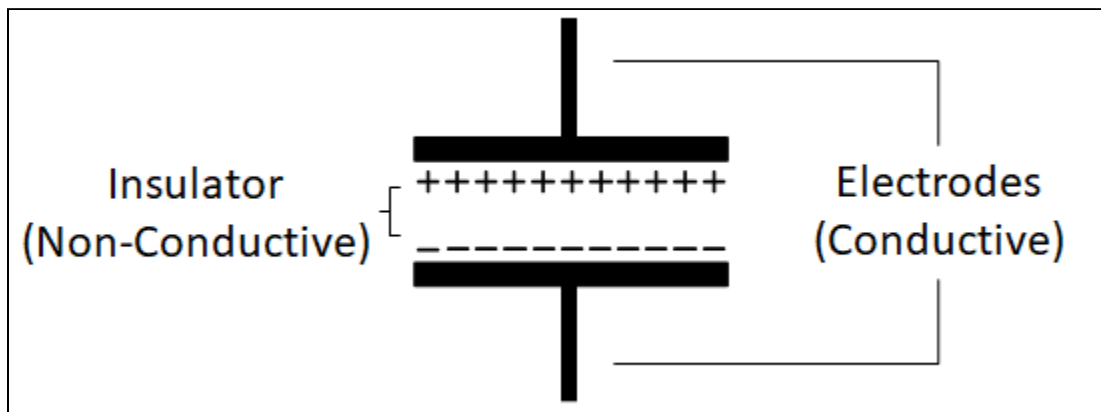


Figure 2: Simple diagram of a charged capacitor. Two conductive surfaces are positioned opposite one another and separated by means of an insulator, such as glass, porcelain, or air. As one side becomes increasingly negative, the other becomes increasingly positive.

To construct a functioning capacitor, a few conditions must be met:

1. **Materials:** One must have some way of identifying and shaping the substances from which the conductive plates and insulators are fashioned. This requires knowing which materials serve this role and how to spot impurities or damage.
2. **Form:** The materials must be proportioned and combined in a particular way. Ideally, the insulator should be relatively thin, as thinner materials reduce the distance between particles on either side of the barrier, increasing the force they exert on one another and allowing more charge to accumulate. It also helps for the insulator to be larger than the conductive materials so as to prevent charge from passing between the edges of the two conductive surfaces.
3. **Voltage:** To acquire a charge, one must connect the two plates to a voltage source. In modern textbooks, this source is typically represented with a battery, which will charge

the capacitor only if its positive and negative terminals are connected to opposing plates on the capacitor.

The first artificial capacitors were developed independently by Ewald von Kleist in October 1745 and by Pieter Musschenbroek and his associates Allamand and Cunaecas soon thereafter. Both consisted of glass containers filled with water and connected to a generator by means of a wire or nail plunged inside (see figure 3). The vessels were held by the experimenter or an assistant while being charged and could be discharged afterward by connecting the glass base and metal tip using a conductive channel.

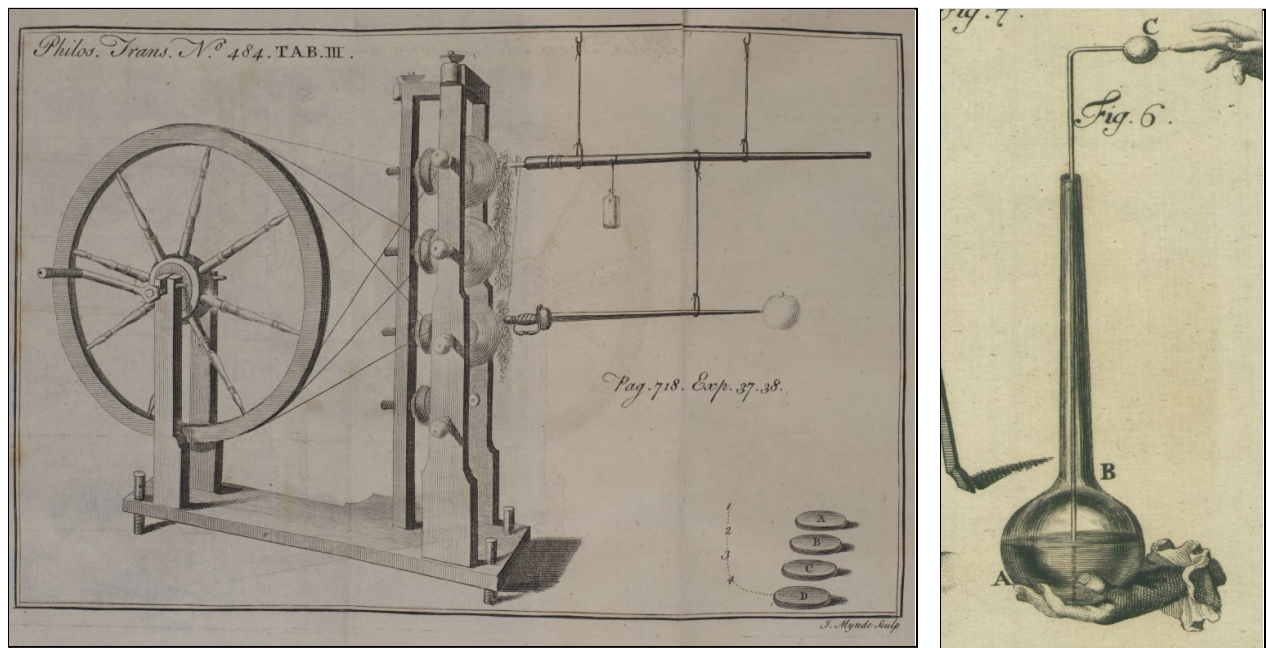


Figure 3: *Left*, four-globe generator and Leyden jar used by William Watson. Note the use of fibers as “collectors” and an apple-piercing sword as a prime conductor (image courtesy of the [Royal Society of London](#)).² *Right*, Leyden jar pictured with method for discharge described by Daniel Gralath (image courtesy of [SLUB Dresden](#)).³

The conditions allowing for the discovery were met over the course of the 1730s and 40s. Both the identification of the necessary materials and the arrangements of the conductive and non-conductive components were furthered by the work of figures such as Stephen Gray, Charles Dufay, and Jean Desaguliers, who established that electricity could be communicated to insulated conductors and extensively documented the range of materials that could play each role. Shortly thereafter, the means of charging a capacitor to high levels of power was established by the widespread use of powerful globe generators like that pictured in figure 3. These machines used a spinning glass globe or cylinder rubbed against a cushion or the hands of an experimenter,

² Watson, “A Sequel to the Experiments and Observations,” table 3.

³ Gralath, “Nachricht von einigen Elektrischen Versuchen,” table 4.

creating positive charge along the surface of the glass that would be conveyed to a conductive rod known as a prime conductor (the glass would usually be connected to the rod by means of a hanging chain or bits of fiber to prevent the rapidly moving glass from breaking).

Charging a glass of water or some other capacitor would essentially require hooking the glass up to the generator in one of two ways. The first way would be similar to how one hooks up a battery. One side of the jar, most likely the outer surface, was attached to the rubbing cushion or body of the generator, while the other side was attached to the prime conductor, most likely by a wire leading from the conductor into the water. In this arrangement, positive charge would be pulled away from the base while being pushed into the interior, resulting in a net negative outside and net positive inside. The second way would involve grounding. Instead of connecting the base of the jar directly to the generator, both would be connected to the ground. In this arrangement, negative charge would be drawn from the ground by the generator and relayed through the prime conductor to the jar's interior. As negatively charged particles repel one another, however, the buildup of negative charge on the jar's interior would force negatively charged particles away from the outside of the jar and into the ground, which would act as a reservoir.

Research Highlights

The following represent the principal arguments and conclusions of the study. Relevant portions of the case study are provided below each highlight. External references have corresponding bibliography entries at the end of the case study itself.

1) The Leyden jar triggered a substantial growth and shift in the makeup of electrical research.

Explanation

The creation of the capacitor is widely recognized as one of the most significant events in eighteenth century natural philosophy, an assessment supported by both contemporary testimony and retrospective assessments of its impacts on the field. Within weeks of its first replication, the jar was recognized as “famous” by the Parisian academic establishment, and by the end of the year, enough had been done with it to fill entire treatises. Over the next five years, the field saw the century's steepest growth in both publications and new authors, both fed by the jar's myriad experimental uses and its considerable entertainment value. Over the long term, widespread use of the technology also facilitated growth in at least three major subdomains: electrochemistry, which studied chemical changes associated with the force; medical electricity, which investigated its potential therapeutic applications; and natural electricity, which covered the functions and manifestations of electricity outside the lab. All three benefited from the device's ability to

produce far more powerful currents than were previously available, while the latter two made extensive use of its portability.

References

- The growth in publications and new authors comes from a bibliometric investigation of the Royal Society Proceedings. See Kryzhanovsky, “An Application of Bibliometrics to the History of Electricity,” 487–92.
- Estimates of the relative prominence of electrochemistry, medical electricity, and natural electricity are available in Heilbron, *Electricity in the 17th and 18th Centuries*, 491.
- On the immediate impact of the jar, see pages 16–17.
- For its long-term impact on experimentation, see pages 27–30.

2) Ewald von Kleist’s discovery of the capacitor resulted from a multi-stage process of refinement.

Explanation

The discovery of the Leyden jar is often cited as an instance of serendipity’s role in science, with the amateurs Cunaeus and Kleist taking what experienced electricians would classify as a misstep by charging a vessel of water while grounded. The story appears to be accurate when it comes to Cunaeus. For Kleist, however, the evidence suggests a more sustained and rigorous process. Rather than standing directly on the ground, he appears to have used an insulating pedestal and a specially designed generator that allowed him to remain insulated while operating it. Instead of coming to the discovery through a single stroke of luck, he appears to have arrived at the jar only after several months of experimentation. Starting with a tin vessel of water suspended by silk, Kleist made his way through steps both small and large to a small medicine bottle and then to the powerful globe design with which he obtained his most striking results. His own discussion of the achievement frames it as a drawn-out process, and while specific circumstances that allowed him to create the device were fortuitous, they were undertaken with care and definite aims.

References

- On the rule against charging the contents of glass containers while grounded, see pages 9, 14–15.
- For a discussion of Cunaeus’s discovery, see page 15.
- The main academic source for the mistake narrative is Heilbron, *Electricity in the 17th and 18th Centuries*, chapter 13.
- On the special design of Kleist’s generator, see pages 10 and 12. For the original description, see Winkler, *Eigenschaften der Electricische Materie*, 44.

— Evidence that both Kleist and his machine were insulated during the experiment can be found in his letters to Krüger and Swietlicki. See appendix A; Kleist to Krüger, December 19, 1745, 177, 180–81.

3) Theory played a limited role in the initial reception of the jar.

Explanation

Given the novelty of the jar, one might expect it to cause a stir in electrical theory. In the initial years following the discovery, however, one finds relatively few shifts in this domain. Many works pass over the theoretical difficulties entirely, and those attempting to tackle them appear content to explain the strange behavior by referencing previously unrecognized properties of glass (which was taken to act as a source as well as a store for electricity). This muted reaction can be traced in large part to the electricians' prior experiences. The "strange" behavior of electricity, the relative youth of the field, and the ubiquitous experience of replication failures (jestingly attributed to a "capriciousness" on the part of electricity itself) were all cited as reasons for caution well-before the jar's 1745 discovery. In practice, efforts were more commonly directed toward exploration and technical improvement, domains in which the jar excelled (see below). While mid- to late-twentieth century accounts of the discovery often framed it as a crisis-generating anomaly, available evidence suggests that it was closer to a windfall (cf. highlight 1 above).

References

- The crisis narrative may be found in Kuhn, *The Structure of Scientific Revolutions*, chapters 1, 6, and 10; and Heilbron, *Electricity in the 17th and 18th Centuries*, chapter 13.
- For a discussion of the electricians' cautious attitude toward theory, see pages 17–19.
- Additional remarks on the explanations offered for the jar's behavior may be found on pages 35–36.

4) The line of experimental investigation by which the capacitor was constructed and refined progressed primarily through trial and error.

Explanation

The principal method by which the capacitor was developed appears to have been a trial-and-error process. Carrying on a tradition of exploratory research visible in the prior work of Charles Dufay and John Desaguliers, electricians interested in the jar set about trying a diverse array of materials and charging arrangements, creating new designs on the basis of prior success. Variations included the use of metals as conductors rather than water, the charging of multiple jars at once, and increases in the vessel's size. The bulk of these efforts were carried out by 1747,

at which point the jar had taken on its canonical forms, including the metal-coated jar pictured in figure 1, the parallel-plate capacitor schematized in figure 2, and the capacitor bank, a collection of jars charged simultaneously. Though it is sometimes suggested that the capacitor's maturation depended on the development of Franklinian theory, each of the major breakthroughs appear to antedate Franklin's system.

References

- The development of the jar is discussed on pages 22–24. Tables of materials tried in the process of discovery may be found on pages 25–27, along with a graph detailing the relations between different designs.
- More general discussions of exploratory experiment, including some discussion of Dufay's approach to classifying conductive and non-conductive materials (known at the time as non-electrics and electrics, respectively) may be found in Steinle, "Experiments in History and Philosophy of Science," 408–32.
- The claim that the capacitor only took its modern form after Franklin's discovery is made by Kuhn in *The Structure of Scientific Revolutions*, 118.
- Both the plate capacitor and coated jar designs were created by John Bevis prior to Franklin. These are reported by William Watson in "A Collection of the Electrical Experiments," 104, and "A Sequel to the Experiments and Observations," 714. The discovery of the capacitor bank was reported by Johann Winkler in his *Die Stärke der Electricischen Kraft*, 48–49.
- For evidence that trial and error might have led to the discovery of the capacitor in the absence of both Kleist and Cunaeus, see appendix B.

5) The main interest of the jar in its first years of existence lay in entertainment and practical use (including experimental uses).

Explanation

Among the driving interests of electricians during this time period were the desire to entertain and an eagerness to display control over nature. The former manifested itself in both personal entertainments and outward demonstrations, including lectures and shows given to members of the nobility. The latter stemmed both from a philosophical commitment to the notion that experimental control constituted the sole mark of truth and to the desire to be of social benefit. Once discovered, the Leyden jar found myriad applications in both domains. As a source of entertainment, it found use not only in large-scale displays, such as the simultaneous electrocution of hundreds of volunteers, but in gadgets and practical jokes, including designs for an electrified door knob and a Leyden jar wineglass that shocked those who tried to drink from it. Meanwhile, as an experimental tool and useful contrivance, the jar found immediate pickup among electricians and doctors both. For the electrician, it represented a way of producing far

powerful and portable sparks in a highly reliable manner. For the doctor, it represented a potential cure for a variety of ailments.

References

- On the status of entertainment as a legitimate goal for experimentation in early electricity, see pages 20–21.
- On the role of control and practical use, see pages 21–22 and 27–31.
- For jokes, see page 31–32.
- For spectacular displays, see pages 32–35.

6) Though it was not the initial focus, the jar allowed for the emergence of a more theory-focused approach to experimentation.

Explanation

Among the most significant long-term impacts of the discovery was the birth of the Franklinian system and the growth of more hypothesis-driven research. Both are widely recognized in the historical literature, and in Franklin’s case, the importance of the capacitor is too clear to be missed (the theory is, in fact, presented in the first instance as a theory of the jar itself). The importance of the capacitor’s instrumental uses in these shifts is less appreciated, however. Its status as an anomaly aside, the capacitor furthered the cause of theory development in at least two ways. First, the increased power and ease of use that accompanied the jar made differences in charge easier to detect, leading electricians to the creation of early electrometers and encouraging early efforts at quantification. Second, by offering cleaner and more easily reproducible experiments, it helped reduce the risk of dedicating time and effort to a single, tailored study, fostering the growth of hypothesis testing. Whereas prior experimental work focused largely on extracting patterns from numerous simple experiments, the capacitor made it possible to conduct more theory-driven forms of research.

References

- Discussion of the experimental benefits of the jar appears on pages 27–30.
- For the theoretical impacts of the discovery, see pages 35–39.
- On the capacitor’s relation to Franklinian theory, see page 36–37.