

# The Discovery and Impact of the Leyden Jar

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## **Abstract:**

The discovery of the capacitor in 1745 initiated an unprecedented period of growth in the study of electricity. By electrifying a simple glass of water, researchers found, they could increase the electrical output of their generators many times over, allowing them to stage a range of new experiments and displays. Though simple in concept, however, the path to discovery was far from easy. The device's construction and use required very specific conditions, and there was little by way of theory to point researchers in the right direction. Nevertheless, the first Leyden jars were developed soon after it became technically feasible to do so, and within two years of the discovery, the device had taken the form it would hold for over a century. The present study details how this process took place and the many changes it brought about. Focusing on the jar's technical features, I document how the electricians went about its construction, refinement, and application, drawing special attention to the importance of exploratory methods in the discovery and the role of entertainment and usefulness as driving factors in its reception.

**Keywords:** history of electricity, Leyden jar, exploratory research, scientific instrumentation

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# Introduction

The events following the Leyden jar's discovery in 1745 are among the most famous in the history of electricity. Independently and in close succession, the Pomeranian Reverend Ewald von Kleist and the Leyden professor Pieter Musschenbroek reported a remarkable method of collecting and delivering electricity. By simply dipping a wire into a glass of water and holding it to a standard generator, one could build up charges orders of magnitude greater than anything previously available. A medicine bottle's worth of water was enough to light fires, and with a small globe, one could easily give blows powerful enough to kill small animals. Upon discharging the device through his hands, Musschenbroek tells us, he felt a blow of such strength that he would not undergo it again "for all the kingdom of France."<sup>1</sup> Writing to his friend Reaumur, the professor advised him in no uncertain terms to avoid doing the same. The risk of electrocution proved little deterrent, however, and within weeks, the result had been replicated across Europe. From there, the device established itself as the premier instrument and fixation of the electricitrical investigation. It was used to amplify the output of their electrical generators many times over, to transport electricity across unheard of distances, and to create all manner of entertainments. Electricians used the mysterious vessel to produce colorful lights, thunderous snaps, and massive displays of power, sending current through chains of people and creating simple electrical machines. Within five years, the number of Royal Society publications on electricity had reached the highest level of the century.<sup>2</sup>

For all its notoriety, however, the story is only partly told. Most discussions are limited to a page or two, and longer treatments have traditionally viewed the discovery less in terms of its immediate applications than its long-term implications for theory. Most often, the jar is presented as a challenge for existing frameworks and a harbinger of the new, Franklinian account, with Kuhn's "revolutionary" reading of the case being the best known.<sup>3</sup> Tracing the jar's development, however, one finds that it was far more, besides. In particular, a sustained examination of its discovery, refinement, and spread reveal an achievement of a distinctively technical kind, something molded by the needs of experimentation and received less as a challenge than a tool and marvel of human creation. Viewed from this perspective, important elements of the narrative come to be seen in a new light. Steps in the discovery commonly viewed as accidents show themselves to be part of a larger strategy, and a post-discovery atmosphere traditionally viewed

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<sup>1</sup> Musschenbroek to Reaumur, 20 January, 1746, reprinted in Daniel Gralath "Geschichte der Electricitat, Zweyter Abschnitt," 428.

<sup>2</sup> Kryzhanovsky, "An Application of Bibliometrics to the History of Electricity," 489. The figures are rivalled only by the period between 1775 and 1780, which followed Volta's creation of the Electrophorus (see Vaughan, "The Reception of Volta's Electrophorus Among Eighteenth-Century Electricians").

<sup>3</sup> Kuhn, *The Structure of Scientific Revolutions*, chapter 1, chapter 6, chapter 10. Kuhn's student Heilbron offers a more detailed discussion of the discovery that is in line with the revolutionary narrative (see Heilbron, *Electricity in the 17th and 18th Centuries*, chapter 13). To his credit, Heilbron does discuss a number of the discovery's practical implications in his landmark study, though they are not the focus.

as a time of crisis is revealed as an era of great excitement. While the Leyden jar eventually changed the way philosophers thought about electricity, its first and most celebrated impacts seem to lay in what it allowed them to do.

The task of reconstructing the events is divided into four principal sections. I begin with a brief overview of the jar itself, examining its basic function and the conditions needed for its construction. I show how each of these requirements was met in the period from 1729 to 1745 and why the specific line of investigation that gave rise to the jar would have appeared promising to those engaged in it. I then detail how the necessary parts came together. Though commonly seen as a product of beginner's luck, I find that the capacitor's discovery came via two very different paths, one resembling the standard "luck" narrative and the other presenting a far more methodical path to the design. From here, I turn to the discovery's immediate reception. Some, I find, were taken with the jar's theoretical implications, but most of the immediate interest seems to have stemmed from its myriad uses, with electricians treating it less as a crisis than a windfall. In the last major section, I consider how the discovery shaped the field over the long term, detailing the jar's technical advantages and outlining its effects on experimental practice, public engagement, and physical theory. The study concludes with a brief discussion of the larger questions raised by the case and how it speaks to our vision of scientific progress as a whole.

## Background

To understand how the Leyden jar was developed, it is useful to have a sense of its construction and operation. 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 negative charge, and because similarly charged particles repel one another, this drives free electrons away from the opposite plate, leaving it positive (see figure 1 for a simple schematic). With time, the increasingly negative charge of one plate and counterbalanced positive charge on 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 up energy is released in a process that may be drawn out or high-instantaneous, depending on the channel (the latter being characteristic of the jar's infamous blow).<sup>4</sup>

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<sup>4</sup> Terms such as electrode, capacitor, and conductor, though anachronistic, shall be employed for ease of communication. Explanatory appeal to contemporary physical theories will also be made, though some authors are reluctant to do so. The use is justified by the fact that our current accounts appear consistent with the behavior of electricity documented at the time and help to account for why the early electricians obtained many of their results. Like any historical claim, these are fallible and subject to revision in light of new evidence.

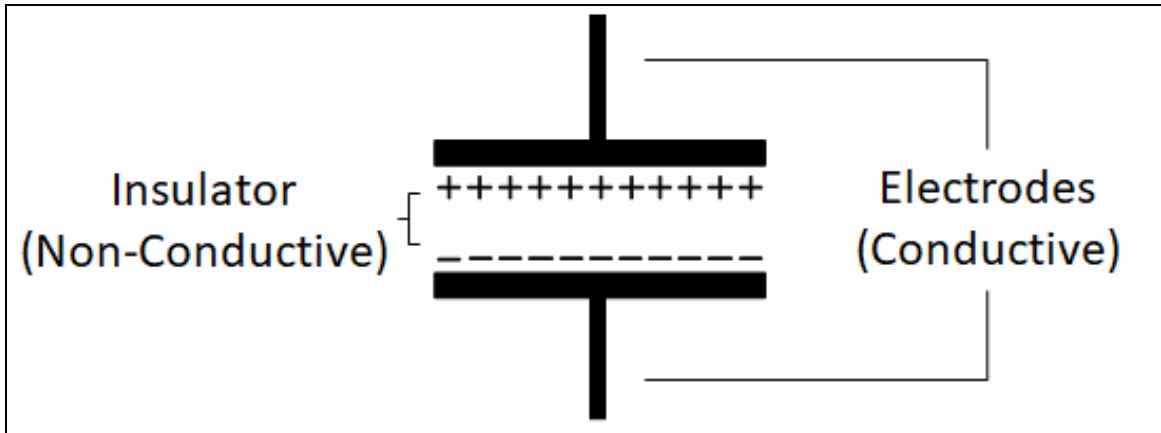


Figure 1: Simple diagram of a charged capacitor. Two conductive surfaces are positioned opposite one another and separated by means of an insulator, such as glass, porcelain, or air. As one side becomes increasingly negative, the other becomes increasingly positive.

Though the design is far from complicated, a few conditions must be met if it is to function. Materially, one needs some way of identifying and shaping the substances from which the plates and insulators are fashioned. Impurities in or damage to the insulator, for instance, will diminish its ability to prevent communication between the conductors, while an improper choice of material will prevent the device from accumulating charge in the first place. The elements must also be of the correct size and shape. Ideally, the insulator should be relatively thin (though not so thin as to break), 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. Proportioning matters, as well. In particular, it 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. Finally, charging the device requires a voltage source that is properly connected to the two conductors and capable of generating sufficiently high levels of electrical charge. In modern textbooks, this is typically illustrated by way of a battery, which will charge the capacitor only if its positive and negative terminals are connected to opposing plates on the capacitor.

Consciously meeting each of these conditions without prior knowledge of the design is not an easy task. Thus, while the needed materials are common (and naturally occurring capacitors can be found in places ranging from the clouds to the nervous system), the first artificial versions emerged only in the mid eighteenth century. These were developed independently by Kleist in October 1745 and by Musschenbroek and his associates soon thereafter.<sup>5</sup> Both consisted of glass

<sup>5</sup> Dating the Leyden discovery involves two complications. The first is that, while Musschenbroek was the first to report the finding, the discovery itself seems to have been made by Cunaeus, who hit upon it while conducting variations on set-ups from Musschenbroek's lab. The second is that the result is reported in a letter from Trembley ("Part of a Letter from Mr. Trembley, F.R.S. to Martin Folkes, Esq.," 58–60.) read in February 1746 but *dated*

containers filled with water and connected to a generator by means of a wire or nail plunged inside (see figure 2). 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. One of the most popular methods involved creating a path through one's own body, a celebrated practice accompanied by sensations ranging from painful to extremely painful.

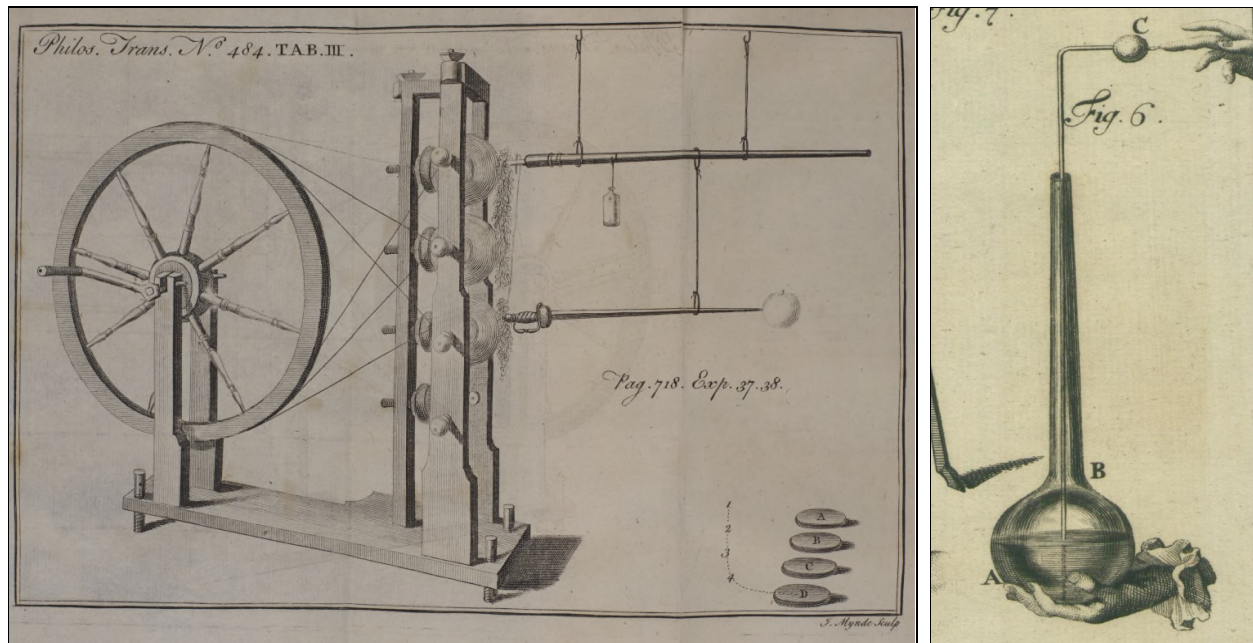


Figure 2: *Left*, four-globe generator and Leyden jar used by William Watson. Note the use of fibers as “collectors” and an apple-piercing sword as a prime conductor (image courtesy of the [Royal Society of London](#)).<sup>6</sup> *Right*, Leyden jar pictured with method for discharge described by Daniel Gralath (image courtesy of [SLUB Dresden](#)).<sup>7</sup>

The discovery's timing can be traced to at least two developments from decades prior, namely the identification of conductive and non-conductive materials and the widespread adoption of powerful globe generators. The first shift took place in the late 1720s and early 30s. Prior to 1729, investigations were closely tethered to objects capable of excitation through heat or rubbing, such as wax, glass, and amber (whose greek name *elektron* gave the phenomena their name). Electricity, variously referred to as a “material” or “virtue,” was thought to reside in these

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February 4, 1745. This has been used to argue that the Leyden group had priority, but the date could have easily been misrecorded on account of the English legal year beginning on March 25th until 1752. On the whole, it appears more likely that the date was erroneous than that the Leyden group delayed reporting their finding for a full year. For this reason, most scholars have given priority to Kleist (for further discussion, see Dorsman and Crommelin, “The Invention of the Leyden Jar,” 275–280.; Heilbron, *Electricity in the 17th and 18th Centuries*, 314, fn 20).

<sup>6</sup> Watson, “A Sequel to the Experiments and Observations,” table 3.

<sup>7</sup> Gralath, “Nachricht von einigen Electricischen Versuchen,” table 4.

objects, appropriately labelled “electrics.” Following Stephen Gray’s reports on the communication of electricity from glass to otherwise “nonelectric” materials such as cork and brass, however, the field’s scope of study began to expand.<sup>8</sup> For one, electricity came to be seen as something that humans were capable of imbuing and, to some extent, storing in the objects of their choice (a supposition rare in earlier work but without which the Leyden jar becomes unthinkable). Investigations into the circumstances and manner of communication also generated a body of new, practical knowledge of how the force could be guided. In particular, Gray found that some materials, like metals, were especially good for communication but that the process only succeeded if they rested on an “electrick body” such as silk or glass.

From here, the electricians went about a more thorough study of the materials involved, with the work of Charles Dufay and John Desaguliers laying out a catalogue of useful insulators and conductors.<sup>9</sup> In a mode of investigation that would become a pattern for subsequent experimenters, they electrified vast numbers of materials in an effort to determine the range and circumstances of communicated electricity (and, one gathers, for the simple joy of seeing what happens). One 1739 study, for instance, electrified such objects as a leek, a bladder, a cane, a drawn sword, a scabbarded sword, a scabbard with no sword, a man’s thigh-bone, some celery, a piece of white hat, a piece of black hat, and a cat (see table I, page 25).<sup>10</sup> Over time, these efforts allowed electricians to classify materials with some confidence. Of the dozens of supports tried, glass, porcelain, wax, and a few others became standard. Bodies noted for their ease of communication, meanwhile, included silver, iron, and water. The last of these was of particular interest, as it seemed to Dufay and others to be the most prone to draw electricity away from other materials and hence the most conductive.<sup>11</sup>

By the mid 1730s, then, the classes of material involved in the capacitor’s construction were familiar. Indeed, glass, porcelain, silver, and other substances employed by the early electricians are still used today. What’s more, the conductive material with which the jar was eventually constructed—water—had been highlighted as particularly powerful, making it a likely topic of study. At this point, however, available charging methods were still quite limited. Both Gray and Dufay used glass tubes as their principal voltage source, rubbing the glass by hand and bringing it close to the objects they sought to electrify. While capable of attracting and repelling pieces of cotton or gold leaf, the rods had difficulty producing sparks of any magnitude, with present-day

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<sup>8</sup> Gray, “A Letter to Cromwell Mortimer, M. D. Secr. R. S. Containing Several Experiments Concerning Electricity,” 18–44; Gray, “A Letter concerning the Electricity of Water,” 227–30; Gray, “A Letter to Cromwell Mortimer, M. D. Secr. R. S. Containing Several Experiments Concerning Electricity,” 166–70.

<sup>9</sup> Dufay, “Seconde Mémoire sur l’Electricité,” 73–84.; Desaguliers, “Some Further Observations Concerning Electricity,” 14–18.

<sup>10</sup> Desaguliers, “Some Thoughts and Experiments concerning Electricity,” 189–91; The source of the thigh-bone is not disclosed.

<sup>11</sup> Dufay, “Troisième Mémoire sur l’Electricité,” 244; Desaguliers, “Some Further Observations Concerning Electricity,” 14–18. Interestingly, modern purified water is a rather poor conductor.

estimates placing their output at roughly a fifth of that obtained by set-ups in the 1740s and 50s.<sup>12</sup> While not impossible, it would have been more difficult to obtain the effects that made the capacitor famous, a fact made clear by co-discoverer Ewald Kleist's own failure to obtain noteworthy results using a tube.<sup>13</sup> It should also be kept in mind that the number of practicing electricians was comparatively small, in part because, relative to what came soon after, the range of experiments that one could conduct was limited. The absence of large, exciting displays meant fewer people were drawn to the study of electricity, and fewer people working on the topic meant fewer opportunities for someone to come across the necessary combination of materials. All told, it is unsurprising that no one came upon the capacitor during this period.

Circumstances improved markedly in the early 1740s, however, as the adoption of globe and cylinder generators began to address the final technical barrier. The idea of mechanizing the rubbing process had been around since the work of Hauksbee decades earlier, but it gained a foothold only after the work of Gray and Dufay on communicated electricity. The new arrangement, refined through years of trial and error by Matthias Bose, Christian Hausen, and Johann Winkler in the years between 1737 and 1745, involved at least two important changes. First, the machine replaced the hand-held glass rod with a sphere or cylinder, which would be spun by crank or pulley instead of by hand. This made the rubbing process far less laborious and much faster, bringing the number of passes a hand or cushion could make over the glass surface to hundreds per minute.<sup>14</sup> The switch also increased efficiency by swelling the surface area of the glass. The globes and cylinders were generally much larger than the rods, and since the process was often operated with pulleys, it was possible to drive many of them at once. Thus, with each pass of the orb across the rubbing cushion, more power could be harnessed. The second major shift was the incorporation of a *prime conductor*: drawing on Gray and Dufay's earlier findings, experimenters took to collecting the charge from their spinning glass using an insulated conductor, such as a metal rod suspended on silk or, in public displays, a child or adult volunteer atop silk or wax. A bit of cotton or linen would be tied to the end of the rod closest to the globe as a means of drawing charge from it, and with each spin, the positive charge left on the surface of the glass after rubbing would be collected and transferred to the metal (with a negative charge being left with the cushion). As more charge was accumulated, more powerful effects were produced, including sparks strong enough to ignite wine spirits and bruise the skin of those shocked.<sup>15</sup>

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<sup>12</sup> Finn, "Output of Eighteenth-Century Electrostatic Machines," 289–91.

<sup>13</sup> Kleist to Swietlicki, February 24, 1746. Reproduced in appendix A.

<sup>14</sup> Hackmann, *Electricity from Glass*, 76.

<sup>15</sup> Hackmann, *Electricity from Glass*, 72.



# Discovery

At this point, all that remained was to bring the materials together and charge them, and as containers of water were already under study by this time, the latter proved the more significant hurdle. Working with a frictional generator, there are essentially two ways of charging a jar, neither of them intuitive from the perspective of early electrical work. The first resembles the closed-loop battery arrangement mentioned early in the previous section. To charge the capacitor, one simply attaches the two plates to opposite sides of the voltage source (the two terminals in the case of the battery, the rubbing cushion and prime conductor for the generator). As positive charge accumulates along one plate, it will be drawn away from the other, like a fixed amount of water being pumped from one container to another. An example of this comes from a well-known experiment of Franklin's showing that the jar could be "charged with its own fire."<sup>16</sup> To eliminate external sources of electricity, Franklin insulated the base of his rubbing cushion with a thick glass plate. Holding a jar from the prime conductor and attempting to charge it in the typical manner, he found that it acquired very little charge. When a chain was tied from the jar's outer coating to the cushion, however, it could be charged to its former power, a fact he attributed to a transfer of "fire" from the outer surface, through the chain and generator, to the jar's interior (a modern schematic is provided in figure 3). The other principal method depends on grounding. In this case, the wire leading into the jar is attached to the prime conductor, just as in the previous example. Instead of attaching the vessel's base directly to the generator, however, it is led to ground.<sup>17</sup> Instead of a pump directly connecting two containers, this set-up operates like two containers separated by a flexible barrier, each connected to a reservoir. As water is pumped in from one reservoir to an adjoining container, the increased pressure pushes the barrier outward, expelling water from the adjacent container into its offshoot.

Experiments prior to October 1745 had come close to the necessary arrangements several times. Work on the attractive power of rubbed thermometers, for instance, implicitly drew on the same physical principles as the jar itself, as did investigations of electricity's behavior in a vacuum. In fact, those working on the latter topic had already developed functional but unappreciated capacitors by the time Kleist made his discovery. One 1745 treatise, for instance, describes a means of producing powerful arc currents by charging metal pins, vessels of water, and other conductive materials above a grounded brass plate in an evacuated bell jar, the metals and water serving as electrodes on which to accumulate voltage and the rarified air serving as the (breached) insulator. Functionally, the components were all in place—the materials, the

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<sup>16</sup> Franklin, *Experiments and Observations on Electricity*, 83–84. The point of this experiment was to show that the jar required no external source of electricity. By charging it when the insulation made no other source available, Franklin was able to argue that the difference between a charged and uncharged jar was the distribution rather than the amount of electric material or fire.

<sup>17</sup> As will be discussed later, the "ground" need not be a direct connection to the earth. An insulated human body is, to some extent, capable of producing similar effects (see Silva and Heering, "Re-Examining the Early History of the Leiden Jar," 318–19).

grounding, and even some recognition of the potential power—but the research was still relatively new, giving electricians little time to discover the effect before Kleist. (The fact that several experimenters came as close as they did suggests less of a dependence on serendipity than has sometimes been implied, however; see appendix B for more discussion).

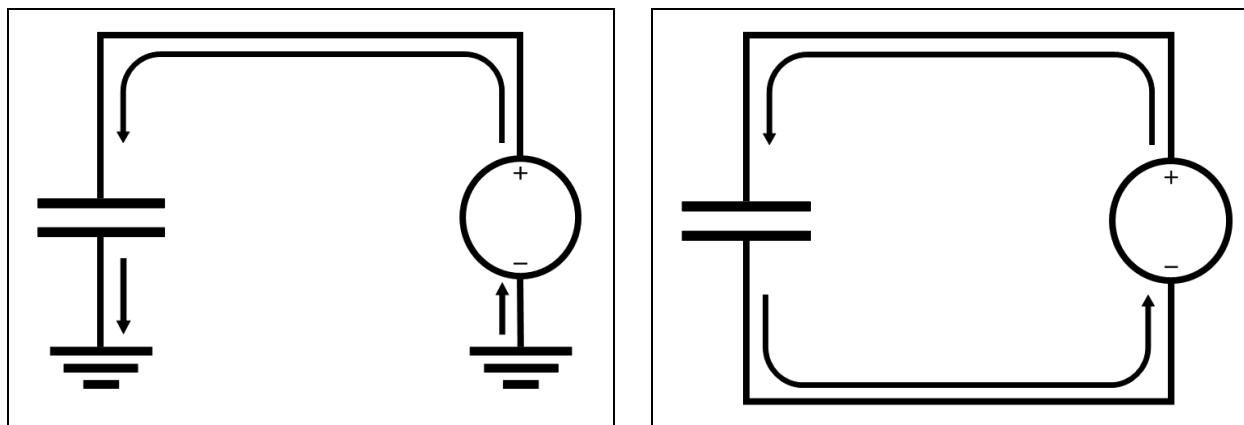


Figure 3. *Left*, diagram of capacitor. Positive charge from the globe (circle) is collected and relayed to the capacitor’s upper plate through the prime conductor, inducing a negative charge on the lower, grounded plate. Both the generator and the jar must be grounded. *Right*, “closed-loop” set-up with voltage source connected to both plates. Grounding is unnecessary but does not inhibit charging. Arrows represent direction of conventional current flow (in the direction of increasing positive charge) rather than electron flow, which proceeds in the opposite direction.

There were also procedural difficulties to overcome. In the case of the water and mercury designs, the main barrier had to do with standard insulating techniques. Bose’s fire-from-water display offers the clearest illustration. Most of the Leyden jar’s core elements were already present in Bose’s work: water was poured into a glass, charged with a generator, and used to give sparks. Following the recommendation of Dufay, however, he and others placed the vessel atop a supplemental glass stand, the thought being that that glass allowed some electricity to pass through it.<sup>18</sup> (The use of insulating stands was a habitual act, owing to their presence in so many other experiments). This reasonable precaution had the effect of preventing what is now labelled negative charge from reaching the container’s outer surface, however, capping the potential energy stored in the device as a whole. While Bose’s design could give flame to a spoon of turpentine, its blow was far weaker than that of the Leyden jar. To reach the latter, one of two things had to happen; interestingly enough, both did.

<sup>18</sup> See Musschenbroek, *The Elements of Natural Philosophy*, 190; Watson, *Experiments and Observations tending to illustrate the Nature and Properties of Electricity*, 47–52.

## Kleist's Discovery

The first breakthrough, corresponding to the closed-loop arrangement of figure 3, was made by von Kleist. Born to a noble Pommeranian family early in the century, Kleist studied at Leyden as a young man and took a position as dean of the Cammin Cathedral in 1722.<sup>19</sup> The position offered him enough free time to engage in a fair amount of electrical experimentation, and while we do not know when he began his studies in earnest, it is clear that by 1745 he was well acquainted with the German electrical literature and recent breakthroughs in generator technology. The few writings that remain of Kleist's demonstrate a clear familiarity with the work of Bose, Winkler, Waitz, and other leading figures, as well as a specific interest in generators; his arrangements include a cutting-edge cylinder generator, a convenient travel-sized machine, and set-ups tried with all manner of personal tweaks, such as the use of pounded chalk on the surface of his leather rubbing cushion. (Incremental generator improvement was a major part of research in the German-speaking world at the time).<sup>20</sup> Indeed, as communications reported in Winkler's 1745 *Eigenschaften der Electricischen Materie* make clear, this line of development most likely served as the central guide and impetus for his work leading to the jar. In particular, Winkler relates two important developments.

The first concerns a small addition made to his cylinder machine. Quite a few experiments at the time involved the use of human participants as conductors. Seeing electricity and passing it through one's own hands was no small part of the appeal for audiences and experimenters alike. With a standard generator, however, these would be impossible to do on one's own. Running the machine meant stepping on the pedal or handling the crank, but since the generator itself was grounded, whoever touched it lost any insulation they might have had. To get around the issue, Kleist opted to insulate the machine as well, placing it atop four glass feet and preventing any leakage caused by contact with the wood-framed mechanism. Though it doubtlessly took some coordination to operate, the machine proved quite convenient for an independent scholar like Kleist. As is clear only in hindsight, it likewise proved useful for uncovering the capacitor, as it ensured a connection between the base of the jar and the voltage source used to charge it. Functionally speaking, charging a capacitor using Kleist's set-up is equivalent to charging one

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<sup>19</sup> Lommel, "Kleist, Ewald Jürgen von," 112–13; "Ewald Jürgen, Hofgerichts-Präsident des Vießow, Erfinder der Leidener Flasche," 202.

<sup>20</sup> Just as figures like Dufay went through a trial and error process in the determination of electrics and non-electrics, the experimenters who popularized generators tried a wide array of materials and mechanical arrangements in their attempts to gain the most output they could. Machines were made with cylinders, globes, rods, and even such oddities as beer glasses and porcelain cups; they were equipped with prime conductors of wire, heavy iron tubes, and steel swords; and they came to feature various "collectors" linking the glass to the prime conductor, including chains, threads, cotton, and comb-like metal wires (direct contact between the rapidly spinning glass and a metal bar being liable to break the former; see figure 2 for detail). An array of machines may be found in the tables of Gordon's *Versuch einer Erklärung der Electricität* as well as Winkler's *Eigenschaften der Electricischen Materie* and *Gedanken von den Eigenschaften, Wirkungen und Ursachen der Electricität* (for an historical overview, see Hackmann, *Electricity from Glass*, chapter 3).

using Franklin's method; the sole difference is that, instead of connecting the jar and generator by way of a chain, Kleist used his own body.

Given this arrangement, the discovery could have been made a number of ways. As we have already seen, any separation of two conductors by a sufficiently thin insulating material will work. In point of fact, however, the discovery was made with water, and this is where Winkler's second communication becomes important. Beyond reporting his generator adjustments, the Leipzig professor tells us, Kleist had described a noteworthy method of "intensif[ying]" a generator's sparks by connecting its prime conductor to water—a precursor to the jar itself.<sup>21</sup> The reasoning was fairly straightforward, fitting in quite naturally with a long line of previous amplification efforts. As Winkler noted, the principle was the same as that which led to his own work increasing the size of prime conductors. If adding metal in the form of larger prime conductors increased machine output, then adding a potentially superior conductive material like water should yield comparable if not greater increases. Though similar in principle, however, the reality of working with the two materials was quite different; water was unruly. While iron rods were easily suspended by a pair of silk ribbons, water required a vessel and special care on the part of experimenters not to contaminate their workspace with leaks or spills. Keist's first recorded attempt at containment, recorded by Winkler, was "a tin container on a silk net," most likely suspended from above.<sup>22</sup> One can imagine the inconveniences of such a design, however. Hoisting the water into a suspended net would have been tricky, and moisture was thought to be such a problem for silk's function as an insulative support that electricians cautioned against excessive breathing near it.<sup>23</sup> If one had a spill or leak, simply wiping it clean was not an option, making each splash a serious inconvenience. While the amplification of power was promising enough to encourage further study, then, there was reason to look for other containers.

What he ultimately came across was a design similar to Bose's, relying on a small glass vessel—a medicine bottle—in lieu of the tin container and silk supports he had been working with. The specific route he took to get to the bottle is unclear. Family lore has it that Kleist's design came after he was served a glass of water on a tin platter; others have suggested that he was following Bose, whose work was known to him.<sup>24</sup> What is clear, however, is that the choice was convenient. The bottle was easily corked, preventing spillage, and glass containers were

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<sup>21</sup> Winkler, *Eigenschaften der Electrischen Materie*, 44.

<sup>22</sup> Winkler, *Eigenschaften der Electrischen Materie*, 44. It is possible that the vessel was hand-held, as "net" is the same word used to describe the silk Kleist stood on while running his machine. If so, the first "jar" may not have been a jar at all. There is little indication that the amplification Kleist achieved with this arrangement was as intense as what he was capable of producing with his medicine bottle and thermometer-based designs, though.

<sup>23</sup> Winkler, *Gedanken von den Eigenschaften, Wirkungen und Ursachen der Electricität*, 62.

<sup>24</sup> "Ewald Jürgen, Hofgerichts-Präsident des Vießow," 202. Heilbron, *Electricity in the 17th and 18th Centuries*, 309. The same family source has him inventing metal linings and the battery. Heilbron suggests that the size of the vessel speaks against its use as an amplifier, but if one thinks of the study as a trial run, the medicine bottle makes sense. A smaller bottle would have certainly been easier to hold aloft for the time needed to charge it.

easily dried, easily handled, and easily obtained. In terms of uses, moreover, one could not find a more fitting choice for the aims of storage and transport, both of which were, as Kleist's subsequent letters indicate, at top of his mind.<sup>25</sup> Though he offers some theory in his later letters, Kleist was quite clearly interested in uses, referring to his creation not as a phenomenon to be explained but as an "instrument" or "machine" and taking pride in its ability to kindle fires, store charges, and emit a luminous glow after a walk of sixty paces (extended to an even hundred when, after a bit of exploration, he switched from the medicine bottle to a thermometer).<sup>26</sup> There is even a case to be made that such applications were the first experiments he conducted, as his ability to light fires and produce a luminous glow while carrying the instrument come *prior* to his description of the celebrated discharge in his letters to Krüger and Swietlicki. (It is also possible that the blow was given lower billing because Kleist assumed the amplification result would be seen as a simple expansion of the result he had already published through Winkler).

Whatever came first, the all-important charging method was the same. We know from his writings that he charged the vessel in his hand, which was a departure from earlier work but not an impermissible one, provided he remained dry and insulated.<sup>27</sup> (Winkler himself had used his hands while electrifying the contents of a thermometer a year before).<sup>28</sup> It has often been claimed that Kleist also took the more dubious step of standing directly on the floor, leading many to view the discovery as a product of something like beginner's luck.<sup>29</sup> Yet he explicitly mentions an insulating stand in his letters, and as was noted earlier, the specifics of Kleist's machine would have given him the full effect of the jar without relying on a "mistake" of this sort.<sup>30</sup> In other words, the fact that he used a self-pedaled machine meant that he was capable of fully charging the jar while following common insulation standards. In holding the vessel while driving the generator, his body would provide the necessary channel from the base of the container to the generator, allowing positive charge to be siphoned from the jar's exterior, relayed to the leather rubbing cushion, and fed by the spinning glass to the jar's interior via the prime conductor. In discharging the device, his body would act as a channel once again, this time more noticeably. Reaching for the prime conductor as he had done with the tin vessel, the concentrated positive charge of the jar's interior would shoot back to the newly negative outer surface, giving Kleist a

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<sup>25</sup> Kleist to Krüger, 19 December, 1745, 177.

<sup>26</sup> Kleist to Krüger, 19 December, 1745, 180–1.

<sup>27</sup> At worst, the human body would be expected to absorb some of the electricity, but the amount would be limited, see Watson, *Observations and Experiments*, 26.

<sup>28</sup> Winkler, *Gedanken von den Eigenschaften, Wirkungen und Ursachen der Electricität*, 53–4. Another report, difficult to track down but quite entertaining, is that Winkler once had an electrified assistant attempt to drink a glass of brandy, lighting the contents on fire when his mouth approached the rim of the cup (Hackmann, *Electricity from Glass*, 75).

<sup>29</sup> Heilbron, *Electricity in the 17th and 18th Centuries*, 310.

<sup>30</sup> Kleist to Krüger, 17 March, 1746, 182. In another letter, he indicates that the generator he used in the jar experiments was the same as Winkler's "Giessingschen Machine," a pedal-driven machine on the same model as that described in his earlier letter to Winkler (Kleist to Swietlicki, 28 November, 1745; see appendix A).

blow as strong as any electrician had drawn before—one powerful enough, as the reverend put it, “that the arm and shoulders are shaken by it.”<sup>31</sup>

Eager to see what this new “machine” was capable of, Kleist spent the next few weeks trying additional applications and variations on the design.<sup>32</sup> The jar was charged on different surfaces; filled with water, mercury, and spirits; and made of several different glasses, including a large globe and the body of a thermometer.<sup>33</sup> With these, he was able to refine the effects. Using the larger thermometer as a vessel, for instance, he could light fires with ease and store charges for longer periods. Strikingly, he also found that, once charged, the small container of water proved a stronger means of electrification by itself than a full table-sized generator. Aware that more experienced hands were at work on similar projects, he fully expected others to have reported the same basic breakthrough. Examining the sources available to him, however, he found nothing had been published on the powerful and portable container; “even Winckler's experiments” passed it over.<sup>34</sup> Accordingly, he sent word to others working in the area. Between November 4th and December 28th, 1745, Kleist drafted letters to Johann Lieberkühn in Berlin, Paul Swietlicki in Danzig, and Johann Krüger in Halle, answering follow-up questions and making additional reports to Winkler in May and the Ritteracademie of Lignitz in March of the following year.

Several of these texts survive, and in them, one finds Kleist adopting a rather cautious note. He is careful to cite a list of forebears in his November letter to Swietlicki, for instance, and he repeatedly describes his work as merely “play value” (i.e., “Spielwert”) relative to his learned correspondents’ own efforts. Nevertheless, the discovery’s novelty was clear to all parties involved, and his correspondents soon turned to creating their own versions of the “amplification machine.”<sup>35</sup> Unfortunately, Kleist had neglected to mention a few key details about his method, leading to disappointment for his would-be replicators. For one, he had not stated explicitly that discharging the jar required one to touch base and wire at the same time, a natural omission for one working alone but significant one for those assigning the holding of the jar or the spirits to an assistant.<sup>36</sup> What’s more, other experimenters were unlikely to use Kleist’s distinctive

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<sup>31</sup> Kleist to Krüger, 19 December, 1745, 178. In terms of electrons, the flow would be in the opposite direction, that is, from the exterior to the interior.

<sup>32</sup> Kleist himself does not say which experiments came first, and as I have already noted, the blow is not the first one in his letters to Krüger and Swietlicki (28 November, 1745; see appendix A). Accounts written by his correspondents, however, tend to present the discharge first. It is also the one most in line with his previous “amplification” work.

<sup>33</sup> Kleist to Krüger, 19 December, 1745, 179–81.

<sup>34</sup> Kleist to Krüger, 19 December, 1745, 177.

<sup>35</sup> The term is used by Gralath (“Nachricht von einigen Electrischen Versuchen,” 512–519) following Kleist’s use of the term “amplified machine” (Kleist to Swietlicki, 12 May, 1746, appendix A). The jar is often described as an “instrument,” “invention,” or “machine” in the German literature. See also Gralath, “Geschichte der Electricitat, Zweyter Abschnitt,” 406.

<sup>36</sup> An interesting report by Miles (“A Letter from the Rev. Dr. Miles, F. R. S. to Mr. Baker, F. R. S. Concerning the Electricity of Water,” 91–93) suggests that it is not impossible to light fires with one person holding the “jar” (a

generator set-up, preventing full charging. Sparks may be obtained by insulated persons not in contact with the generator, but they are weaker (though far from negligible, as is sometimes assumed, see below).

These issues might have been cleared up with more careful description or the staging of a demonstration, but neither took place. Instead, a somewhat humorous exchange ensued in which the correspondents' reports of failure were met with incomprehension by the discoverer, who gave some additional information about his generators but less than was needed to replicate the success. The frustrated electricians were effectively taunted with reports of how he had stored charges for days on end, lit up the gilding of volunteers' clothing, and written his name in lights by discharging the jar through a series of nails in a board. It was not until March 5th that Daniel Gralath and assistant Gottfried Reyger, who had learned of the jar by way of Swietlicki, finally thought to place their hands on the base and wire simultaneously.<sup>37</sup> By this time, however, Musschenbroek had already sent his famed letter to the Paris Academy, earning his town and university the honor of titling the famed Leyden jar.

## Musschenbroek and the Leyden Group

Examining Musschenbroek's path to the capacitor, one finds an interesting mixture of contrast and parallel. Like Kleist, Musschenbroek was a student at Leyden in his youth and a connoisseur of scientific instrumentation. Where the former pursued his interests occasionally, however, the latter followed them as a matter of profession and family legacy. His father, Johannes, had earned renown as an instrument maker and inventor in the previous century, developing tools for Huygens, van Leeuwenhoek, and other major experimentalists of the time, while his elder brother, Jan, had served as one of the premier instrumentalists of his time, helping his friend 'sGravesande to produce one of the first demonstration courses to be published in physics.<sup>38</sup> Pieter, for his part, entered the field as an educator, coming to occupy 'sGravesande's seat at the University of Leyden after stints in Duisburg and Utrecht.<sup>39</sup> The position was in many ways ideal, as Musschenbroek proved both a spirited lecturer and meticulous experimenter (his

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porcelain basin) atop a wax cake and another bringing a spoon of spirits to it. The set-up here involved an electrified person holding the basin up to a metal rod suspended from the ceiling. When a spoon of spirits was brought to the rod by another participant, Miles reports, it was kindled "with vehemence" (92). This occurrence seems to have stemmed from the humidity of the environment, however, as the author notes that it succeeds better under such conditions. Were the silk used to suspend the metal compromised, the arrangement would be equivalent to the grounded jar, the only difference from the standard set-up being that the inner surface would be the grounded one and the outer one would be connected to the generator.

<sup>37</sup> Gralath, "Nachricht von einigen Electriscen Versuchen," 512–19; Gralath, "Geschichte der Electricitat, Zweyter Abschnitt," 406–11. See also appendix A.

<sup>38</sup> Hackmann, *Electricity from Glass*, 50–1.

<sup>39</sup> Ducheyne, "Petrus van Musschenbroek (1692–1761) on the Scope of Physica and Its Place within Philosophia," 1–15.

posthumous *Introductio ad Philosophiam Naturalem* runs well over 1100 pages, including extensive tables and figures).<sup>40</sup>

It is difficult to place a starting date on Musschenbroek's interest in electricity, though the family connections suggest an early date. Certainly by the mid-1730s he was of the view that the "wonders of nature" documented by Gray and Dufay pointed toward a particularly fruitful area of study.<sup>41</sup> In addition, his close instrument-making ties ensured that Musschenbroek had ready access to globe generators before they had been widely adopted. A 1740 inventory of his instruments indicates that he was already in possession of a globe generator at that time.<sup>42</sup> Looking at the material requirements, then, Musschenbroek was well placed to make the discovery—certainly better positioned than Kleist. Other factors ran against him, however. As an esteemed professor, he had no shortage of assistants and, consequently, neither the need nor occasion to create the individually operated generator used by Kleist. The closed-loop charging arrangement would have been unavailable, then. The prospect of holding an object uninsulated while charging it would be unlikely, as well. Again, common practice recommended more insulation, and Musschenbroek himself subscribed to the view that glass had some degree of permeability.<sup>43</sup> This extra step might have been overlooked for the sake of convenience or as part of the extensive variations to which Musschenbroek subjected his designs, but the prospect of his doing so is far from certain.<sup>44</sup> The likeliest scenario for discovery would have involved holding the vessel while standing on atop an insulator. As recent testing has shown, this still produces a substantive shock.<sup>45</sup> Without the closed circuit of Kleist's charging arrangement, however, the effect would have been somewhat attenuated and may not have had quite the subsequent impact that it did.<sup>46</sup>

Whatever might have been the case, however, available evidence suggests that the actual discovery was made by Andreas Cunaeus, whose "prudent council" and "most noble endeavors" the professor credits for his success in the preface to his 1748 *Institutiones Physicae*.<sup>47</sup> Cunaeus was a lawyer by trade, but like many in the Dutch republic, he had developed an interest in

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<sup>40</sup> Musschenbroek, *Introductio ad Philosophiam Naturalem*, vol. I–II.

<sup>41</sup> Musschenbroek, *Beginselen der Natuurkunde*, 256–9.

<sup>42</sup> In fact, Jan van Musschenbroek appears to have been selling Hauksbee's globe design in advance of Bose's work; Hackmann, *Electricity from Glass*, 49, 52.

<sup>43</sup> Musschenbroek, *The Elements of Natural Philosophy*, vol. 1, 190; Musschenbroek's need of outside intervention is presented most forcefully by Heilbron ("A Propos de l'invention de La Bouteille de Leyde," 133–42).

<sup>44</sup> As Hackmann (*Electricity from Glass*, 93) observes, intellectual commitments may be relaxed in the lab if their practical impacts are less than substantial.

<sup>45</sup> Silva and Heering, "Re-Examining the Early History of the Leiden Jar," 318–19. The reason for this is that the human body itself can serve as a reservoir for free electrons.

<sup>46</sup> Experimenters after the discovery tried the set-up with and without standing on the insulator, judging that the fully grounded condition was the stronger (see Watson, "A Sequel to the Experiments and Observations Tending to Illustrate the Nature and Properties of Electricity," 717).

<sup>47</sup> Musschenbroek, *Institutiones Physicae: Conscriptae in Usus Academicos*, Praefatio.



electricity, frequently visiting his friend Musschenbroek's well-equipped laboratory to see and practice demonstrations. In 1745, this included work on water. Most likely, the professor started the research with Bose's famed studies in mind, as an April 1746 letter explicitly acknowledges Bose's design as a precursor to his own.<sup>48</sup> Musschenbroek's manuscripts detail extensive variations on the experiment's design, including tests with different materials and arrangements aimed at determining the flow of electricity in the glass.<sup>49</sup> As a letter from lab assistant Jean-Nicolas-Sébastien Allamand to Nollet makes clear, however, the key step of holding and discharging the jar was taken by Cunaeus.<sup>50</sup> Hoping to reproduce some of Musschenbroek's phenomena at home, Allamand reports, Cunaeus set about running his own versions of the tests he had seen at the Musschenbroek lab. Whether from convenience, ignorance, or curiosity, however, he opted to hold the vessel up to the prime conductor while standing on the ground, making him the first of the group to feel the terrible blow.<sup>51</sup>

After Cunaeus himself, Allamand was the first to try the new arrangement. It was, as he wrote to Nollet, “un coup de foudre,” a thunderbolt or, in colloquial French, love at first sight: “I was so stunned that I lost my breath for a few moments.”<sup>52</sup> Two days later, Musschenbroek underwent the experience himself. His notebooks suggest that his first experience came with a common beer glass half filled with water. Taking the glass in hand and bringing his finger to the wire, the professor experienced a pain he described as “unbearable.”<sup>53</sup> For reasons that are difficult to fathom, he then decided to make the glass larger, taking the body-shaking beer glass and substituting a globe five inches in diameter.<sup>54</sup> The blow was, predictably, larger than in prior iterations. “I thought I was done for,” he later told Reaumur.<sup>55</sup> Following up on these initial successes, Musschenbroek and Allamand ran through a bevy of experimental parameters, much as Kleist had done (presumably operating with smaller charges). Their central aim appears to have been somewhat different, though. While Kleist primarily sought to extend and apply the tool, the Leyden group's initial studies focused more on the circumstances needed to produce it. After an initial run of tests, Musschenbroek came to believe that the effect was not dependent on the shape or thickness of the glass but instead relied on something related to its origin. In particular, German glass seemed to succeed where English and Dutch-origin vessels did not, a

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<sup>48</sup> Musschenbroek to Bose, April 20, 1746, reprinted in Georg Matthias Bose, *Tentamina Electrica Tandem Aliquando Hydraulicae Chymiae Et Vegetabilibus Utilia: Pars Posterior*, 35–36.

<sup>49</sup> Present, “Petrus van Musschenbroek and the early Leiden jar,” 15–17.

<sup>50</sup> Nollet, “Observations sur quelques nouveaux phénomènes d'Électricité,” 3. Cunaeus' priority is similarly attested to by an unnamed Leyden professor quoted by Gralath in his “Geschichte der Electricitat, Zweyter Abschnitt,” 431.

<sup>51</sup> Though accounts of Cunaeus' discovery are sparse, grounding was specifically mentioned by Musschenbroek and Allamand (see Musschenbroek to Reaumur, 20 January, 1746; Trembley, “Part of a Letter from Mr. Trembley, F.R.S. to Martin Folkes, Esq.,” 58–60).

<sup>52</sup> Nollet, “Observations sur quelques nouveaux phénomènes d'Électricité,” 3.

<sup>53</sup> Present, *Learning in the World*, 264.

<sup>54</sup> Nollet, “Observations sur quelques nouveaux phénomènes d'Électricité,” 3.

<sup>55</sup> Musschenbroek to Reaumur, 20 January, 1746, 428.

fact that, judging from his manuscripts, Musschenbroek himself seems to have regarded as the most curious of the observations.<sup>56</sup>

The findings were written up by Musschenbroek and sent to the French Academy on January 20th, followed sometime afterward by a letter from Allamand detailing the study and providing additional information as to its discovery. In the English-speaking world, word arrived in early February from Royal Society Fellow Abraham Trembley, who happened to be in the Netherlands at the time (the experiment is listed among several others he had seen in the country).<sup>57</sup> In line with the focus of their early experiments, these communications were brief but exact. All the information needed to run the experiment was provided in both, and the French letter in particular reads with all the clarity of a practiced lecturer, including a visual for ease of description and explicit instructions “that the man should stand directly on the ground” and “that the same one who holds the globe should draw the spark.”<sup>58</sup> Within weeks, the central discovery had been confirmed and expanded upon by experimentalists in both countries.<sup>59</sup>

## The Jar’s Reception

From the time of its first replication onward, the jar spread like wildfire, becoming “famed” and “admired” well in advance of its official presentation to the French Academy and supplying enough novelties to fill an entire treatise by the year’s end.<sup>60</sup> By the close of the decade, the Royal Society had published more on electricity in five years than in any twenty year interval before 1745, with the number of new authors exceeding the combined entrants of the preceding eighty five years.<sup>61</sup> The impact would prove to be a lasting one. For the remainder of the century, the number of authors, entrants, and papers would be higher than any pre-discovery decade, with an estimated eighty to ninety percent of post-1745 works having some connection to the jar.<sup>62</sup> To say that the discovery revolutionized the field is entirely fair.

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<sup>56</sup> Musschenbroek to Reaumur, 20 January, 1746, 428; Present, “Petrus van Musschenbroek and the early Leiden jar,” 16–20. It remains something of a mystery why the non-German glass failed. One possibility is that the other glass had unnoticed imperfections. Humidity could have been another factor as the Netherlands are a relatively humid region (as Musschenbroek once complained to Bose; source in note 46).

<sup>57</sup> Trembley, “Part of a Letter from Mr. Trembley, F.R.S. to Martin Folkes, Esq.,” 58–60.

<sup>58</sup> Gralath’s German translation (translated into English) reads “The person attempting the experiment can outright stand on the floor. But the individual holding the vessel in one hand has to excite the spark with the other hand.” Nollet’s French translation reads similarly.

<sup>59</sup> The specificity of reporting did not prevent misinterpretation, of course. The first replication in the pages of the *Philosophical Transactions*, for instance, ignored the charging arrangement. See note 36.

<sup>60</sup> Nollet, “Observations sur quelques nouveaux phénomènes d’Électricité,” 3.; Winkler, *Die Stärke der Electricischen Kraft*, 49.

<sup>61</sup> Kryzhanovsky, “An Application of Bibliometrics to the History of Electricity,” 487–92.

<sup>62</sup> Kryzhanovsky, “An Application of Bibliometrics to the History of Electricity,” 490.

Why and how this substantial shift was effected is a bit more difficult to say, though. Traditionally, the discovery has been framed in broadly Kuhnian terms, that is to say, in terms of theory change. Seizing upon remarks like Musschenbroek's that he had "found out so much about electricity" that he could "understand nothing and...explain nothing," scholars have presented the early years as a crisis point for the field. The jar's strange behavior is said to have "shattered accepted theory," leaving the electricians in a state of collective confusion and effectively clearing the way for the emergence of a new, Franklinian theory in the 1750s.<sup>63</sup> Individual accounts differ on matters of detail (e.g., on the sophistication of pre-Franklin accounts), but at a fundamental level, the narrative is one of *ideas*—of one-fluid and two-fluid theories, laws and forces. There is doubtlessly a measure of truth in this frame. It is, as we shall see, quite difficult to imagine the emergence of the Franklinian picture in the jar's absence, and there is little doubt that the framework marked a significant departure from prior theoretical work. In examining the state of play around the time of the discovery, however, one finds that the analysis proves misleading in several important respects. While central for many histories of the era, theory was, for the practitioners themselves, only one piece of a much larger endeavor—and a rather small piece for many.

## Theory and Practice

The most obvious indication of theory's overemphasis is the tone with which the jar was greeted. Historians often present the challenges it posed to existing frameworks as immediate and serious, even intimidating.<sup>64</sup> Reading through the initial reactions, however, one finds little soul-searching. The jar's curiosity was certainly commented upon, and there are occasional comments, like Musschenbroek's, that speak to a mood of bafflement, but these are most often directed at its sensory effects or the surprise, shared by lay audiences, of producing such a great spark from such a humble object.<sup>65</sup> As we'll see momentarily, such expressions were also commonplace before the jar (including by Musschenbroek himself), with the inexplicability of electricity being an understood feature of the territory. Many early discussions bypass the question of explanation entirely or contain little more than passing mentions of effluvia.<sup>66</sup> In the period between 1746 and 1756, for instance, a majority of Royal Society publications make no reference to the vessel's theoretical difficulties and no effort to explain its operation.<sup>67</sup> To the

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<sup>63</sup> Heilbron, *Electricity in the 17th and 18th Centuries*, 315–16.

<sup>64</sup> Finn, "An Appraisal of the Origins of Franklin's Electrical Theory," 363. According to Finn, "the theoretical difficulties...were so great, that Nollet was the only European to attempt an explanation."

<sup>65</sup> "Coup Foudroyant," 338. That the remarkable nature of the Leyden jar did not require a philosophical eye was, in fact, one of its most distinctive features. See note 142.

<sup>66</sup> "Mémoire sur les nouvelles découvertes qu'on a faites par raport à l'Électricité," 113; Hart, "Part of a Letter from Cheney Hart, M. D. to William Watson, F. R. S. Giving Some Account of the Effects of Electricity in the County Hospital at Shrewsbury," 786–88; Trembley, "Part of a Letter from Mr. Trembley, F.R.S. to Martin Folkes, Esq.," 58–60; Watkins, *A Particular Account*, 3–4. A good portion of the early research was medical.

<sup>67</sup> Of the publications bringing with theory, moreover, a majority come from just two authors, Watson and Nollet (see Nollet, "Part of a Letter from Abbé Nollet, of the Royal Academy of Science at Paris," 187–94; Nollet,

extent that explanations were offered, moreover, they were often presented in a manner casual enough to belie any serious trepidation. Benjamin Martin and William Watson, for instance, appear content to absorb the result into Gray's earlier finding that electrics preserve the charge of non-electrics resting on them.<sup>68</sup> Little indication is given by either that the experiment presents a serious anomaly, let alone a generational challenge. In terms of space, in fact, the matter amounts to only a couple of paragraphs in a pair of full-length treatises. Authors on the continent appear to have been more concerned, but even here, the tone is more muted than one might expect. Winkler, Nollet, and Gralath all give some sense of the challenges at play—accounting for the apparent amplification of electricity inside the jar, for example—and the last of them even credits the discovery with having overturned a recognized law. After reviewing the difficulties, however, the authors invariably arrive at unassuming responses attributing the strange behaviors to special, previously unrecognized properties of glass.<sup>69</sup> The need for revisions was recognized, but it is difficult to see the matter as a reckoning for the field as a whole. Noting exceptions and overlooked properties of different materials was simply part of the process.

For some writers, in fact, blatant contradiction seems to have been an occasion for amusement more than anything else. On seeing the apparatus draw power from the hand of a grounded assistant, for instance, the future Royal Society Fellow John Needham reacted not with alarm but a kind of lighthearted approval. While glass usually blocked electricity from flowing, he commented, it could pick up the slack when the wire “refuse[d] to perform its expected office,” allowing charge to pass.<sup>70</sup> That this required a selective, almost intentional permeability on the part of the material was, judging from the report's tone, a less than disturbing prospect for the author. Indeed, the curiosity is greeted with a sense of familiarity, absorbed into a larger pattern showing that “in the course of electrical experiments...a man can scarce assert any thing in consequence of any experiment, which is not contradicted by some unexpected occurrence in another.”<sup>71</sup> Nature, the letter suggests, had bested the electricians once again.

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“Extracts of Two Letters of the Abbè Nollet,” 553–58; Nollet, “An Account of a Treatise, Presented to the Royal Society, Intituled, ‘Letters Concerning Electricity,’” 201–16; Watson, “A Sequel to the Experiments and Observations,” 704–49; Watson, “Observations Upon So Much of Monsieur Le Monnier the Younger's Memoir,” 388–95; Watson, “A Collection of the Electrical Experiments Communicated to the Royal Society by Wm. Watson,” 49–120).

<sup>68</sup> Martin, *An Essay on Electricity*, 31; Watson, “A Sequel to the Experiments and Observations,” 727.

<sup>69</sup> Gralath, “Geschichte der Electricitat, Zweyter Abschnitt,” 447–48; Nollet, *Essai sur l'Electricité des Corps*, 154–66; Winkler, *Die Stärke der Electrischen Kraft*, 71–83. The most dramatic expression of concern in these passages is Gralath's, who notes that scholars had previously believed that contact with a conductive body was an “unfailing” means of weakening an electrified body and that “no one ever thought that this general rule would have to suffer an exception with respect to glass” (447). Just how exceptional the behavior was was a matter of dispute, though, and as Nollet noted, exceptions had been spotted before (see the brief discussion on pages 34–35 below). It is also worth noting that Gralath, following Nollet, qualifies the exception on the following page.

<sup>70</sup> Needham, “Extract of a Letter from Mr. Turbervill Needham to Martin Folkes, Esq.,” 259.

<sup>71</sup> Needham, “Extract of a Letter from Mr. Turbervill Needham to Martin Folkes, Esq.,” 258.

Reactions like Needham's are, from the perspective of a traditional, theory-driven narrative, somewhat strange. If one examines the electricians' experimental context and overarching aims, however, they begin to make sense. To start with, the early researchers had looked upon electricity with a cautious eye for some time, and for good reason. The crackling, flashing forces were unlike any they had encountered before, manifesting an array of "curious" and "strange" behaviors (suspending objects in mid-air, lighting up the tips of swords, and so on). The common experimenter's confidence in their ability to anticipate the force's mysterious behaviors was less than high, then. Even among the system-builders, in fact, one finds the phenomena described as "a crowd of wonders" and a "Gordian knot" yet to be cut.<sup>72</sup> At the same time, the lack of standardized materials and the experimenters' inability to control the "infinity of different causes" at play meant that exceptions and contradictions were a part of life.<sup>73</sup> As the Newtonian philosopher John Desaguliers noted in 1742:

There is a sort of capriciousness attending these experiments, or something accountable in their phaenomena, not to be reduced to any rule. For sometimes an experiment, which has been made several times successively, will all at once fail; or have quite a contrary success, tho' the circumstances seem to be the same.<sup>74</sup>

Finally, most experimenters recognized that the discipline was relatively young.<sup>75</sup> Unlike mechanics, the theory of which was held in the highest esteem by electricians like Desaguliers, electricity had become a major topic of investigation only relatively recently. As a result, much was still unknown. Live questions included not only those expected by the modern reader, such as the relation between electricity and gravity, but whether the force was influenced by the color of different communicative media, if it bore a special relation to biological products like wood and wax, and whether it was a material or some other variety of being. Experimenters still wondered if the glow of nocturnal animals' eyes was electrical.<sup>76</sup> Committing to a specific framework in the face of so many unknowns seemed, to many, a premature and needless act. "Caution," Musschenbroek observed in his *Beginselen der Natuurkunde*, "teaches us not to proceed too rashly. This learning is still new. It has just begun and an infinite amount of things are required before one will be able to mathematically demonstrate everything."<sup>77</sup> "Electricity," Haller concurred, "is a vast country of which we only know a few shores, it is not the time to

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<sup>72</sup> Bose, *Recherches Sur La Cause Et Sur La Veritable Théorie De L'Électricité*, i–iii. Bose does, however, express strong confidence in the charging methods devised by Dufay.

<sup>73</sup> "Des Effets de l'Électricité sur les Corps Organisés," 9.

<sup>74</sup> Desaguliers, *A Dissertation Concerning Electricity*, 30.

<sup>75</sup> Nollet, "Observations sur quelques nouveaux phénomènes d'Électricité," 7; Freke, *An Essay to Shew the Cause of Electricity*, 16.

<sup>76</sup> Miles, "A Letter from the Reverend Henry Miles D.D. and F.R.S. to the President," 441–46.

<sup>77</sup> Van Musschenbroek, *Beginselen der Natuurkunde*, 2nd ed., 259. Cited and translated in Present, "Petrus van Musschenbroek and the early Leiden jar," 7.

give a map of it and to pretend to assign the laws which govern it.”<sup>78</sup> The attitude was so common, in fact, that Nollet felt it necessary to begin his *Essai sur l'Électricité des Corps* with a preemptive reply to those “savants, who claim that we must refrain from all theory until we have exhausted the facts.”<sup>79</sup>

Just as important as their cautious view of theory was their positive commitment to non-theoretical experimental aims, including both entertainment and control. The default framing of science today—and one that held still greater sway in past decades—is that of a rigorous and, in modern times, professional search for truth (understood as a kind of theoretical adequacy). In the 1730s and 1740s, however, the community functioned more like an affinity group, with friends communicating their latest successes, sharing tips, and passing along jokes and stories relating to their shared interest. Many participants were professionals in the sense that they had academic postings, but the space was such that books of poetry and strange tales were not out of place.<sup>80</sup> Theory construction was a recognized goal, but it was far from overriding. Other ends were just as important. Amusement, for instance, played a central role in the selection and spread of philosophical studies. As often as not, experiments were undertaken primarily for the enjoyment of doing so or a simple desire to see what happens. Authors routinely dwell on the “curious” and “entertaining” nature of their work, selecting experiments “most likely to give [their reader] pleasure” and proposing designs that might amuse their fellows.<sup>81</sup> As late as 1770, one still finds introductory texts released in the hope “that others may copy [the experiments] for their own amusement and that of their friends.”<sup>82</sup> What’s more, most leading electricians had at least some experience “giving a spectacle to the people,” whether in the form of large public displays or in smaller lecture hall and parlor gatherings.<sup>83</sup> Show culture would become an object of scorn in later years, but in the 1740s, the ties were still quite close. A number of electricians had, like Benjamin Martin, begun their work as itinerant lecturers, and many established

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<sup>78</sup> Haller, “Histoire des Nouvelles Découvertes faites, depuis quelques années en Allemagne, sur l'Électricité,” 10–11; The discovery of Haller’s authorship is due to Heilbron (“Franklin, Haller, and Franklinist History,” 539–49). See also Watkins, *A Particular Account*, 3–4; Needham, “Extract of a Letter from Mr. Turbervill Needham,” 257–58. Cf. the comment of a writer for the same publication one year after the jar was reported:

The Reader will not expect from me an extract of what has been said on the theory of electricity. It’s always for me what is least useful. Electricity has been known for too short a time for its cause to be deciphered. Do we have that of Magnetism, known for so many years? (“Mémoire sur les nouvelles découvertes qu’on a faites par raport à l'Électricité,” 113)

<sup>79</sup> Nollet, *Essai sur L'Électricité des Corps*, x.

<sup>80</sup> See, e.g., Bose, *L'Électricité, son Origine et ses Progrès*. 1–72. For wider discussion, see Paola Bertucci, “Sparks in the Dark,” 88–93.; Sutton, *Science for a Polite Society*, part 3.

<sup>81</sup> Watkins, *A Particular Account*, 70; see also Trembley, “Part of a Letter from Mr. Trembley, F.R.S. to Martin Folkes,” 58; Needham, “Extract of a Letter from Mr. Turbervill Needham to Martin Folkes,” 247.

<sup>82</sup> Ferguson, *An Introduction to Electricity*, advertisement. In reflecting on the future progress of electricity, Priestley reveals a similar set of priorities. “What a glorious scene shall we see unfolded,” he proclaims, “what a fund of entertainment is there in store for us, and what important benefits may be derived to mankind!” (*The History and Present State of Electricity*, vol. 1, 231)

<sup>83</sup> Nollet, “Éclaircissements sur plusieurs faits concernant l'Électricité Second Mémoire,” 149.

experimenters relished their “educational” displays. Gray, Desaguliers, Nollet, Winkler and countless others engaged audiences in exciting displays of skill, undertaking what could easily be framed as a public good and even a means of reinforcing public morality (electricity serving to humble humanity before the works of God).<sup>84</sup> A skilled performer, it is worth adding, could also earn the esteem of the nobility, as a growing number had taken to hosting private shows. A 1745 text on German electricity, for instance, mentions displays made for the high-born of Saxony, Hannover, Gotha, and Brandenburg-Bayreuth; indeed, “even Poland, which has a bit of a reputation for being barbaric, was not insensible to these wonders.”<sup>85</sup>

Like many affinity groups, however, the community of electricians preferred to see their work as a useful endeavor, one that contributed immediate benefits as well as more abstract goods in the form of practical knowledge or a generalized control over nature. For some, in fact, the attainment of truth itself was understood in these terms. The production of desired effects was not only virtuous but the ground on which one’s identity as an experimental philosopher rested. Without works, Bacon famously noted, theories were but “idols” and “arbitrary abstractions”; “truth” and “utility” were, for God and the true philosopher, “the very same things.”<sup>86</sup> Accordingly, texts of the time are littered with allusions to the “useful knowledge” that would follow their studies and exhortations to go beyond the merely curious. Producing entertainments for the wealthy might keep the project afloat, but an honorable enterprise demanded something more. “However interesting the study of physics may be,” the thinking went, “it would not merit nearly as much as it does...if it ended only in curious speculations, which could not contribute in any way to the advantage of society.”<sup>87</sup> “Curiosity” must eventually give way to “interest” and the “demand that what we admire be useful.”<sup>88</sup>

In practice, this meant that the electricians had a more exploratory and technically directed approach to experimentation than might be expected. Rather than focus on refining available theories or parsing the implications of competing hypotheses, the better part of their efforts were aimed at gaining control or practical familiarity with their object of study. The reasoning behind the strategy is straightforward. One can go quite far in the domains of amusement and control without anything close to a worked-out theory, as the electricians knew from the case of the

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<sup>84</sup> Bertucci, “Revealing Sparks: John Wesley and the Religious Utility of Electrical Healing,” 341–62; Schaffer, “Natural Philosophy and Public Spectacle in the Eighteenth Century,” 1–43. Interestingly, the founder of Methodism, John Wesley, became quite interested in electricity and its theological uses after witnessing a show of Desaguliers’.

<sup>85</sup> Haller, “Histoire des Nouvelles Découvertes faites,” 9.

<sup>86</sup> Francis Bacon, *Aphorisms*, CXXIV. Pérez-Ramos’ *Francis Bacon’s Idea of Science and the Maker’s Knowledge Tradition* discusses this line of thought at length.

<sup>87</sup> “Sur l’Électricité,” 8. Cf. Nollet, *Recherches sur les Causes Particulières des Phénomènes Électriques*, 342; Franklin, *Experiments and Observations*, 34.

<sup>88</sup> Nollet, “Observations sur quelques nouveaux phénomènes d’Électricité,” 18

exceedingly useful but still mysterious compass.<sup>89</sup> One can hardly use what one cannot direct, though, and while unwieldy forces can be quite entertaining, they are ill-suited to parlour displays, particularly those involving one's friends and superiors. In fact, control would have to be given priority even if one limited oneself to purely theoretical interests. Just as with amusement and practical use, theory development was subject to a certain asymmetry: one can further the cause of experimental control a great deal without anything close to a theoretical consensus, but one can hardly expect to construct or test a system whose associated phenomena so irregular as to resist the simplest demands of consistency. "Common" experience, as the German physicist Daniel Gralath noted in 1747, is the ground on which formal understanding rests, but when it comes to measurement and experimental control, "one can very often do without philosophical knowledge, indeed,...it is not uncommon to arrive at this only after you have the thing in your power."<sup>90</sup>

## Technical Developments

With the foregoing discussion in mind, we are in a better position to see why the discovery was so popular and how a single device could find itself implicated in so much of the work following it. Fundamentally, it is a process of growth more than destruction. From very early on, the electricians approached the jar much as a child approaches a new toy, inundating the presses with new reports on exciting new capacities and applications. They subjected it to all manner of prodding, flipping every switch they could find, swapping materials, and seeing what different objects did when subjected to the marvelous new invention. The jar was used to electrify trees, produce lights of varying colors, and deliver shocks to unsuspecting friends; a few electricians even put the thing in their mouths.<sup>91</sup> As curious as some of the studies were, however, the method bore fruit. Indeed, Kleist's own process of discovery represents a manifestation of the approach.<sup>92</sup> His motivations, as letters to Krüger and Swietlicki indicate, were primarily those of

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<sup>89</sup> "Mémoire sur les nouvelles découvertes qu'on a faites par raport à l'Électricité," 113.

<sup>90</sup> The quote comes while addressing an objection to his efforts at measuring electrical pull:

Wollte jemand einwerfen ob es nicht zu frühe sen, die Kräfte der Electricitaet auszumessen, und eine Mathematische Erkenntnis davon zu verlangen da man mit der Philosophischen darin noch nicht weit gekommen und die wahre Ursach der Electricität noch nicht unter die ausgemachten Wahrheiten zu zehlen ist; so lässt sich dieser Einwurf bald heben, wenn man erweget dass die gemeine Erfahrungen und die historische Erkenntnis den Grund zur Mathematischen Erkenntnis legen, und dass man der Philosophischen sehr oft haben entbehren könne, ja dass man nicht selten erst zu dieser gelanget, wenn man jene schon in seiner Gewalt hat. (Gralath, "Nachricht von einigen Electriscen Versuchen," 533)

<sup>91</sup> Browning, "Part of a Letter from Mr. John Browning, of Bristol, to Mr. Henry Baker, F. R. S. Dated Dec. 11. 1746. Concerning the Effect of Electricity on Vegetables," 373–75; Watson, "A Sequel to the Experiments and Observations," 713.

<sup>92</sup> Dufay's work is, in fact, a standard case in the philosophical and historical literature on exploratory experimentation. For classic discussions of exploration in science, see Sargent, *The Diffident Naturalist: Robert Boyle and the Philosophy of Experiment*; Burian, "Exploratory Experimentation and the Role of Histochemical Techniques in the Work of Jean Brachet," 27–45; Steinle, "Entering New Fields," S65–74.; "Experiments in History and Philosophy of Science," 408–32; *Exploratory Experiments: Ampère, Faraday, and the Origins of Electrodynamics*.



entertainment; his discovery, as he wrote in May of 1746, was an incremental one, grounded in successive experiments and extrapolations.<sup>93</sup> The generator that allowed him to charge the vessel while insulated emerged because he wanted to electrify himself without an assistant, the medicine bottle with which he obtained his first results was likely chosen because of its convenience as a handheld and potentially portable store, and the thermometer design which proved so influential in later work was tried on the hunch that a larger vessel might allow more power to be collected, as had been the case with prime conductors.<sup>94</sup> Kleist did eventually try to offer some explanations, but only after he had gone through a considerable number of experimental variations and improvements.<sup>95</sup>

We need not focus solely on Kleist, though, as the pattern was quite general. An immediate sense of this can be gained by looking at the jar itself. Rather than emerging all at once, the device underwent considerable refinement in its first few years. Vessels were filled with materials as diverse as ink, oil, vinegar, butter, and iron filings, leading eventually to the use of thin metal coatings along the interior and exterior walls. Tests were likewise conducted with all manner of insulators, including talc, horns, wax, and wood, as well as glasses of all different sizes, shapes, and origins, yielding both the large, thin-walled containers synonymous with the jar today and the simple, parallel-plate capacitors that populate our textbooks and consumer electronics. Finally, individual jars were placed in all manner of charging arrangements, finding themselves tangled up with one another and embedded in all manner of materials, giving rise to powerful capacitor banks composed of many jars charged in parallel.<sup>96</sup> What started as a medicine bottle in late 1745 had, by the end of the next year, blossomed into more than a dozen forms, including designs so well suited to their experimental purposes as to remain essentially unchanged for the next century and a half.<sup>97</sup> With each refinement, moreover, came the promise of new applications, more exciting displays, and a host of novel experimental tools. Indeed, most early electrometers and the famed Electrophorus, a seemingly perpetual source of electric charge

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<sup>93</sup> Kleist to Krüger, 19 December, 1745, 177; Kleist to Swietlicki, 24 February, 1746; Kleist to Swietlicki, 12 May, 1746. His comments regarding his electrical “toys” and the “rousing” atmosphere of a good demonstration, made in the December and February letters, indicate a concern with personal amusement. His comment on the incremental nature of the discovery occurs in the last Swietlicki letter.

<sup>94</sup> Each innovation, it is worth adding, came alongside other, less celebrated trials, including studies electrifying a wooden spool, trials of blunted vs. sharp-ended conductors, and a range of entertaining applications.

<sup>95</sup> Kleist to Swietlicki, 24 February, 1746. The proposal involves an equilibrium model in which, during electrification, the interior of the jar is evacuated of all electrical material, leaving it poised to draw matter violently from the hand of the experimenter.

<sup>96</sup> Franklin, *Experiments and Observations on Electricity*, 26; Winkler, *Die Stärke der Electricischen Kraft*, 48–49.

<sup>97</sup> The absence of theory is worth emphasizing as it has been claimed that major developments, such as the transition from jars to glass plates, came after Franklin (Kuhn, *The Structure of Scientific Revolutions*, 118). In fact, both were developed beforehand (see Watson, “A Sequel to the Experiments and Observations Tending to Illustrate the Nature and Properties of Electricity,” 714–15; Watson, “A Collection of the Electrical Experiments,” 104).

created by Volta in 1775, stemmed from existing capacitor designs.<sup>98</sup> The device kept yielding novelties. In the remainder of the study, I hope to provide a better sense of their range and significance.

Attempting to capture the entirety of the Leyden jar's impact is a futile endeavor. As the previously cited Royal Society statistics testify, the jar touched nearly every area of electrical study and would continue to do so for the remainder of the century. That said, the changes it helped usher into the field were more strongly felt in some areas than others. As a result, much of the capacitor's impact can be traced to a few central factors. Three are particularly worth noting:

1. **Experimental and Practical Use:** By making electricity more easily manipulable and far more powerful, the jar vastly increased the range of experimental and practical applications, expanding the literature and ensuring the tool's use for decades to come.
2. **Entertainment Value:** The vessel's power, novelty, and ease of use allowed greater numbers of people to create far more impressive spectacles and entertainments, leading to an increase in popularity and contributing to shifts in the public's relation to natural philosophy.
3. **Laying a Groundwork for Theory:** In providing a host of new phenomena and allowing for more fine-grained control of electricity, the jar led to the creation of a new, Franklinian theory and facilitated the growth of hypothesis-driven research.

Each shall be discussed in turn.

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<sup>98</sup> Lane, "Description of an Electrometer Invented by Mr. Lane," 451–460; Richmann, "De Indice Electricitatis," 301–40.; Volta, "Of the Method of Rendering Very Sensible the Weakest Natural or Artificial Electricity," 7–35; Vaughan "The Reception of Volta's Electrophorus Among Eighteenth-Century Electricians"

Table I: Examples of Electrified Materials (1739–1752)<sup>99</sup>

<i>Metals, stones, and minerals</i>	White diamond	Sapphire	Emerald
	Colored diamond	Ruby	Opal
	Garnet	Topaz	Jacinth
	Peridot	Amethyst	Selenite
	Cat's eye	Rock crystal	Alum
	Jasper	Granite	Porphyry
	Marble	Muscovite	Slate
	Jet	Sulfur	Pumice
	Ammoniac	Water mixed with nitre	Lodestone
	Copper (tube, bar, wire)	Antimony	Mercury
	Iron (tube, bar, wire)	Gold	Silver
	Brass (tube, bar, wire)	Steel	Tin
	Lead (tube, bar, wire)		
<i>Manufactured goods</i>	Porcelain	Faience	Glazed earthenware
	Ink	A tobacco pipe	Parchment
	A drawn sword	A scabbarded sword	A scabbard
	A sword belt	A glass tube	Lead glass
	A tallow candle	A tallow candle <i>with</i> Wick	Crape
	A glass globe	A black hat	White paper
	A cane	A white hat	Flannel
	Brown paper	Tape made of thread	White thread
	A tobacco pipe	A bunch of keys	
<i>Foods</i>	A Pear	Grapes	White peas
	Celery	A leek	Black peas
	Flesh	Sugar	Bread
	Fresh milk	Olive oil	Vinegar
	Raw beef	Salted beef	
<i>Other animal products, animals</i>	Grease	Silk	Tortoiseshell
	A human thigh bone	Feathers	Hair
	Horn	Shells	Ivory
	Urine	Fish skin	Wax
	A cat	A thong of sheep skin	Spanish wax
	A sponge	Whalebone	Wool
	A boy		
<i>Other plant products, plants</i>	Cotton	A black thorn	Fir
	Mastic (resin)	Copal gum (resin)	Shellac (resin)
	Sandarac (resin)	Turpentine (resin based)	Hay
	Rushes		

<sup>99</sup> Taken from Nollet, *Essai sur L'Électricité des Corps*, 36–38; Desaguliers, “Some Thoughts and Experiments concerning Electricity,” 193–99; Bohadsch, *Dissertatio Inauguralis Philosophico-Medica De Utilitate Electrificationis In Arte Medica*, 5–8.

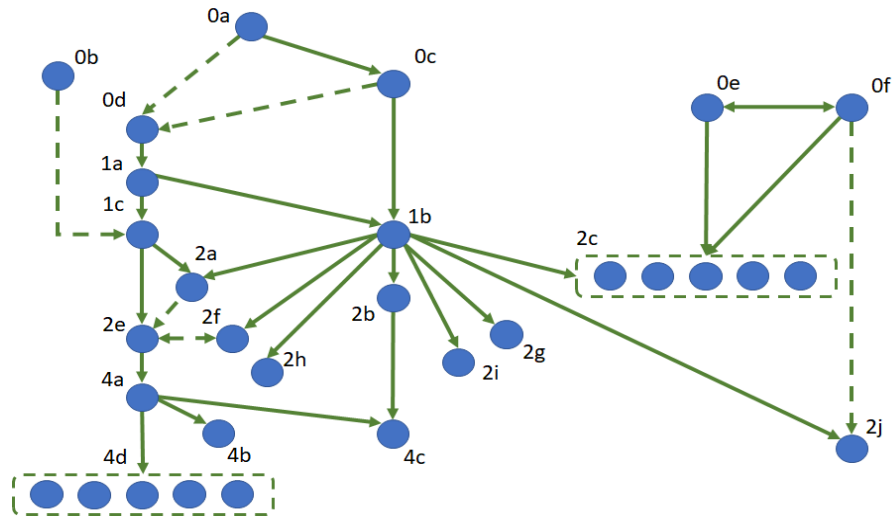


Figure 4: Evolution of the Jar<sup>100</sup>

Generation	Construction	Creator(s)
0-predecessors	a. Water in wooden bowl b. Mercury barometer c. Glass of water on table d. Tin vessel on silk e. Cup of coffee on silk f. Various objects in air pump	Gray Ludolff, Picard Bose, Gordon Kleist Winkler Winkler
1-first jars (Investigated prior to reporting)	a. Medicine glass, water b. Glass globe, water c. Thermometer, mercury or spirits	Kleist Kleist, Musschenbroek Kleist
2-immediate offshoots	a. Glass with metal filings b. Wax substituted for glass c. Various items substituted for water (butter, coffee, etc.) d. Metal-coated glass e. Capacitor bank ("battery") f. Porcelain substituted for glass g. Bowl of water h. Vessel of water in water i. Vacuum capacitor	Gralath, Winkler Nollet Various Bevis Winkler, Franklin Manteufel, Nollet Miles Winkler, Dutour, Allamand Nollet
3-secondary designs	a. Plate capacitor b. Dissectible plate capacitor c. Parallel-plate air capacitor d. Various materials substituted for glass plates (talc, mica, etc.)	Bevis, Smeaton Wilcke, Franklin Aepinus, Wilcke Various

<sup>100</sup> See note 100 for sources.

Table II: Selected Variations in Capacitor Design (1746–1768)<sup>101</sup>

<i>Insulator material</i>	Medicine bottle	Wax	A flat glass pane
	Wood	Earthenware	Spanish wax
	A globe of glass from the Netherlands	A globe of glass from Germany	A globe of glass from England
	A horn	A wine glass	A vacuum chamber
	Pitch (resin)	A sulfur vase	Porcelain
	Thermometer tube	Metal (unspecified)	A sheet of talc
	Enamel	Cracked glass	Rock crystal
<i>Electrode materials</i>	A nail	Ink	Water
	Warm water	Boiling water	Cold water
	Saltwater	Seltzer water	Brass wire
	A birch twig	A sheet metal tube	Vinegar
	Beer	Wine	Melted butter
	Tree oil	Mercury	Vitriol
	A metal bowl	Turpentine	Warm coffee
	Lead filings	Copper filings	Iron filings
	Melanteria	Olive oil	Walnuts
	Linseed	Gilding	Silver
	Metalwork byproducts	The human hand	Blood
	Urine	Whale oil	Bile
	Sal ammoniac	Spirit of salt	Spirit of nitre
	Gold	Bronze	Tartar oil
	Petroleum		
<i>Other forms of variation</i>	Charging method	Absolute size	Mode of discharge
	Insulator dimensions		

## The Jar as Tool

The jar’s first and most direct impact stemmed from its uses as an instrument. From its inception onward, the “amplification machine” found application as both an experimental apparatus and popular gadget, appearing in labs and homes soon after its existence was widely known. It was simple to construct and, after some initial refinements, relatively reliable. It was also exceedingly inexpensive, requiring no more than common household items to create. Most importantly,

<sup>101</sup> Winkler, *Die Stärke der Elektrischen Kraft*, 14, 23, 28–30; Nollet, *Essai sur L’Electricite des Corps*, 35–40; Nollet, “A Ceux de l’Electricite,” 422; Watson, “A Collection of the Electrical Experiments,” 104; Watson, “A Sequel to the Experiments and Observations,” 714; Rabiqueau, *Le Spectacle Du Feu Élémentaire*, 133, 137, 146; Gralath, “Nachricht von einigen Electriscen Versuchen,” 519; “Geschichte der Electricitat, Zweyter Abschnitt,” 428; Paulian, *L’Électricité soumise à un nouvel examen, dans différentes lettres adressées à M. l’abbé Nollet*, 73–78; Musschenbroek to Bose, April 20, 1746, cited in Present, “Petrus van Musschenbroek and the early Leiden jar,” 23; Present, *Learning in the World*, 269.

however, it served two supremely important functions. The first was storage or, more precisely, storage and transport.<sup>102</sup> Comments on the remarkable endurance of the vessel may be found in the writings of Kleist, Galath, Watson, Martin, and others, where it is often cited as among the most exciting results to come from the invention. Needham even went so far as to label it “the most surprising property.”<sup>103</sup> The reaction is, on first reading, a bit surprising. That someone could view a thirty-six-hour charge with a degree of amazement comparable to that of a bowel-shuttering electrical shock seems odd to the modern reader. If one keeps the experimental context, however, the attention becomes more, if not fully, understandable.

Before the discovery, electricity was a relatively ephemeral phenomenon, a natural force that could be produced with specialized equipment but proved difficult to direct or keep around.<sup>104</sup> The capacitor changed this more or less overnight, giving the philosophers a means of capturing and deploying on command what had been the most unwieldy of forces. It was as though they had learned to bottle the wind or sunlight. With time, moreover, their degree of control only grew. With adjustments to the vessel’s size and composition, the thirty-six-hour mark that so amazed Needham was soon replaced by a duration of three to eight *days*, and in less than a year’s time, the journey that Kleist had measured in paces was replaced by one measured in miles.<sup>105</sup> In practical terms, this meant that electricity could be taken anywhere one cared to go. It became possible to transport charges to the houses of friends, to deploy them in outdoor demonstrations, and to shuttle them back and forth between work and home, as Monnier was said to do quite regularly.<sup>106</sup> At the same time, it meant that natural phenomena could be studied and acted upon outside the lab. An indoor affair in 1745, electricity had, by 1747, been taken through gardens, shot through stone and earth, and discharged over the breadth of the Pleisse, Thames, and New rivers; by 1752, it had even been used to bottle lightning from the clouds, placing in the philosopher’s pocket a power once reserved for the gods.<sup>107</sup> Over the next several decades, the field would see a significant growth in the study of “natural electricity,” including models of lightning, studies of electrical effects on plant life, and of the electric torpedo fish, all facilitated by the electricians’ improved command over the when, where, and how much of electrical

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<sup>102</sup> See Galath, “Nachricht von einigen Electriscen Versuchen,” 516; Needham, “Extract of a Letter from Mr. Turbervill Needham to Martin Folkes, Esq.,” 255.

<sup>103</sup> Martin, *An Essay on Electricity*, 34.; Needham, “Extract of a Letter from Mr. Turbervill Needham,” 255–56.

<sup>104</sup> Prior to the jar, the lengthiest report Needham might have been aware of was Gray’s finding that an electrified child suspended from silk could still attract thread after 21 to 50 minutes (see Gray, “A Letter from Stephen Gray, F.R.S. to Dr. Mortimer, Secr. R. S. Containing Some Experiments Relating to Electricity,” 170).

<sup>105</sup> “Nachricht von einigen Electriscen Versuchen,” 516. Watson, “A Sequel to the Experiments and Observations Tending to Illustrate the Nature and Properties of Electricity,” 713. The longer times were actually discovered prior to Needham’s writing but were only published later.

<sup>106</sup> Needham, “Extract of a Letter from Mr. Turbervill Needham,” 255–56.

<sup>107</sup> Cavallo, *A Complete Treatise of Electricity*, 340–41. Watson, “A Collection of the Electrical Experiments,” 49–120.; Winkler, *Die Stärke der Electriscen Kraft*, 27–28; Franklin, “A Letter of Benjamin Franklin, Esq; to Mr. Peter Collinson, F.R.S. Concerning an Electrical Kite,” 565–67.

discharge.<sup>108</sup> A marginal area in 1740, natural electricity would represent five to ten percent of electrical publications in the years between 1752 and 1797.<sup>109</sup>

Just as significant was the power the unassuming vessel provided. Electricians had been making efforts to increase generator output for nearly a decade, and had had a degree of success in doing so. The incorporation of prime conductors in the design of frictional generators was, as we have seen, a major step. Compared to the power obtained with the capacitor, however, these earlier designs appear quite limited. Even a small vessel, we know, was sufficient to increase a generator's output markedly. Reportedly, a glass sphere one inch in diameter could give "as great a shock as a man can well bear" when filled with mercury.<sup>110</sup> Not content to produce the merely unbearable, however, the electricians took a serious interest in strengthening the current available to them, increasing the vessels' size and fine-tuning the materials and dimensions of the conductors and insulators. Studies conducted with generators and metal-lined jars in the Smithsonian indicate that adding a typical jar to a globe generator increased output by approximately two orders of magnitude.<sup>111</sup> In human terms, the effect was like moving from the shock one gets from a plastic chair to the sort that comes from a Taser.<sup>112</sup> What's more, this figure could be increased many times over by simply charging jars in parallel, a technique independently discovered by Winkler in 1746 and Franklin in 1747.<sup>113</sup> Charging a mere two jars in this way places one at levels deemed hazardous by the US Department of Energy, but it became common after the discovery to see shelves full of capacitors.<sup>114</sup> By 1773, the electrician Edward Nairne was making use of up to sixty-four jars at a time, an arrangement powerful enough to wither branches on a privet tree.<sup>115</sup>

This massive increase in power brought with it a host of new possibilities, which the electricians pursued with zeal. They produced lights at ever larger scales, sent jolts across increasingly long distances, and subjected materials to chemical changes unattainable with a prime conductor only.

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<sup>108</sup> Cavendish, "An Account of Some Attempts to Imitate the Effects of the Torpedo by Electricity," 196–225; Henley, "Experiments Concerning the Different Efficacy of Pointed and Blunted Rods," 133–52; Nairne, "Electrical Experiments by Mr. Edward Nairne," 80.

<sup>109</sup> Heilbron, *Electricity in the 18th and 19th Centuries*, 491; The figures are based on the papers reviewed or abstracted in the *Comentarii de rebus in scientia naturali et medica gestis*.

<sup>110</sup> Franklin, *Experiments and Observations*, 24.

<sup>111</sup> Finn, "Output of Eighteenth-Century Electrostatic Machines," 289–91.

<sup>112</sup> This is a highly conservative estimate given the jar's speed of discharge. Charging a jar with a globe generator would provide around 5 joules of energy, released at once. A Taser C2 delivers a pulse of around 0.076 joules at ~17 pulses per second (1.292 Joules per second, or 1.3 Watts). Nominally, it is capable of around 5 Joules per second, or 5 Watts at the main capacitors. See "Taser C2 Series Electronic Control Device Specification," 2007.

<sup>113</sup> Finn, "An Appraisal of the Origins of Franklin's Electrical Theory," 362–69.

<sup>114</sup> Franklin, *Experiments and Observations on Electricity*, 26; U.S. Department of Energy, *Electrical Safety*, Sec. 10-6, Sec. 10–24. Winkler, *Die Stärke der Elektrischen Kraft*, 27–28, 48–49. Winkler's initial experiments used three and five jars at once. Franklin's design involved eleven plate capacitors.

<sup>115</sup> Nairne, "Electrical Experiments by Mr. Edward Nairne," 80.

Sparks from a traditional generator could light up a dark room; those given off by the jar could be seen and heard at 200 paces in broad daylight.<sup>116</sup> These possibilities allowed, in turn, for a greater variety of studies. The increased communication distances, for instance, allowed for early measurements of the speed of electricity while the chemical changes produced by discharge proved useful in early studies on calcination (a process removing volatile substances, often from metals).<sup>117</sup> Traditional lines of investigation stood to benefit, as well. Operating with a glass tube, as most experimenters had done a decade prior, left the production of effects highly subject to the elements. With the use of generators and capacitors, however, the production of common effects became far more reliable. Odd failures and irregularities were not fully eliminated, as Musschenbroek's curious inability to construct a jar from non-German glass illustrates, but as designs became more standardized and set-ups became more powerful, desired effects became easier and easier to rely on. Tellingly, the device was so useful as a lab instrument that it would continue to be used through the 19th century and into the 20th, appearing in the writings of figures such as JJ Thompson.<sup>118</sup>

The vessel also showed promise outside the lab. The motive force of electricity, for instance, inspired various mechanical designs. Electrically driven solar systems and self-chiming clocks were among the first designs to be suggested, to which Franklin added an electrical turning spit for roasting turkey.<sup>119</sup> Later developers foresaw even greater contributions, constructing model gristmills and water pumps that promised a new age of machinery.<sup>120</sup> The fact that the device made lighting fires so easy was another source of inspiration. Beyond the fun of lighting oils and spirits on fire, the jar could kindle plant materials and gunpowder, suggesting the potential for military applications.<sup>121</sup> In 1801, a Lexington man even wrote to President Thomas Jefferson suggesting that one could hurl them at enemies.<sup>122</sup> The most interesting of the early practical suggestions, however, were probably those in the realm of communication. Impressed with the speed of electricity and the considerable distances that the jar could propagate it (up to 12,276 feet in 1748), authors began dreaming up ways of "conveying intelligence" through wires as early as 1753, starting with systems assigning a wire to each letter and arriving by the century's end at a design using only one.<sup>123</sup> Such a system was even said to have been implemented in

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<sup>116</sup> "Mémoire sur les nouvelles découvertes qu'on a faites par rapport à l'Électricité," 112.

<sup>117</sup> Le Monnier, "Recherches sur la Communication de l'Électricité," 455–7; Priestley, *The History and Present State of Electricity: With Original Experiments*, vol. 2, 3rd ed., 289–92.

<sup>118</sup> See, e.g., Thomson, "On the Discharge of Electricity Through Exhausted Tubes Without Electrodes," 321–36.

<sup>119</sup> Watkins, *A Particular Account*, 16–20, 23; Franklin, *Experiments and Observations on Electricity*, 35.

<sup>120</sup> Ferguson, *An Introduction to Electricity*, plate 2.

<sup>121</sup> Franklin, *Experiments and Observations on Electricity*, 35. Many of these individual feats could also be accomplished with generators alone, but less reliably. See Priestley, *The History and Present State of Electricity*, vol. 1, Period VII.

<sup>122</sup> William Caruthers to Thomas Jefferson, July 29, 1801. Cited in Delbourgo, *A Most Amazing Scene of Wonders*, 15.

<sup>123</sup> Watson, "An Account of the Experiments Made by Some Gentlemen of the Royal Society," 495; Sabine, *The History and Progress of the Electric Telegraph*, 5–12.



Spain in the mid-1790s, when a battery of Leyden jars were used to send impulses some twenty-seven miles from Madrid to Aranjuez.<sup>124</sup> The spectacular Spanish telegraph aside, few of the mechanical proposals were feasible for immediate adoption. Yet the electricians were no longer in the position Desaguliers had been in circa 1739, having to justify the usefulness of electrical study by appeal to its ubiquity and divine providence.<sup>125</sup>

Finally, there were its uses in medicine. Though medical electricity was a topic of investigation prior to the capacitor, the period after 1745 witnessed a clear surge in publications on the topic, as well as a minor craze amid the public at large. In part, this stemmed from the novelty of the sparks and the common association between electricity and vitality, an association encouraged by the fact that electrification increased one's heart rate and hastened the growth of plants, among other things.<sup>126</sup> More prosaically, the device was also convenient. One could take a jar of "fire" to a patient's home with as much ease as a bottle of salts, amplifying the most compact and portable of generators to levels of output thought useful in treating a range of maladies.<sup>127</sup> Attempts to treat paralysis via shock can be found as early as April, 1746, followed shortly thereafter by efforts to cure patients of headaches, infections, tumors, gout, and a range of conditions that would today be labelled mental illnesses.<sup>128</sup> In a testament to the sheer range of applications considered, early investigators even tried to deliver medicines by pouring them into the jar and having patients discharge it through their bodies.<sup>129</sup> Not all of these would survive, but interest remained high for the duration of the century, occupying between thirty and seventy percent of typical articles published at a given time in the period between 1752 and 1797.<sup>130</sup>

## The Jar as Wonder

It is clear, then, that the jar offered more than enough practical advantages to establish itself as a central instrument in the electricians' repertoire. The medical and outdoor uses alone would earn

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<sup>124</sup> "Nachricht von einem Elektrischen Telegraphen," 61; Sabine, *The History and Progress of the Electric Telegraph*, 11–12.

<sup>125</sup> Desaguliers, "Some Thoughts and Experiments concerning Electricity," 186.

<sup>126</sup> Freke, *An Essay to Shew the Cause of Electricity*, v–vi, 40–4; Martin, *An Essay on Electricity*, 20; Nollet, *Recherches sur les Causes Particulières des Phénomènes Électriques*, 59–60.

<sup>127</sup> Bertucci, "Therapeutic Attractions: Early Applications of Electricity to the Art of Healing," 271–83.

<sup>128</sup> Bertucci, "Therapeutic Attractions," 271–83.; Graham, *The Guardian Goddess of Health: Or, the Whole Art of Preventing and Curing Diseases, Etc.*; Hart, "Part of a Letter from Cheney Hart, M. D. to William Watson, F. R. S. Giving Some Account of the Effects of Electricity in the County Hospital at Shrewsbury," 786–88.; Lowndes, *Observations on Medical Electricity: Containing a Synopsis of All the Diseases in Which Electricity Has Been Recommended or Applied with Success*; Nollet, "Observations sur quelques nouveaux phénomènes d'Électricité," 18; Roche, "A Letter from Mr. Robert Roche to the President, of a Fustian Frock Being Set on Fire by Electricity," 323–25.

<sup>129</sup> Watson, "An Account of Professor Winkler's Experiments Relating to Odours Passing Through Electrified Globes and Tubes," 231–41; Baker, "A Letter From Mr. Henry Baker F. R. S. to the President, Concerning Several Medical Experiments of Electricity," 270–75; Nollet, *Essai sur l'Électricité des Corps*, 3rd ed., 219–39.

<sup>130</sup> Heilbron, *Electricity in the 17th and 18th Centuries*, 491. The figures are once again based on the *Comentarii* (see note 106).

it a place among the most significant technical developments of the century. Examining the discussions surrounding the jar, however, one finds that it represented far more than a mere apparatus. It was, for the electricians and public alike, a toy, marvel, and conversation piece, as well—something so entertaining that more than fifty years after its discovery its results were still “viewed with wonder and surpris[e].”<sup>131</sup> Travelling shows and parlour room amusements were common before the discovery, but as period testimony confirms, the jar brought something different. “It was this astonishing experiment,” Priestley tells us, “that gave eclat to electricity,” drawing in nearly every practicing electrician as well as “the vulgar of every age, sex, and rank.”<sup>132</sup> At a fundamental level, these impacts traced to the same functional properties as the jar’s success in practical endeavors, namely its power and ease of handling.

To start with, the jar’s portability and unassuming size made it ideal for practical jokes and at-home displays, of which there were many. Mixed into Watson’s second book of *Experiments and Observations*, for example, one finds instructions on how to send electricity through the gilding of a man’s coat, draw “red fire” from an egg, and how to trick friends into completing the jar’s circuit by way of a wire running under a rug (adapted by de la Fond into the much-celebrated electrified door knob joke).<sup>133</sup> Likewise, Franklin instructs the readers of his *Observations* on how to create a dancing spider that leaps between conductive surfaces, charge a glass of wine that shocks those who drink it, and craft a “magical picture” of George III whose electrified crown rebuffs those who dare to remove it.<sup>134</sup> A popular and even simpler version of the wine joke involved telling one’s friends about the wonderful fragrance of one’s “magic smelling bottle” and watching them bring the vessel to their nose.<sup>135</sup> For one looking for amusement or simply to inflict pain on unwary friends, the jar proved an ideal medium.<sup>136</sup>

The increased power also allowed for all manner of spectacle. The jar could produce flames and explosions, give off strange and frightening sounds, and emit lights of all different colors

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<sup>131</sup> Adams, *An Essay on Electricity Explaining the Principles of That Useful Science*, 5th ed., 223.

<sup>132</sup> Priestley, *History of Electricity*, vol. 1, 108; Cf. “Coup Foudroyant,” 337–38. The context of the quote is reproduced in note 142.

<sup>133</sup> Watson, “A Sequel to the Experiments and Observations Tending to Illustrate the Nature and Properties of Electricity; in a Letter to the Royal Society from the Same,” 22, 31. de La Fond, *Précis historique et expérimental des phénomènes électriques, depuis l’origine de cette découverte jusqu’à ce jour*, 729–32. The electrification of clothing was reported by Kleist as well, see appendix A.

<sup>134</sup> Franklin, *Experiments and Observations on Electricity*, 16–17, 27–28, 35.

<sup>135</sup> “Pocket Electrical Apparatus,” 250.

<sup>136</sup> A wonderful example of pain for pain’s sake, as well as the limits of the electricians’ sadism is provided by Watkins, who relates the following dubious experiment:

If a wire be tied pretty close about the naked head, and every thing order’d as in the foregoing experiment [electrifying a person holding a Leyden jar and discharging through their wig]; upon the operator’s touching the wire, a smart pain will be felt all round, just under the wire, as if the skin were suddenly cut thro’ with a knife; on which account I call it the scalping experiment, and only mention it, without recommending the practice on persons unappris’d thereof. (*A Particular Account*, 44)

depending on the materials used in its construction and discharge.<sup>137</sup> If shaken, the water inside would sparkle, and as we have seen, it could be used to electrify a wide range of objects indoors and out.<sup>138</sup> Beyond their “scientific” merits, drawing fire from the clouds and passing charges across the Thames were also quite exciting to see and hear. Perhaps the best-known display of which the jar was capable involved discharging it through a chain of people, a possibility independently arrived at by Galath and Nollet before news of the jar had even become public.<sup>139</sup> With successive increases in power derived from the jar, the number of people that could be electrified in a single blow grew exponentially. Starting from a jar that produced only a comparatively weak blow when run through two or more people, experimenters expanded the number of volunteers to eight and, in time, to 140, 180, and 600 (the 180 being shown to Louis XV himself).<sup>140</sup>

Most exciting of all was the feeling it produced in one’s own body. It is often remarked that, for Europe, the eighteenth century was an era of sensation, one marked by the ascendance of empiricist epistemologies and a culture of sensation-seeking fed by the tastes, smells, and colors brought by empire.<sup>141</sup> For those who could, experiencing the newest import or show was a mark of distinction, and few experiences were as novel or distinctive as that provided by *l’expérience de Leyde*. At low power, the device was capable of producing sensations across the body, and at higher voltages, it was said to produce still stranger and more terrible experiences.<sup>142</sup> French and German sources told of convulsions, a quickening of the blood, and temporary paralysis while one of the earliest English discussions told readers that the feeling was both comparable to having one’s arms blown off and, paradoxically, “not to be termed a pain.”<sup>143</sup> The blow was “impossible to express” and, intimidating as it was, simply had to be felt.<sup>144</sup> Within weeks of the reports, then, the electrical community witnessed a surge in interest the likes of which it had

<sup>137</sup> Watkins’ *A Particular Account* is particularly rich in such designs.

<sup>138</sup> The sparkling is one of the first phenomena noted about the jar, appearing in Kleist’s letters. Nollet comments on it as well (see Nollet, *Essai sur l’Électricité des Corps*, 159–60).

<sup>139</sup> Nollet, “Observations sur quelques nouveaux phénomènes d’Électricité,” 18; Galath, “Nachricht von einigen Electrischen Versuchen,” 516–17.

<sup>140</sup> Galath, “Nachricht von einigen Electrischen Versuchen,” 516–17.; Priestley, *History of Electricity*, vol. 1, 125–26.

<sup>141</sup> Purnell, *The Sensational Past*, introduction, chapter 1; Riskin, *Science in the Age of Sensibility*, chapter 1.

<sup>142</sup> Trembley, “Part of a Letter from Mr. Trembley, F.R.S. to Martin Folkes,” 59; Winkler, “An Extract of a Letter From Mr. John Henry Winkler,” 211–12.

<sup>143</sup> Winkler, “An Extract of a Letter From Mr. John Henry Winkler,” 211–12.; Needham, “Extract of a Letter from Mr. Turbervill Needham to Martin Folkes, Esq,” 254. Cf. “Mémoire sur les nouvelles découvertes qu’on a faites par rapport à l’Électricité,” 110–11: “It is not a pain, it is a violent emotion, which seems to tear the arm from the one experiencing it.”

<sup>144</sup> “Coup Foudroyant,” 338. The whole sentence is worth reproducing:

What could be more surprising, in fact, than a bottle which produces no sensation, which appears to have brought no change to your [conductor], but whose effect is such, however, that when you grab it, the spark you previously pulled from the driver without any consequence while feeling only a slight pain, then makes you feel a violent concussion in the arms & in the chest so abruptly & with such rapidity, that it is impossible to express it.

never seen. To be sure, show culture was a healthy part of electrical practice in the years prior—increasingly so after the adoption of generators with prime conductors attached. With the jar, however, the field’s popularity reached new heights, and despite a ballooning number of lecturers—one that, again, had already grown considerably in the preceding five years—demand continued to outpace what the electrical world could give. Physicists accustomed to quiet, solitary research were “overwhelmed with people, who demanded to ascertain for themselves what was involved,” creating a scene that, the *Encyclopédie* tells us, “would be hard to imagine, if the thing were not too recent to be doubtful.”<sup>145</sup>

In reflecting on these events, it is easy to see why electricity experienced the boom it did. As ambivalent as the contemporary scientist may be toward popularization, good publicity earns support, and the electricians had few qualms about using the discovery to swell their coffers and ranks (subject to certain constraints, see below). The entertainment value of electricity was among the most commonly cited reasons for study in the electricians’ appeals to students, and there is little disputing that these new and more powerful demonstrations gained many electricians a standing otherwise out of reach.<sup>146</sup> That meetings were held with the likes of Louis XV tells us all we need to know in this respect. The most striking and perhaps the most important impact of the spectacles, however, was the way they shifted the relation between philosophers and their audiences. On one hand, the jar’s usefulness in conducting demonstrations further cemented the practice, particularly in the era of controversy that began in the 1750s. Demonstrations served not only to signal the skill of an experimenter but to establish the credibility of their claims through the assent of an innocent eye.<sup>147</sup> In his battle with the Franklinians, for instance, Nollet appealed quite directly to the hundreds who had attended his public lectures, declaring that they represented “a tribunal in which I shall never be condemned if we go to the plurality of votes”; “It takes only eyes,” he noted, “to appreciate a simple fact.”<sup>148</sup> Electricians in England would use similar tactics in arguing their positions, employing massive

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<sup>145</sup> “Coup Foudroyant,” 337–38; Cf. Priestley’s comment that

It was this astonishing experiment that gave eclat to electricity. From this time it became the subject of general conversation. Every body was eager to see, and, notwithstanding the terrible account that was reported of it, to feel the experiment; and in the same year in which it was discovered, numbers of persons, in almost every country in Europe, got a livelihood by going about and plowing it. (*History of Electricity*, vol. 1, 108).

<sup>146</sup> Priestley’s *History* offers a clear example of such an appeal to entertainment. In urging students to take up the study, he notes of experiments that:

They are performed with the least trouble, there is an amazing variety in them, they furnish the most pleasing and surprising appearances for the entertainment of ones friends, and the expence [sic] of instruments may well be supplied, by a proportional deduction from the purchase of books, which are generally read and laid aside, without yielding half the entertainment. (*The History and Present State of Electricity*, vol. 2, xii)

<sup>147</sup> See Delbourgo, *A Most Amazing Scene of Wonders*, chs. 1, 3; Riskin, *Science in the Age of Sensibility*, chapters 5–6; Schaffer, “Natural Philosophy and Public Spectacle in the Eighteenth Century,” 1–43.

<sup>148</sup> Nollet, *Recherches sur les Causes Particulières des Phénomènes Électriques*, 14.

jars and generators to defend the superiority of blunted or pointed lightning rods and displaying layered-capacitor models of the mysterious electric eel to London audiences.<sup>149</sup>

With the increasing prominence of display, however, came a flare in the perennial concern over the philosopher's epistemic authority. The Leyden jar made electricity far easier to handle and display on one's own, threatening to democratize the study. Healers, mystics, and eccentrics from across Europe were drawn to the device and with a little training could position themselves as rivals or peers of the professors and churchmen. These included figures such as John Wesley, the founder of Methodism and an ardent advocate of medical electricity, James Graham, whose Temple of Healing in Adelphi and Temple of Hymen in Pall Mall offered all manner of healing services, and the "divine philosopher" Gustav Katterfelto, a Prussian showman whose displays included not only electrical sights but a solar microscope and a devilish black cat whose progeny came to live with the queen of France, among others.<sup>150</sup> Indeed, as early as 1747, the Italian Jesuit Jacobo Belgrado complained that:

Electrical phenomena have become so common and vulgar nowadays, that even the roughest and vilest people boast of having observed them, and claim their rights at reasoning about them, almost placing themselves at the same level as the sharpest philosophers.<sup>151</sup>

Yet it was the scientific societies' own talk of wonders and affirmation that the facts were available to anyone that the new entrants appealed to in presenting their claims. It was not to their positions that these figures appealed but to their works and to the audience's own eyes—to the hundreds who had seen the strange electrical powers and felt their wonderful healing effects. So it came to be that, in describing the cures of Mesmer to his friend Franklin, James Hutton could write that "you are philosopher enough, if a Fact really is, not to dispute the Fact, though the *quo modo* has all the appearance of Quackery."<sup>152</sup> By catalyzing the shift from closed philosophical discussion to a more open public one, the jar helped bring to science a contest of authority that remained long after the spectacles themselves had gone.<sup>153</sup>

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<sup>149</sup> Schaffer, "Fish and Ships," 71–105; Henley, "Experiments Concerning the Different Efficacy of Pointed and Blunted Rods," 133–52. In still later years, figures such as Volta and Giovanni Aldini would incorporate similarly spectacular appeals.

<sup>150</sup> Wesley, *The Desideratum: Or, Electricity Made Plain and Useful*; Graham, *The Guardian Goddess of Health: Or, the Whole Art of Preventing and Curing Diseases, Etc.*; "Sketch of the most wonderful Prussian Philosopher, Colonel Katterfelto, the Breeder of Kittens, and the Eolus of Piccadilly," 415–8.

<sup>151</sup> Belgrado, *I fenomeni elettrici con i corollari da lor dedotti*, 1. Cited in Bertucci, "Domestic Spectacles: Electrical Instruments between Business and Conversation," 76.

<sup>152</sup> Hutton to Franklin, 2 May 1783, cited in Riskin, *Science in the Age of Sensibility*, 222.

<sup>153</sup> See esp. Riskin, *Science in the Age of Sensibility*, chapters 5–6.

## The Jar as Foundation

Finally, there are the jar's theoretical impacts. Though I have argued that theory has been overemphasized, this should not be taken to imply that its impacts were insignificant. The discovery challenged important assumptions within existing accounts and offered both an impetus and an opening for Franklin's account in the late 1740s and 1750s. As we've seen, the common view of communicated electricity from Gray onward held that charging an object required placing it on an insulator or "electric," and early on, the assumption was that the jar operated in the same manner. The electric material or force from the spinning glass globe would flow through the prime conductor and into the jar, where its flow would be halted by the less-conductive glass. As time went on, greater and greater concentrations of electrical power would build up, releasing like a breached levy when a connection was made from the interior of the glass to the outside. There were several difficulties, though. It was unclear, for instance, why grounding the device proved so important in the charging process and why the charge remained for as long as it did. Glass was often though not invariably assumed to be semi-permeability and in need of additional insulation, but increasing the jar's thickness and placing it atop insulating stands seemed to undermine rather than aid charging.<sup>154</sup> There was also the question of where the extra power came from. That bodies resting on glass could be electrified was known from Gray and Dufay but that the amount of power collected in a glass-supported body should so thoroughly outpace that of silk-suspended materials was something of a puzzle, particularly given the common belief that silk was the less-permeable support.

Commonly, these and a few other issues are presented as decisive. As was noted earlier, however, the fortunes of existing electrical theories were of limited importance to many electricians, who assumed that accuracy would only come later in the process. For those who did favor existing accounts, moreover, there were sufficiently plausible patches to the older account to avoid destruction, most having to do with the nature of glass. In addition to storing charge, it was argued, the jar's base and walls served as a secondary power source.<sup>155</sup> Just as friction on the surface of a globe served to excite or transmit electricity to a prime conductor, close contact between the jar's interior and a highly excited conductor channeled power to the water stored inside. The fact that the blow was so much greater than with a typical generator was accounted for by the fact that the water had far more points of contact with the jar than a cushion or hand did with a glass globe (more contact allowing more transmission).<sup>156</sup> Likewise, the placement of the hand or other conductive materials on the outside of the jar was supposed to help excite the glass, an effect of increased circulation on Nollet's account and a similar process of

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<sup>154</sup> Gordon provides one example of an electrician who was not convinced of the permeability of glass (see Gordon, *Versuch einer Erklärung von den Ursachen der Electricität*, 45).

<sup>155</sup> Winkler, *Die Stärke der Elektrischen Kraft*, 71–2; Cf. Nollet, *Essai sur l'Electricité des Corps*, 154–66. See also Gralath, "Geschichte der Electricität, Zweyter Abschnitt" 447–9; Watson, "A Sequel to the Experiments and Observations Tending to Illustrate the Nature and Properties of Electricity," 709–10, 727.

<sup>156</sup> Winkler, *Die Stärke der Elektrischen Kraft*, 71–72.

“concentration” on Winkler’s.<sup>157</sup> As for whether it contradicted older views about the need for electric supports, this depended on how one read the recommendations. Some, such as the French Academic le Monnier, argued that the role of grounding did violate existing prescriptions, pointing to the fact that the diminution of insulation led to greater charge. Others, like England’s William Watson, contended that the old norms were still in place, arguing that the experiment still depended on the jar’s glass preventing the water from losing charge.<sup>158</sup> For many, though, the question of charging methods amounted to little. As Nollet noted, exceptions to the old rules were nothing new, and even if the Leyden jar proved a violation of the standards, they still served as good heuristics—something akin to the claim that one should close the doors if one wishes to heat a room.<sup>159</sup>

Even if we doubt the crisis narrative, however, we may follow other claims associated with the classical picture, and there are at least two that fit quite well with the available data. The first is the claim that the Leyden jar represented the major driver of Franklinian theory. It is all but impossible to see the account emerging in the absence of the jar, as the experiments on which it was built rely overwhelmingly on the device’s power, storage, and other distinctive properties.<sup>160</sup> In fact, Franklin’s theory was first proposed as an account of “M. *Muschenbroek’s* wonderful bottle,” with a vast majority of the experiments justifying his vision of positive and negative charge making use of the device.<sup>161</sup> Reading through the further refinements and discussions contained in his *Experiments and Observations*, moreover, one finds the vessel referred to over and over again. In a text of only eighty-six pages, the statesman manages to reference the jar at least one hundred and thirty times.<sup>162</sup> To remove the capacitor would be to remove the theory itself. Even if we suppose Franklin or someone else could have formulated the account some other way, moreover, it is doubtful that it would have gained traction. For one, the account faced

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<sup>157</sup> Winkler, *Die Stärke der Elektrischen Kraft*, 81–83; Nollet, *Essai sur l'Electricité des Corps*, 164–66.

<sup>158</sup> Le Monnier, “Recherches sur la Communication de l'Électricité,” 447–64; William Watson, “Observations upon So Much of Monsieur Le Monnier the Younger's Memoir, Lately Presented to the Royal Society, as Relates to the Communicating the Electric Virtue to Non-Electrics,” 388–95. Heilbron (*Electricity in the 17th and 18th Centuries*, 322) dismisses this as a “quibble” in a footnote, but it does not appear to have been regarded as such at the time. Le Monnier’s interpretation is certainly closer to Dufay’s stated views (see Dufay, “Seconde Mémoire sur l'Electricité,” 84), but Watson’s interpretation points to an ambiguity in the canonical statement of the view (and with Gray’s earlier statement of it). While Le Monnier’s reading makes the most sense if one interprets the rule to mean that more insulation leads to better communication of charge, Watson’s is natural if one takes it to mean that, in order to charge a conductor, it must not be grounded. One presents insulation as a correlate, the other as a threshold or pre-condition.

<sup>159</sup> Nollet, “Éclaircissements sur plusieurs faits concernant l'Électricité Second Mémoire des circonstances favorables ou nuisibles à l'Electricité,” 194–95.

<sup>160</sup> A review of Franklin’s process of discovery deserves and requires a distinct treatment. Classic discussions may be found in Cohen’s *Franklin and Newton* (ch. 10) and Heilbron’s *Electricity in the 17th and 18th Centuries*, 323–43.

<sup>161</sup> Franklin, *Experiments and Observations on Electricity*, 1.

<sup>162</sup> The word “bottle,” Franklin’s preferred term, appears over one hundred times, while “phial” is used on at least twenty eight occasions.

notoriously thorny problems in accounting for attraction and repulsion, the traditional focus of electrical study. Most pointedly, defenders of the account struggled for some time with the question of why two negatively charged bodies repelled one another.<sup>163</sup> The theory also had commitments that, without the jar, would have been much more difficult to defend. The stance that glass was impermeable, for instance, was defended by Franklin on the grounds that, while thinner glass worked better for the jar, the presence of cracks undermined it.<sup>164</sup> Without this, it would have been little to say against well-known demonstrations of permeability, such as the observation that electrified bodies could attract substances from behind glass. Finally, the degree of experimental control used to test and refine the account over the next several decades depended largely on the jar's presence, bringing us to our second major point.

The second point of agreement with common narratives is that the jar allowed for a new approach to theory in general. After the discovery of the jar, one finds a growth in appreciably hypothesis-driven work. Previous theoretical discussions, as has often noted, were rough and largely *post hoc*.<sup>165</sup> Occasional studies would begin with a specific idea or implication to test, but experimental work was, as we have seen, a largely exploratory process. Where present, theory played more of a systematizing role. In the years after the jar's discovery, however, one begins to see a shift. For one, the theories at issue become more exact and, with time, more quantified, a fact closely related to improvements in measurement and experimental control. Though still subject to error, the jar's power made differences in electricity more easily discernible not simply by human observers, whose reactions were somewhat variable, but by specially designed apparatuses. In the wake of the discovery, then, one finds an increasing interest in indexing the amount and speed of electricity.<sup>166</sup> Indeed, as was noted earlier, many early electrometers were little more than extensions of the jar itself, using the displacement of hanging thread or discharge length as an index of stored power.<sup>167</sup> These technical improvements allowed, in turn, for more

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<sup>163</sup> Finn, "An Appraisal of the Origins of Franklin's Electrical Theory," 362–69; see also Vaughan, "The Reception of Volta's Electrophorus Among Eighteenth-Century Electricians," 3–11.

<sup>164</sup> Franklin, *Experiments and Observations on Electricity*, 70.

<sup>165</sup> Heilbron states that work like Nollet's and Winkler's "offered no guidance or stimulation" and describes the pre-Franklin era as one marked by "feebleness, imprecision, and incompleteness" in the realm of ideas (*Electricity in the 17th and 18th Centuries*, 323). Cohen even more harshly states of Nollet's account that it "did not coordinate the observed data particularly well; it led to no predictions of new phenomena nor to practical applications in important devices; it did not even challenge scientists to produce a better theory to explain the phenomena which it was designed to serve. So far as the growth of scientific ideas is concerned, this theory might just as well never have existed at all." (*Franklin and Newton*, 12–13). More recent writings have been kinder to the mechanical accounts (see, e.g., Home, "Fluids and Forces in Eighteenth-Century Electricity," 55–59), but the presence of a shift in the two decades following the jar's discovery is generally agreed upon.

<sup>166</sup> Franklin, *Observations and Experiments*, 2–3; Watson, "A Collection of the Electrical Experiments Communicated to the Royal Society by Wm. Watson," 71–83; Le Monnier, "Recherches sur la Communication de l'Électricité," 447–64.

<sup>167</sup> Richmann, "De Indice Electricitatis," 301–40. A third design, arrived at in the 1760s, assessed strength of charge by the length of discharge between knobs attached to the positive and negatively charged elements of the jar (see Lane, "Description of an Electrometer Invented by Mr. Lane," 451–460).



refined hypotheses to emerge. Before the discovery, attempts to render the theory of electricity exact in the absence of comparably exact measurement involved a degree of speculation that many would have been uncomfortable with. With the forces indexed to concrete differences in pointers, timers, and the like, however, the prospect of an exact theory of electricity became a viable, if still controversial line of research.<sup>168</sup>

Nor was the benefit limited to quantification. As was noted earlier, the increased power also allowed for the emergence of prototypical hypothesis testing. With increasingly powerful capacitors at their disposal, the ability to successfully execute a range of studies became less and less dependent on the cooperation of the elements or the skill of any one investigator. This, in turn, helped make the dedication of time and effort to single, tailored studies less risky. Hence, while prior efforts focused largely on extracting patterns from a wide range of experiments, work from the late 1740s onward included narrower designs, as well. Franklin's demonstration that a jar could be charged "with its own fire," discussed at the beginning of section 3, is a good example. Instead of trying out a range of materials and arrangements, the design involves a relatively specific combination of circumstances—the insulation of his rubbing cushion and the chaining of the jar's base to the cushion—built around his idea that the amount of electric material or "fire" in a jar is constant and changes only with respect to its distribution.<sup>169</sup> The study and its implications are presented simply and on their own, as only one confident in the reliability of their design may do. This is not to say that concerns about replicability simply dissolved; such issues will always be present when one is pressing the bounds of one's tools, and early work with the jar could still be touch and go.<sup>170</sup> By the 1760s and 70s, however, electricity had become far less capricious and consequently tailored studies like Franklin's were far more common, appearing in the work of Aepinus, Cavendish, Volta, and others (each making heavy use of the capacitor). Open-ended work continued to be a foundational part of electrical research, but with increasingly refined theories and means of technical control, the electricians' use of it was no longer as dominant.<sup>171</sup> While the accounts differ on the question of reception, then, the present narrative ultimately comes to a similar position on the jar's long-term theoretical impacts to that of the classical picture. The capacitor shaped the practice of theory construction and assessment in fundamental ways, just as it shaped the scope and public profile of electrical study.

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<sup>168</sup> On the disputes surrounding mathematization, see Riskin, *Science in the Age of Sensibility*, chapter 2.

<sup>169</sup> As Kleist's case illustrates, however, the phenomenon could have been discovered without seeking it out in the way Franklin did.

<sup>170</sup> Given the complexity of the system being intervened on, medical applications were often difficult to generalize.

<sup>171</sup> Steinle's *Exploratory Experiments: Ampère, Faraday, and the Origins of Electrodynamics* offers an extended discussion.

## Conclusions

Considering the case as a whole, one is confronted with a narrative at once familiar and strange. In many ways, the electricians' approach is quite consonant with the common view of science. Their curiosity when faced with a new phenomenon and caution in pronouncing too early on matters unknown both fit rather easily with traditional framings. In other ways, however, the narrative looks rather different from what one might expect. The popular vision of scientific methodology is a process driven by ideas.<sup>172</sup> One begins with various hypotheses and sets about testing and refining them, bringing to bear a characteristic set of virtues, including evidential accuracy, internal coherence, and simplicity. Yet the early years look less like a battle of systems than a process of taming or domesticating the object of study. Instead of the narrowly specified hypotheses that populate contemporary grant proposals, the experimenters cast a remarkably wide net, picking out the best designs by running through vast numbers of small variations. While there were theoretical discussions, a good number dismissed them out of hand as premature or treated them in a purely heuristic manner, allowing inconsistencies and inaccuracies as part of the process. Their motives appear different from what we are used to, as well. Though the scientific enterprise is often framed as a dispassionate search for truth, the common electrician seems to have been at least as concerned with control and the various practical and amusing ends to which it could be put. Among the first experiments made with the device were the illumination of coat gildings, the shocking of birds, and the formation of human circuits.

We are not used to thinking of the enterprise in these terms. That philosophers should be unconcerned with underlying causes or that a discovery as momentous as the capacitor should find immediate use in the creation of dancing spiders and practical jokes doubtlessly feels odd for some, perhaps even undignified. The historian I.B. Cohen once went so far as to defend Franklin from the accusation that he was a practical man, insisting that, like any good scientist, his first concern was to capture the truth.<sup>173</sup> In reviewing the case, however, it is clear that the electricians succeeded not despite these features but in part because of them. Theory at the time was, as was noted many times by the participants themselves, quite limited. None could have anticipated the capacitor, and it is unclear whether a program focused on perfecting existing theories would have recommended the lines of investigation that ultimately led to it. Their primary interests, rather, seem to have been the practical aim of increasing generator output and the educational and entertaining purpose of putting on a rousing display for students.<sup>174</sup> Nor

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<sup>172</sup> Note, however, that among historians and philosophers of science, there has long been pushback on this theory-focused picture, with texts like Hacking's *Representing and Intervening* and Galison's *How Experiments End* marking important departures.

<sup>173</sup> Cohen, *Benjamin Franklin's Science*, chapter 3.

<sup>174</sup> There is a sense, perhaps, in which the expectation that adding water to one's prime conductor would increase power represents a theoretical position. The simple extrapolation on which this suspicion was based is rather different from the systems of laws and mechanistic hypotheses that typically go under the term.

should we underrate the role of spectacle in securing interest. Kleist's studies were self-avowedly conducted in a spirit of play, and it was in witnessing the itinerant lecturer Archibald Spencer and hearing of the marvelous displays made by European generators that Franklin first decided to begin his studies.<sup>175</sup> Ultimately, what drew experimenters to capacitance was its power to give light, thunder, and "violent emotion," and for decades to come, this is what sustained the field in its search for acolytes and sponsors.<sup>176</sup> As odd as they seem from the theory-focused perspective, these interests are inseparable from the "scientific" curiosity and caution so recognizable to us. If we look closely, we may find them elsewhere, as well.

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<sup>175</sup> Cohen, *Benjamin Franklin's Science*, chapter 4; Heilbron, *Electricity in the 17th and 18th Centuries*, 324–30.

<sup>176</sup> The quote is from "Mémoire sur les nouvelles découvertes qu'on a faites par rapport à l'Électricité," 113.

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## Appendix A: Unpublished Kleist Letters

The following are three previously unpublished letters from Kleist detailing his early studies. They were reported to the Societatis Physicae Experimentalis in Danzig and are available in the Biblioteka Politechniki Gdańskiej. However, the documents were written in Kurrent, a cursive script commonly used in German-speaking countries at the time. This has made them difficult to consult, and perhaps because of this, they have not, to my knowledge, been used in English-language histories. The texts contain important information about Kleist's method and the tools he used, however, supplementing the published letter to Krüger. The text has been as lightly edited as possible, leaving antiquated and erroneous spellings in place. In cases where abbreviations or the writing itself may be unclear, however, bracketed text has been added. An image of two generators similar to those described by Kleist is included at the end of the appendix. Thanks to Dejan Makovec for guidance on several passages and Helen Hunter for the transcriptions and careful editing of the translations.

### *A.1. Original Text*

#### *A.1.1. Kleist to Swietlicki, November 28, 1745*

HochEhrwürdiger, Hochgelahrter Herr,  
Insonders Hochzuehrender Herr *Archi-Diaconus*,  
Liebwehrtester Freund.

Ew[er] HochEhrwürden lieben alles was zur Gelehrsamkeit gehört, mithin auch die *Physicalischen* Wissenschaften. Mir ist bekandt, daß dieselben, nebst andern Gelehrten, sich die Erweiterung der Natur-Lehre auf eine rühmliche art angelegen seyn lassen. Die Stunden, welche Ihnen von dero ordentlichen Amptsgeschäften frey bleiben, können gewiß nicht besser angewendet werden. Wenn ich mir also das Vergnügen mache Ew[er] HochEhrw[ürden] von einigen, wenigstens in ansehung meiner neuen *Electrischen* Erfahrungen zu benachrichtigen; so hoffe daß solches Ihnen nicht unangenehm seyn werde. Villeicht ist Ihnen und dem Gelehrten H[err]n *Professor Hanow* (deßen Freundschaft ich mich bestens empfehle) dieses alles schon bekandt: deßen ohngeachtet aber lasse ich mich nicht abhalten, davon Eröffnung zu thun, weil weder der H[err] *Professor Winckler*, noch auch H[err] *Waitz* in ihren neuen *Electrischen Tractaten* davon etwas gedacht haben. Der geschickte H[err] *Doctor Lieberkühn* aus Berlin schreibt mir gleichfalls unterm 18 Nov: h[uius] a[nni] daß man daselbst hierauf noch nicht hätte acht gehabt.

Seit jahres frist habe ich mittelst der von H[err] *Professor Winckler* beschriebenen so genannten *Giessingschen Machine*, alle nur bekandte *Electrische Experimenta* nachgemacht, und bin darin

nach meiner Meynung nicht unglücklich gewesen. d[en] 11 O[ktober] h[uius] a[nni] sind mir folgende *Experimenta* zur Hand gekommen.

1.) Bis anhero ist nicht wahrgenommen worden, daß aus *Electrisiertem* Holtze von selbst Blitze und schießenden Strahlen hervordringen, sondern wenn an demselben sich einiges Licht zeigen sollen, hat sich etwas unelectrisches nähern müßen.

Allein, man darf nur eine Rolle, worauf drat[h]en[d]e Sayten gewesen auf ein gläsernes Röhrchen von einem *Thermometro* oder *Barometro* stecken, die Rolle *Electrisiren*, so zeigen sich die von selbst heraus schießende Strahlen und Blitze gar bald. Daß Holtz und Röhre recht trocken und allenfalls etwas erwärmet seyn müßen, verstehet sich von selbst.

2.) Auf dieses Rollchen wird ein Eyserner Nagel, Scheere [etc.] gesteckt, so strömen die Flammen so wol aus dem Holtze, als aus dem Eysen hervor.

3.) Wenn ein Nagel, starker Meßingner Drath etc. in ein kleines *Medecin* Gläßchen gesteckt und electrisiret wird, so erfolgen besonders starke Wirkungen. Das Gläßchen muß recht trocken, oder auch warm seyn. Ins gemein reibe ich es zuvorhero durch die mit geschabte Kreyde bestreuten Finger. Thut man ein wenig *Mercurium* oder ein paar Tropfen *Spiritus vini* hinein, so geht alles noch besser von statten. So bald das Gläßchen mit dem Nagel von dem *Electrisirten* Glase oder der Röhre weggenommen wird, so äußert sich der flammende *penicillus*, und habe ich mit dieser brennenden *Machine* über 60 Schritt in dem Gemache herum gehen können.

4.) *Electrisire* ich den Nagel stark, welches sich an dem in dem Gläßchen findenden Licht und heraus schlagenden Funken spüren läßt, so kan ich den in einer andern Kammer befindlichen *Spiritus vini* noch damit anzünden.

5.) Wird währendem *Electrisiren* der Finger oder ein Stück Geld an den Nagel gehalten, so ist der herausfahrende Schlag so stark daß Arme und Achseln davon erschüttert werden.

6.) Eine auf Glas, oder blau seyde Schnüre liegende blecherne Röhre, läßt sich durch dieses *Instrument* viel stärker *electrisiren*, als wenn es *immediate* durch die Kugel geschiehet. It[em] Ein auf ein *Electrisches Postement* stehender Mensch.

7.) Wird der blecherne Röhre, wozu ich einen *Tubum* von 15 Fuß gebrauche, auf gewöhnliche art *electrisirt*, und ich halte so dann den in dem Gläßchen befindlichen Nagel daran, und fahre mit *Electrisiren* fort; So sollte man nicht glauben in welche stärke die *Electricität* gesetzt werde, wenn nicht die Erfahrung den besten beweiß darböte. Ich bin versichert, daß bey dergleichen starcken Funcken der HE[rr] *Professor Bose* zu Wittenberg das wiederholte Küßen mit seiner *veneranda venus* wohl hätte sollen bleiben laßen. Ist das Gläßchen Kurtz etwa 2 Zoll lang, also daß die Finger in der erforderlichen *Sphæra activitatis* sich befinden, so schläget der Funcken



aus dem Nagel nach dem Finger zu. Dünnhälsigte Gläser sind ein paar mahl durch den heftigen Schlag zersprenget worden.

Als etwas besonders deucht mir hierbey, daß, wenn das Gläßchen mit dem Nagel in andere fortpflanzende oder nicht fortpflanzende *Matterie* gefügt wird, diese starke Würkung nicht erfolgen wolle. Ich habe es auf Holtz, Metall, Glaß, Siegel-Lack etc. geküttet und *Electrisiret*, allein der *Effect* hat sich nur schwach gezeiget. Der Menschliche Körper muß also hiezu wohl etwas beytragen. Dieser Satz wird bestärket, wenn ich zur zeit noch keinen *Spiritum* anzünden können, außer wenn er in der Hand gehalten worden ist. Es kann seyn, daß die HErrn *Physici* andere erfahrungen haben, davon die Nachricht gar sehr wünsche. Sonst kann ich nach meiner geringen Einsicht nicht begreifen, wie nach den neu *Waitzischen* und andern bishero bekandten *Principiis* möchte erklärt werden, daß in diesem Fall der menschliche Körper eine stärkere Würkung, als Metall, Holtz, u[nd] d[er]g[leichen] hervorbringe. Noch muß ich erinnern, daß dieses alles sich durch reiben einer gläsernen Röhre nicht gut wolle bewerkstelligen laßen. Die *Electricitæt* kan dadurch nicht stark genug erreget werden. Von Ew[er] HochEhrw[ürden] gütigen Freundschaft bin versichert, daß Sie sich nicht werden entgegen seyn laßen, mir hierüber dero Gedankann und Meynungen zu eröffnen, und ob es gleich in Kleinigkeiten bestehet, sich doch zu erinnern: *Quod Natura in minimis sit Maxima*.

Ich sehe dero wehrtem Antwort Schreiben mit verlangen entgegen, und versichere mit besonderer Hochachtung alle mahl zu verbleiben,

Ew[er] HochEhrwürden  
Meines insonders HochzuEhrenden HErrn *ArchiDiaconi*  
Liebwehrtesten Freundes

Dom Camin d. 28. Nov:  
1745/.

Ergebenster Diener  
Kleist.

Schreiben des HErrn von *Kleist* an HErrn *Swietlicki*  
HochEhrwürdiger Hochgelahrter Herr

HochzuEhrender Herrn *Archi Diaconus*  
sehr Wehrtgeschätzter Freund.

Ew[e]r HochEhrw[ürden] geehrteste Zuschriften können niemahlen zu späte bey mir einlauffen. Selbige sind mir zu allen Zeiten angenehm. Meine Begierde mit *Electrischen* Versuchen fortzufahren, wird mehr und mehr rege, da ich das Vergnügen habe, daß das vorhin überschriebene der Gelehrten Dantziger *Physicalischen* Gesellschaft nicht mißfällig gewesen sey. Nur kann ich die Ursache nicht ergründen Warum die von mir gemeldete ungekünstelte Versuche, nicht haben von statten gehen wollen. Die erregte *Electricitæt* ist dazu vermögend genug gewesen, welches ich aus dem zünden des Zugespitzten Apffels und des genetzten Schwammes schließe. Ich bediene mir keiner Kugell, sondern eines in die Drehbanck gespannten 3. biß 4. Zolligen *Cylinders*. Mit der daran gehaltenen Hand, will es so gut nicht angehen alß mit ein ledern mit weicher Kreyde bestreuten Kißen. Ich habe eine kleine Reise Machine Verfertigen laßen, womit eben wie mit der Drehbanck alle Versuche angestellet werden können. Selbige bestehet aus zwey mit gehörigen Spitzen, und einer Schraube versehenen Stange Eisen, an welche Füße mit Holtz Schrauben befindlich, um solche auff ein *Postement* befestigen zu können. Die bewegung des Glases, wird durch einen stählern Drehbogen zu Wege gebracht. Wegen Landes Geschäfte habe ich mich ietzo an die 5. Wochen in Stettin aufgehalten, und daselbst mittelst dieses *compendiösen* Machine alle und jede *Electrische* Versuche mit guten erfolge zu Wege gebracht. Von den Handgriffen habe ich nichts verschwiegen, dahero vermuthe, daß durch Wiederholen ietzo alles werde bewerkstelliget worden seyn. Wenn das Gläserne Röhrchen recht trocken oder auch etwaß warm, und die Rolle gleichfalß ohne Feuchtigkeit ist, so werden die schießende Blitze nicht ausbleiben. Selbige sind nicht *Cylindrisch*, sondern *Conischer Figur*, also daß die Spitze von der Rolle anfänget. Über dem ist es auch wieder meine Erfahrung, daß auß einen stumpff abgerundeten Eisen, nicht dergleichen *Conische* Blitze hervor strahlen solten. Eine Fingers Dicke Eiserne Stange mag an den Enden so abgestumpffet seyn wie sie will, so wird der feurige *Penicillas* sich doch allemahl sehen laßen. Die Gläserne Röhre thut freylich nichts mehr dabey, alß daß sie die *Electricitæt terminiret*; doch aber ist auch gewiß, daß meiner Bemühung ohngeachtet, die Wirkung mit Lack, Pech, blauer Seyde etc. nicht erfolgen will. Stecke ich die kleine Scheere auff die Rolle, so sind die Strahlen gleich da obgleich die Ringe an der Scheere abgerundet seyn. Die Verstärkung der *Electricitæt* durch den in *Medicin* Gläßchen befindlichen Nagell wird nun ein großes Theil mercklicher, Wenn ich eine Röhre von einem *Thermometer* mit einem *Spiritu* halb erfülle, und darin ein Oben mit einer bleynen Kugell versehenen Eysen Draht stecke ohngefähr in dieser Figur:



*Spritus Vini* läßt sich mit diesem kleinen *Instrument* ohne Schwierigkeit anzünden, wenn selbiger auch in einem andern Gemach befindlich ist. Nehme ich aber eine größere Kugell e. g. Wie die Meinige den 3. biß 4. Zoll im *Diameter*, und *Electrisire* den darin in etwas *Spiritu* befindlichen starcken Draht, (an welchen oben [or “eben”] gleichfalß ein Kugel seyn muß) so ist der Schlag so starck daß man solchen mehr alß einmahl nicht außzustehen verlangt. Kinder von 8 biß 9. Jahren werden dadurch von der Stelle wo sie stehen weggeprellet. *Spiritus* läßt sich hiemit nicht bequem zünden; das Gefäß wird enntweder aus der Hand geschlagen, oder doch wenigstens der *Spiritus* Verschüttet. Anfangs war ich eben wie der Gelehrte HE[rr] *Gralath* der Meynung daß die in dem engen Raum des Glases eingeschrenckte *Electrische Materie* und deren *Elasticitæt* diese starke Wirkung hervor bringen müße. Wie ich aber bemerckte, daß ie größer die Gläserne Kugell war, ie stärker auch die Krafft wurde. überdem auch die Gefäße völligen Zufluß der Luft haben, so wurde ich anderen Meynung. Nach den Waytzschen *Principiis*

habe ich mir hievon Folgendes *hypotesin formiret*. *Electrisiren* ist nichts anders, alß einen Körper seiner *Electrischen Materie* berauben. (Waytz §99) ie stärker also ein Körper *Electrisiret* oder beraubet wird, je stärker ist der *Nisus* der ihn umgebenden *Electrischen Materie* wieder in den beraubten Ort einzudringen. Dieses ist die Eigenschafft aller flüßigen *Materien*. Des Nagels oder Drahts Spitze in dem Glase muß mit etwaß Feuchtigkeit umgeben, die äußerste Fläche des Glases und die Hand gantz trocken seyn. Soll ein Körper starck *electrisiret* oder beraubet werden, so ist natürlich daß zuvorhero viel *Electrische Materie* darin befindlich seyn müße. Diese *requisita* finden sich bey dem Nagele und der feuchten *Materie*. Winckler hat schon angemerket daß die *Electricitæt* in seiner Eisernen Stange verstärket werde, wen solche über eine Waßer fläche hinfähret. Dieses stimmt mit dem Versuch überein. Wenn also der Nagell und das *fluidum* in dem Glase starck beraubet oder ausgesogen ist, so folget von selbst daß mittelst der auß dem Menschlichen Körper etc. zuschießenden *Electrischen Materie* dergleiche starcke Wirkung sich ereignen müße. Auff gleiche Weise wird auch klar, warumb eine Stange Eysen stärker *Electrisiret* werde, wenn das gemeldete *Electrische Instrument* dran gehalten wird: Den wenn die Beraubung geschehen, so dringet die *Electrische Materie* durch die Stange auch nach dem Nagell zu. Nagel, Draht und Glaß muß nur gewisse Auß der Erfahrung genommene größe haben. Ist es zu groß so kann die Beraubung schwerlich erfolgen; Ist es zu klein, so ist nicht genug *electrische Materie* vorhanden welche weggenommen werden könne.

Nach meinem wenigen Bedüncken laßen sich hierauß alle *Phænomena* erklären nur aber nicht wie es zugehe, daß e. g: *Spiritus* nicht anderss, alß wenn ich das Glaß in der Hand halte,

entzündet werden möge. *item* setze ich die Kugell mit dem *Electrischen* Draht auf den Tisch, so ist der herausfahrende, oder viel mehr hinein dringende Schlag gantz leise. Halte ich das *Instrument* an eine große Stange Eysen so ist der Schlag gleichfallß geringe, Lege ich aber den Finger an die Stange so wird er starck genug. Es ist nicht einmahl nöhtig, daß die Stange auff die sonst erforderliche *Stative* geleet werde. In der großen Kugell hält sich die *Electricität* sehr lange. Nach Verlauff von Mehr den 8. Tagen habe ich noch etwaß verspühren können. Ein vieles trägt dazu bey, Wenn die Kugell an einem warmen Ort aufbehalten wird. Wenn der geschickte Herr *Gralath* sich die Mühe geben will, diese *Experimenta* zu wiederhohlten so werden ihm von selbstn mehrere Erfahrungen davon zufallen alß ich ihm melden können. Ein angenehmes Schauspiell ist es, wenn ich auff eine lange Stange Baum-Wachs viele Eyserne Nagell so dichte mit den Köpfen stecke, daß sie Funcken geben können. Electrisire ich den äußersten Nagell und berühre das andere Ende so siehet man die Nägell insgesamt leuchten. Ich habe dadurch Leuchtende Nahmen vorstellig gemacht. Dieses und dergleichen gehöret nur zu dem *Electrischen* Spielwercke.

Bey einer Müßigen Stunde bitte ich mich mit dero wehrten Zuschrift zu beehren, übrigens aber die aufrichtigen Versicherung von mir anzunehmen, daß mit vollkommener Hochachtung allemahl seyn und bleiben werde.

Ew[e]r: HochEhrw[ürden]:  
Meines HErrn *Archi Diaconi*  
sehr wehrten Freundes.

*Dom-Camin d: 24 Februarii*  
1746.

Ergebenster Diener  
*v. Kleist*

Schreiben des Herrn von *Kleist* an Herrn *Swietlicki*.

HochEhrwürdiger Hochgelahrter Herr

HochzuEhrender Herr *Archi Diaconus*

Sehr werthgeschätzter Freund

Daß die von mir überschriebene *electriche* Erfahrungen einen guten Fortgang gewinnen, gereicht mir zu einem besondern Verernügen. Ich bin schon zum Voraus überzeugt gewesen, daß die Geschicklichkeit des Herrn *Gralath* es hierin weiter alß ich bringen würde. Diese Vermuthung ist zu meiner Freude eingetroffen. Nur wird durch den Beyfall einer so gelehrten Gesellschaft, und daß dieselbe meiner in den Berlinischen Zeitungen auf eine so gütige Art erwehnen wollen, bey mir ein gewißer Stoltz erregt, welchen dieselbe mir zu gutt halten wird. Wenn in dergleichen Sachen nur erst die Grund worauff es ankombt bekannt ist, so lassen sich durch Schlüssen, und gehöriges Nachdencken unzählige Veränderungen hervor bringen; daß nur Derjenige welcher das Glaß in der Hand hält die Hefftige Würkung empfinden solte habe ich nicht melden können, weil solches wieder meine Erfahrung ist. So wohl dieser alß auch derjenige, welcher den Draht oder die Kugel berührt, erfahren gleiche Erschütterung. Daß von selbst herausfahren der Strahlen aus *electrisierten* Holtze oder Stumpffen Eisen erfolgt bey mir allezeit. Und bey dem *Experiment* mit den Nägeln wird vielleicht vergeßen seyn, daß an dem äußersten Nagell der Finger oder ein Metall in gehöriger Weite gehalten werden muß. Die Stärke der ursprünglichen *Electricität* muß die Weite der Nägel *determiniren*. Es ist nicht einmahl nöthig, selbige in Wachs sondern nur in Holtz zu fügen. Einige Dutzend aneinander liegende silberne Meßer, Gabell und Löffell zeigen eben daßelbe, wann nur der Finger an das äußerste *Objectum* gehalten wird.

Nach den bekandten *Electricchen* Gesetzen kann nur einer den Schlag empfinden, wenn er einen electrisirten Körper berührt. Wenn also der HE[rr] *Gralath* die Kugel und zugleich ein anderer den Drath angefaßt, so ist die Würkung nur bey einem Verspürt worden. Ein anders ist wen viel Persohnen sich dergestalt an einander fügen, daß Funcken erfolgen können. Es ist *par ratio* mit dem *Experiment* der Meßer und Nägel etc. Mit lebendigen Thieren habe ich es noch nicht versucht, glaube aber fast daß ein Vogel einen recht starcken *electricchen* Schlag ohne getödtet zu werden nicht aushalten könne, wenn er nur nicht auff den Tisch gesetzt, sondern in der Hand gehalten wird. Das abrupffen der Federn ist eine nöthige Vorsicht. Schon vor mehr dann Jahres frist habe ich Herrn Professor Wincklern die Nachricht gegeben, daß auff Federspahlen sich die Körper fast eben so starck alß auff blauseydenen Schnüren *electrisiren* ließen.

Die *Beatificationem Bosianam* kann ich nicht vollkommen zu Stande bringen. Mit erwachsenen angekleydeten Persohnen wird es nach meiner Einsicht schwerlich angehen, Schuhe, Strümpffe,

Wolle und Seydenzeug, womit der Mensch bekleidet ist, Verhindern die Völlige Beraubung, welche hiebey doch nothwendig erfordert wird. An den blossen fußen eines auff der *electrischen* [Bande?] stehenden 9. jährigen Knaben habe ich das Leuchten ohne Schwierigkeit zuwege gebracht. Silberne und Goldene Tressen an den Kleydern leuchten gleichfalß, sonderlich wan sie in der Hand gehalten werden. Nimt der *electrisirte* Mensch einen bloßen Degen, Drath etc. in die Handt, so zeigt sich an dem Spitzen der feurige *Penicillus* so bald nur mit dem *electrisiren* der Anfang gemachet wird. So viel ist gewiß daß die gantze *beatification* mit der Verstärckten *Machine* am alle ersten zu bewürcken seyn würde, nur muß man sich bey der Arbeit nicht die Geduld vergehen laßen.

Schieß Pulver wird sich daher nicht zünden laßen, weil es versprudelt, und ohnedem fast auß lauter *electrischen* Theilchen bestehet. Ich habe Kampfffer dicke darauff gestreuet, iedoch ohne erfolg.

Den Dampff eines ausgeblasenen Lichtes anzuzünden hat mir gleichfals nicht gelingen wollen. Es zeigt sich zwischen den Fingern zwar das Feuer aber das Licht hat dadurch nicht angezündet werden wollen. Den also begreiffe ich dieses Zünden, und bin sehr begierig zu wißen, ob ich hierin irre oder nicht. Wird das Licht zum brennen gebracht, so ist es gewiß ein die gröste Auffmercksamkeit verdienender Versuch. *Mon cher ami* werden so gütig seyn, mir mit ein paar Worten davon die Umstände zu melden.

Noch werden sie mir erlauben, Von dem Zünden und den Funcken einige Veränderungen anzuzeigen.

- 1) Warmer Spiritus Vini wird in einem Löffell auf ein trockenes Glast gesetzet, die Verstärckte *Maschine* an den Löffell und der Finger über den *Spiritum* gehalten, so ist das Zünden gleich da.
- 2) Ich *electrisire* ein breites stählernes *Lineal* worauff in ein *Metall* Gefäße eben der *Spiritus* gesetzet wird so zündet der Finger gleichfalß.
- 3) Hält man den Finger in ein großes Gefäß mit Waßer oder nahe über die Waßerfläche läßt die *Machine* an dem andern Ende des Waßers den Schlag thun, so empfindet man den Schlag an dem Finger.
- 4) An ein mit Golde *laquirtes* Uhr gehäuse lege ich den Finger laße an dem Golde den Schlag thun, so empfindet solchen nicht allein der Finger sondern es wird auch die gantze Fläche, zwischen dem Finger und dem *Instrument* erleuchtet.

Waß Herr *Musschenbroek* seit Kurtzem entdecket, komt mit meinem Versuchen im Grunde völlig überein. Der Unterschied ist, daß er fort Anfangs die stercke Wirkung von ohngefahr gehabt, ich aber erst im Kleinen angefangen, und durch Schlüße und Versuche weiter habe

kommen müssen. Die Stärke oder schwäche bey dergleichen Versuchen machen keinen Wesentlichen Unterschied aus. Mit Mittelmäßigen Gläsern den Versuch anzustellen ist bequemer und weniger schädlich alß mit den großen.

Der dasigen Gelehrten Gesellschaft empfehle ich mich zu Beständiger Freundschaft und gütigem Andencken, nebst angefügter Versicherung mit ergebenster HochAchtung allerzeit zu Verbleiben.

*Dom-Camin den 12. Maij*  
*1746*

Meines sehr wehrteschätzten Freundes  
ergebenster Diener  
*von Kleist*

*P: S.* Nach Schließung dieses erhalte ich den hiebey Copeylich einliegenden Brief von HErrn *Professor Winckler* auß Leipzig.

## A.2. Translations

### A.2.1. Kleist to Swietlicki, November 28, 1745

Letter from Mr. von Kleist Dean of the Cathedral Chapter  
in Camin to Mr. Swietlicki dated November 28th, 1745.

Reverend, Highly Learned Sir,  
Venerable *Archdeacon*,  
Dearest Friend.

Your Reverence loves everything that belongs to learning, and hence also the *physical* sciences. It is known to me that you yourself, along with other scholars, have devoted yourself in an admirable manner to the advancement of the natural sciences. The hours in which you are free from ordinary official business certainly cannot be better spent. Thus, if I allow myself the pleasure of notifying your Reverence of some of my new electrical studies, I hope it will not be displeasing to you. All of this may already be known to you and the learned *Professor Hanow* (to whose friendship I heartily recommend myself); nevertheless, I will not be deterred from imparting it, as neither *Professor Winckler* nor Mr. Waitz has considered it in their new *electrical treatises*. Likewise, the skillful *Doctor Lieberkühn* of Berlin writes to me on November 18th of this year that no one there has as yet thought of it.

For a year now, I have been using the so-called *Giessing Machine* described by *Professor Winkler* to replicate all known *electrical experiments* and have, in my opinion, not been without success. On the 11th of October this year, I came across the following *experiments*.

1.) Up to now, *electrified* wood has not been seen to produce flashes and shooting rays of its own accord; rather, if light is to be produced from it, something nonelectric must have approached it.

However, if one only takes a spool on which wire strings have been wound, fixes it on the glass tube of a *thermometer* or *barometer*, and electrifies the bobbin, rays and bolts may be observed, almost at once, shooting out of it spontaneously. That the wood and tube must be quite dry and should ideally be a little warm goes without saying.

2.) If an iron nail, scissors, etc. is stuck to the bobbin, flames stream out of the wood as well as the iron.

3.) If a nail, thick brass wire, etc. is stuck in a small glass *medicine* bottle and electrified, the effects are particularly strong. The bottle must be quite dry or warm. In general, I rub it beforehand with chalky fingers. If you put in a little *mercury* or a couple of drops of *spiritus vini*, things go even better. As soon as the bottle with the nail is taken away from the *electrified* glass



or tube [i.e., the spinning glass or prime conductor], the flaming *penicillus* manifests itself, and I have been able to walk around the room with this burning *machine* for over 60 paces.

4.) If I strongly *electrify* the nail, as can be ascertained from the light inside the bottle and the sparks shooting out, I can even use it to ignite *spiritum vini* in another room.

5.) If the finger or a coin is held against the nail during *electrification*, the issuing shock is so strong that one's arms and shoulders are shaken by it.

6.) A tin tube lying on glass or blue silk cords can be *electrified* much more strongly through this *instrument* than when it is done directly with the sphere. Likewise, a person standing on an *electric pedestal*.

7.) If the metal pipe, for which I use a 15-foot *tube*, is electrified in the ordinary way, and I hold the nail in the bottle to it and continue with *electrification*, one would not believe the strength of electricity reached if experience did not offer the clearest proof. I am certain that with similarly strong sparks *Professor Bose* of Wittenberg would have had to have stopped the repeated kissing of his *veneranda venus*. If the bottle is around 2 inches long, such that one's fingers find themselves in the requisite *sphere of activity*, the spark shoots from the nail to the fingers. Thin-necked glasses have been shattered a few times by the violent shock.

Something that seems particularly noteworthy to me here is that, if the bottle with the nail is placed on other conductive or non-conductive *matter*, this strong effect does not occur. I have cemented it to wood, metal, glass, sealing wax, etc. and electrified it, but the effect produced was only weak. The human body must therefore contribute something to it. This proposition is supported insofar as I cannot presently light any *spiritum* unless it is held in the hand. It may be that the Dons of *Physics* have other discoveries, word of which I am most solicitous to hear. Otherwise, I cannot see from my limited understanding how, under the new *Waitzian* and other hitherto recognized *principles*, one explains that, in this case, the human body produces a stronger effect than metal, wood, and the like. I must also note that all of this cannot be easily accomplished by rubbing a glass tube. The *electricity* cannot be sufficiently excited in this way. I am assured by your Most Reverend's kind friendship that you will not be opposed to informing me of your thoughts and opinions in this matter, and though it may amount to trivialities, one recalls yet again: *Quod Natura in minimis sit Maxima*.

I very much look forward to your esteemed reply, and assure you most respectfully that I shall remain at all times,

Your Reverence,  
My Most Venerable Lord *Archdeacon*  
[and] Dearest Friend's

Camin Cathedral, 28th November  
1745.

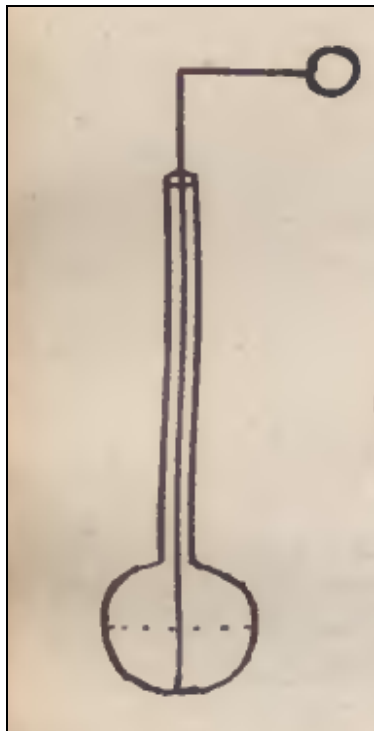
most devoted servant  
Kleist.

*A.2.2 Kleist to Swietlicki, February 24, 1746*

Letter from Mr. von *Kleist* to Mr. *Swietlicki*

Reverend, Highly Learned Sir  
Venerable *Archdeacon*  
Most Esteemed Friend.

Your Reverence's most honored correspondence can never come too late for me. They are pleasing to me at all times. My desire to continue with *electrical* experiments becomes more and more animated, since I have the pleasure of the previous letter not being displeasing to the learned Danzig *Physical Society*. Only I cannot fathom the reason why the artless experiments I reported did not allow themselves to be replicated. I gather from the ignition of the pointed apple and the moistened sponge that the excited electricity was powerful enough for it.<sup>177</sup> I do not use a globe, but a 3 to 4-inch *cylinder* clamped in a lathe [i.e., the *Giessing Machine*]. It does not go as well with a hand held on it as with a leather cushion sprinkled with soft chalk. I had a small travel machine made with which all the experiments could be made just as with the lathe. It consists of two iron rods with appropriate points and a screw, on which feet are placed with wooden screws so as to fasten them to a pedestal. The movement of the glass is brought about by a steel bow drill. Owing to state business, I have stayed in Stettin for around five weeks now.



Here, by means of this *compendious machine*, I have carried out each and every *electrical* experiment with good results. I have not withheld anything with respect to the techniques, so I assume that, with repetition, everything should work. If the glass tube is quite dry or even a little warm, and the spool is also without moisture, the shooting flashes will not fail to appear. These are not *cylindrical* but *conical* in shape, such that the point starts from the bobbin. In addition, it is also contrary to my experience that a bluntly rounded iron should not give off such conical flashes. An iron rod with the thickness of a finger may be as blunted at the ends as you like; the fiery *penicillus* will always be seen. The glass tube does nothing more than *halt the electricity*; but it is also certain that, despite my efforts, the effect does not occur with

ggests a cut apple, but context suggests a skewering. Piercing and electrifying an relatively common display. For a visual, see figure 2.

varnish, pitch, blue silk, etc. If I stick a small pair of scissors on the bobbin, the rays emerge immediately even though the rings on the scissors are rounded. The amplification of *electricity* by the nail in the *medicine* jar becomes much more noticeable when I half fill the tube of a *thermometer* with *spiritu* and stick an iron wire with a lead ball on top inside, as in this figure:

*Spiritus Vini* can be lit with this small *instrument* without difficulty, even if it is in another room. But if I take a larger globe, like mine, which is 3 to 4 inches in *diameter*, and *electrify* the strong wire which is inside in a little *spiritu* (and which must also have a ball on top), then the shock is so strong that one would not wish to endure it more than once. Children of 8 or 9 years are knocked away from where they stand by it. *Spiritus* cannot be easily ignited with this; the vessel is either knocked out of the hand, or at least the *spiritus* is spilled. At first, I was, like the learned Mr. *Gralath*, of the opinion that the *electrical material* enclosed in the narrow confines of the glass and the elasticity of this material must produce this strong effect. As I noticed, however, that the larger the glass globe, the stronger the force also became [and that,] in addition, the vessels also have a complete inflow of air, I formed another opinion. Following *Waitz's* principles, I have *formed* the following *hypothesis*: *Electrification* is nothing other than depriving a body of its *electrical matter* (*Waitz* § 99).<sup>178</sup> Hence, the more a body is *electrified* or deprived, the stronger the *nisus* [i.e., effort or urge] of the surrounding *electrical matter* to re-enter the deprived place. This is a property of all liquid materials. The tip of the nail or wire in the jar must be surrounded by some moisture, the outermost surface of the jar and the hand completely dry. If a body is to be strongly *electrified* or deprived, it is naturally the case that there must first be a lot of *electrical matter* in it beforehand. These *requisita* [requirements] are met by the nail and the damp matter. *Winckler* has already noted that the *electricity* in his iron rod is increased when it passes over a body of water. This accords with the experiment. Hence, if the nail and the *fluid* in the glass are severely deprived or exhausted, it follows of its own accord that the same strong effect must occur by means of the *electrical matter* that shoots out of the human body, etc. In the same way, it also becomes clear why a rod of iron becomes more electrified when the aforementioned *electrical instrument* is held against it: for when the deprivation has occurred, the *electrical matter* also forces its way through the rod to the nail. Nail, wire and glass need only be a certain size, based on experience. If it is too big, the deprivation can hardly take place; if it is too small, there is not enough *electrical matter* that can be removed.

In my humble opinion, all the *phenomena* can be explained from this, but not how it happens that e.g., *spiritus* cannot be ignited except when I hold the glass in my hand. If, for example, I place the globe with the *electric* wire on the table, the shock which issues from it, or rather forces its way into it, is very gentle. If I hold the *instrument* against a large iron rod, the shock is also slight, but if I put my finger on the rod, it becomes strong enough. It is not even necessary for the rod to be placed on the otherwise essential *tripod*. The *electricity* lasts a very long time in the

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<sup>178</sup> *Waitz, Abhandlung von der Electricitat, 28.*

large globe. I was still able to feel something after more than 8 days. It helps a lot if the globe is kept in a warm place. If the skillful Mr. *Gralath* will make the effort of repeating these *experiments*, he will necessarily obtain more knowledge of it than I can report to him. It is a pleasant spectacle when I stick many iron nails into a long stick of resin with their heads so close that they can give off sparks. If I electrify the outermost nail and touch the other end, you can see all of the nails shine. I have brought forth shining names thereby. This and the like amount only to *electrical* toys.

During an idle hour, I ask you to honor me with your worthy letter, but otherwise to accept the sincere assurance from me that with complete respect I will always be and remain

Your Reverence,  
My Lord *Archdeacon*  
[and] Most Esteemed Friend's

*Camin Cathedral, 24th February*  
*1746.*

most devoted servant  
*von Kleist*

A.3 Kleist to Swietlicki May 12, 1746

Reverend, Highly Learned Sir  
Venerable *Archdeacon*  
Most Esteemed Friend

It gives me particular pleasure that the electrical research which I have written about is progressing well. I was already convinced beforehand that the skill of Mr. *Gralath* would take it further than I. To my delight, this assumption has proved correct. Of course, acclaim of such a learned society, as well as their gracious mention of me in the Berlin papers, will stir a certain pride in me, which [the society] will graciously allow me. When, in such matters, the critical cause is but known, innumerable variations can be brought about by inference and proper reflection; that only the one who holds the glass in their hand should feel the violent effect, I cannot report, as this is contrary to my experience. Both this person and the person who touches the wire or the ball experience the same shock. I have always found that rays emerge on their own accord from electrified wood or blunt iron. And in the experiment with the nails, it may have been forgotten that the finger or a metal must be held at a proper distance from the outermost nail. The strength of the original *electricity* must *determine* the spacing of the nails. It is not even necessary to put them in wax, just in wood. A few dozen silver knives, forks, and spoons lying next to one another show the same thing if only the finger is held against the outermost *Objectum* [object].

According to the known electrical laws, only one person can feel the shock when touching an electrified body. Thus if Mr. *Gralath* touches the globe and at the same time another touches the wire, the effect will only be felt by one of them. It is different when a large number of people join together in such a way that sparks can occur. It is *par ratio* [the same rule] with the *experiment* on knives and nails, etc. I have not yet tried it with living animals, but I suspect that a bird could not withstand a very strong *electric* shock without being killed if it were held in the hand rather than placed on the table. Removing the feathers is a necessary precaution. Already more than a year ago, I gave the news to Professor Winkler that bodies could be *electrified* almost as strongly on quills as on blue silk cords.

I cannot fully accomplish the *Beatificationem Bosianam*. It is, in my view, going to be tough to achieve with people in adult garments. Shoes, stockings, wool, and silk items with which a person is clothed prevent the total deprivation which is necessary here. On the bare feet of a nine-year-old boy stationed on *electrical* ribbon[s], I managed to bring about a glow without difficulty.<sup>179</sup> Silver and gold braids on clothes also shine, especially when they are held in the

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<sup>179</sup> Most likely, Kleist is referring to the silk supports on which children were suspended during electrification experiments. There is some doubt as to how “der Bande” in Kleist’s original should be translated, but ribbons has been chosen for ease of reading and comprehension.

hand. If the *electrified* person takes an unsheathed rapier, wire, etc., in his hand, the fiery *penicillus* shows itself on the point as soon as the *electrification* begins. This much is certain, that the whole *beatification* will be accomplished most readily with the amplified *machine*, only one must not let one's patience slip while working.

Gunpowder will not ignite because it sprays out and, in any case, consists almost entirely of electrical particles. I have spread camphor thickly on it, but without success.

I also did not succeed in kindling the fumes of a blown-out light. The fire does appear between the fingers, but the light did not allow itself to be lit by it. For this is my understanding of this kind of ignition, and I am very eager to know whether I am wrong or not. If the light is made to burn, it is certainly an experiment that deserves the greatest attention. *Mon cher ami* will be so kind as to inform me of the circumstances in a few words.

Nor will you begrudge my reporting some variations on ignition and sparks.

1) Warm *Spiritus Vini* is placed in a spoon on a dry glass, the amplified *machine* is held on the spoon and the finger is held over the *spiritum*; there is ignition at once.

2) I *electrify* a wide steel *ruler* on which a *metal* container filled with *Spiritus* is set; the finger ignites it in the same way.

3) If you hold your finger in a large vessel of water or just above the surface of the water, and let the *machine* strike the other end of the water, you will feel the shock in your finger.

4) I place my finger on a watch case *lacquered* with gold and let the gold be stricken, not only does the finger feel it, but the whole area between the finger and the *instrument* is also illuminated.

What Mr. *Musschenbroek* has recently discovered is, at base, completely in line with my studies. The difference is that he more or less had the strong effect from the beginning, while I started on a small scale and had to advance through inferences and experiments. The strength or weakness does not make any real difference in such studies. Carrying out the experiment with regular glasses is more convenient and less harmful than trying large glasses.

To the present learned society, I recommend my lasting friendship and kind remembrance, in addition to the further assurance to always remain with the utmost respect

*Camin Cathedral, 12th May*  
1746.

My highly esteemed friend's  
most devoted servant  
*von Kleist*

*P. S.* After concluding this, I received the letter from *Professor* Winkler of Leipzig, of which a copy is enclosed.

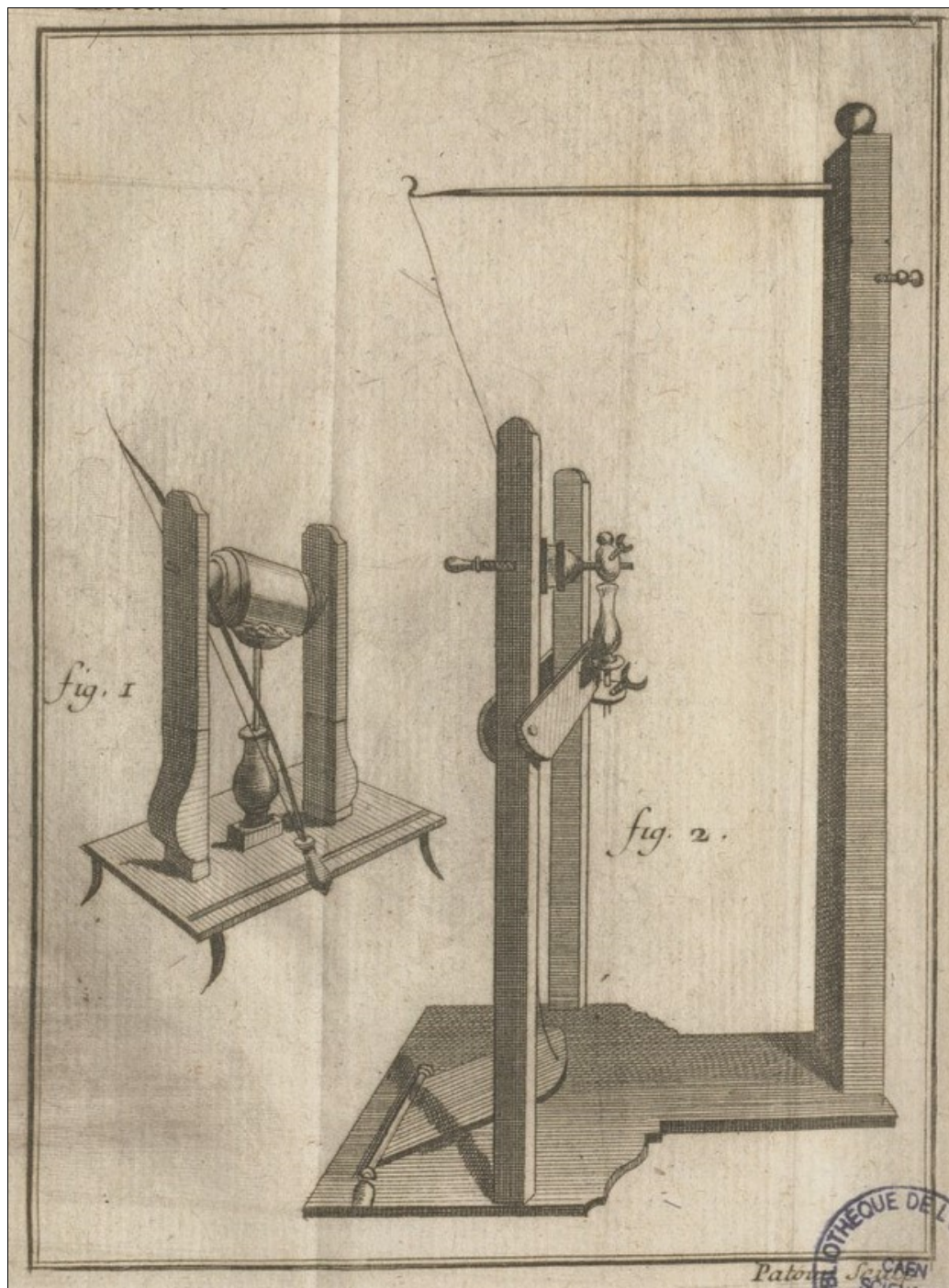


Figure 5. Generators similar to those described by Kleist. The image, taken from de la Fond's *Traité de l'électricité*, depicts a small design attributed to Gordon and the pedal-driven design used by Winkler (image courtesy of the [Bibliothèque nationale de France](https://www.bnf.fr/)).<sup>180</sup>

<sup>180</sup> de la Fond, *Traité de l'électricité*, plate 1.



## Appendix B: Alternative Paths to the Capacitor

Focusing on the details of Kleist and the Leyden group's cases, it is easy to see their discoveries as accidents, and in a sense, they were. Were Kleist not driving his own machine and if Cunaeus had not lifted his glass to the prime conductor uninsulated, neither would have hit upon the design. In examining other investigations active at the time, however, one finds that others were quite close, remarkably so given the brief timeframe (there are approximately two years separating the first published descriptions of the new generators and Kleist's 1745 discovery).<sup>181</sup> Plausibly, these efforts could have hit upon the capacitor in the absence of both Kleist and Cunaeus. Insofar as one is interested in making counterfactually robust claims about the case, then, these alternative paths are worth considering.

Two clusters of work are particularly worth noting. The first involved the electrification of thermometers and barometers (and may have inspired Kleist's eventual choice of a thermometer for a vessel). Mercury barometers had long been known to emit light when rubbed. Following a 1743 report by Ludolff on the attractive force of rubbed barometers, however, the phenomenon gained a renewed interest on the part of electricians, including the Leyden group itself.<sup>182</sup> In retrospect, we can say that the forces underlying these effects are the same as those underlying the Leyden jar—charge on the tube's exterior draws an opposite charge from the mercury along the inner surface—and while the phenomenon was soon absorbed into discussions of the water-based capacitor, it is easy to see the design leading to functional capacitors in the latter's absence. Sticking a wire into the metal and electrifying it directly would have been a fairly straightforward test to make as electricians had a pattern of electrifying by communication substances previously electrified by friction (the common interpretation of the mercury experiments).<sup>183</sup>

The major step, as in the case of the water-filled jar, would have been grounding it. This may not have been such a great hurdle, though, even if we assume no amateur intervention. To start with, it is still possible to obtain weaker but still noticeable blows if a glass is charged in the hand of an insulated assistant. While less efficient than a true ground, the human body has enough free electrons to act as a kind of reservoir or stand-in for earthing.<sup>184</sup> Having observed this, all that an experimenter would need to do would be to notice that this blow was stronger than what was obtained from a glass charged on insulation. Reversing the trend and trying the experimental arrangement on a larger non-electric or on the ground itself yields the capacitor. The path is less

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<sup>181</sup> Gralath, "Geschichte der Electricitat," 279.

<sup>182</sup> Ludolff, "Memoire sur L'Electricite des Barometres," 3–7. The topic was taken up by Allamand, among others. See Trembley, "Part of a Letter from Mr. Trembley," 58–59.

<sup>183</sup> Nollet (*Essai sur l'Electricité des Corps*, 41–44) provides a clear example of the general pattern; Trembley ("Part of a Letter from Mr. Trembley, F.R.S. to Martin Folkes," 58–59) testifies to the frictional electricity in mercury.

<sup>184</sup> Silva and Heering, "Re-Examining the Early History of the Leiden Jar," 314–42.

direct, but given the wide array of exploratory experiments the electricians were willing to try, it is still plausible. A more direct path would have been to notice the sparks that issue from one's hand when bringing it to a vessel hanging from the prime conductor, a phenomenon Winkler observed when bringing a key to the outside of an electrified cup of coffee just prior to the jar's discovery.<sup>185</sup> Following this, all that remains is to discharge the cup, thermometer, or other vessel. (Kleist's surprise at not finding the jar described in Winkler's prior work was not, it seems, without warrant).<sup>186</sup>

A second, and more interesting, possibility stems from work using air pumps. As with the barometer, the air pump had been used in electrical experiments for some time. Francis Hauksbee had found as early as 1705 that rubbing an evacuated glass globe produced a remarkable glow.<sup>187</sup> Like much else in electricity, however, it was the subject of renewed attention in the 1740s, and once again, we find a particularly suggestive line of investigation being pursued by Winkler, who appears to have developed an early vacuum capacitor consisting of a charged pin anchored in the top of an evacuated bell jar and a brass plate at its base. In a series of experiments published in his 1745 book, he describes what resemble current arcs resulting from what would today be labelled a short-circuit:

If there is butter on the plate: different currents run from the end of the pin onto the same, and illuminate the whole surface of the butter so that it can be seen clearly...If a glass black inkwell with ink, the opening of which is an inch in diameter, stands on the plate: the electric rays fill the whole rim in the form of an abbreviated white cone, the base of which ends on the rim of the vessel.<sup>188</sup>

In a set-up that may derive from Bose, he even places something similar to the eventual water-jar inside the chamber:

If a beer glass, in which there is water an inch or two high, is placed under the bell, so that the pin goes several inches deep in the middle of the opening of the glass: various electric streams run down the length of the sides of the glass bell; and the electrical matter which comes out of the pin illuminates the whole beer glass, and the surface of the water and the bottom of the glass, so that in those parts of the water that touch it one can

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<sup>185</sup> Winkler, *Die Stärke der electrischen Kraft*, 28–30.

<sup>186</sup> See Kleist to Krüger, 19 December, 1745, 177.

<sup>187</sup> Hauksbee, "An Account of an Experiment Made before the Royal Society at Gresham College," 2277–82.

<sup>188</sup> The original reads:

Liegt Butter auf dem Teller: so fahren verschiedene Ströme aus dem Ende des Stifts auf dieselbe, und erleuchten die ganze Fläche der Butter, dass man sie deutlich sehen kann...Stehet ein gläsernes schwarzes Tintenfass mit Tinte, dessen Oeffnung einen Zoll im Diameter hat, auf dem Teller: so erfüllen die electrischen Strahlen den ganzen Rand, in Gestalt eines abgekürzten weissen Kegels, dessen Grundfläche sich auf dem Rande des Gefäßes endiget. (Winkler, *Eigenschaften der Electrischen Materie*, 71–72.)

see very many bright points.<sup>189</sup>

The vacuum design lacks the jar's simplicity and ease of use, and it is clear from the surrounding description that Winkler does not realize the implications of the arrangement. Yet, the set-up is, functionally speaking, a capacitor, and the phenomena described are sufficiently eye-catching as to make further investigation plausible. The sparks are considerably more impressive than typical discharges from a prime conductor, and in fact, one of the jar's many uses was the creation of streams of light like those described.<sup>190</sup>

Supposing the design was able to gain traction, however, the community would have been studying the same phenomenon as they did with the jar, picking up a loose thread of Hauksbee's just as they had in the case of the generator. What this would mean for the history of electricity as a whole is difficult to say. It is quite possible that the technology would have been limited to the study of vacuum discharges or gasses. If at any point the experimenters made contact between the base and prime conductor, though, they would be in for a shock, and the odds of this happening are significant.<sup>191</sup> A deliberate attempt to bring pin and base together is not out of the question, and the chances of a connection made in the course of day-to-day study or as a result of residual charge are non-negligible. As with the barometer case, nothing necessitates this specific turn of events, but it is relatively probable, and this is enough to raise doubts for the luck narrative insofar as it implies the unlikelihood of discovery or a dependence on some specific happenstance. Any one case may depend on sufficiently many contingencies to seem accidental, but with enough chances, these contingencies cease to matter. As one of Gralath's Leyden correspondents noted of the jar's discovery: "provided one accumulates *experimenta experimentis* all sorts of ways, one cannot fail to observe something new."<sup>192</sup>

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<sup>189</sup> The text continues:

Setzt man ein Bierglas, in welchem einen oder zween Zoll hoch Wasser ist, unter die Glocke, dass der Stift etliche Zoll tief mitten in die Oeffnung des Glases gehet: so lauffen verschiedne electrische Ströme an den Seiten der gläsernen Glocke der Länge nach herab; und die electrische Materie, welche aus dem Stifte kommt, erleuchtet das ganze Bierglas, und die Oberfläche des Wassers und den Boden des Glases, dass man in denen ihn berührenden Theilen des Wassers sehr viel leuchtende Punkte erkennen kann. (Winkler, *Eigenschaften der Electrischen Materie*, 72.)

<sup>190</sup> Nollet, *Recherches sur les Causes Particulières des Phénomènes Électriques*, 425–27.

<sup>191</sup> Nollet, *Recherches sur les Causes Particulières des Phénomènes Électriques*, 425–27. According to Nollet, the experience is indistinguishable from the original Leyden experiment.

<sup>192</sup> Gralath, "Geschichte der Electricitat, Zweyter Abschnitt," 431.

