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Re-examining the early history of the Leiden jar: Stabilization and variation in transforming a phenomenon into a fact

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Abstract
In this paper, we examine the period that immediately followed the invention of the Leiden jar. Historians of science have developed narrations that emphasize the role of grounding during the process of charging the jar. In this respect, this episode shows significant aspects that can be used to characterize science, scientific knowledge production, and the nature of science. From our own experimentation, we learned that grounding was not necessary in order to produce the effect. These experiences inspired us to go back to primary sources. In doing so, we came to a new understanding of the early period after Kleist's and Musschenbroek's initial creation of the effect. From our analysis, we conclude that it is not the grounding which was perceived as a major innovation (as well as a challenge) during this early period of the discussion but the concept of an electrical circuit. This understanding was fundamental in characterizing the Leiden jar as a new device challenging the then current knowledge of experimental practices in the field of electricity.

Keywords
Electricity, Leiden jar, experimental practice, replication method, exploratory experimentation

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Introduction

This paper analyzes the experiments and related discussions in the eighteenth century between the first accounts of the Leiden jar and Franklin's interpretation of the device. The Leiden jar, or the electric condenser as it is nowadays called, is a device that stores electricity and enables discharges that are increased compared to those which can be achieved with an electrostatic generator. The jar (to stay with the classical design of the condenser) is a phial filled with water with a rod that is inserted in this water. The grounded experimenter holds it in one hand and draws sparks from the prime conductor of the electrical machine.[1] When the experimenter touches the nail with the other hand (while still holding the bottle), she or he experiences a severe shock.

When we look at typical accounts by historians of science, we find a narrative that demonstrates the superiority of 'experts' to 'amateurs' – in this case with respect to placing sufficient emphasis on the necessity of grounding the jar while charging it. When redoing some of the experiments from the very early period, we realized that the Leiden jar can be charged without grounding – this is in contradiction to historians' accounts. As a result, we went back to the primary sources, analyzing in particular the period immediately following the first accounts of the device. In doing so three communities were prominent, namely the ones in France, London, and the German-speaking areas.[2] From this analysis, it became evident that the early period following the first accounts has to be told differently. In particular, it was not grounding that posed a challenge and led to a new understanding, but the concept of the electrical circuit. From this discussion, questions about the historiography arise which will be discussed in the final section of this paper.

The common history of the invention of the Leiden jar

In this section, we are going to summarize the historians' account of the invention of the Leiden jar. In this respect, it appears to be useful and justified to follow the discussion by John Heilbron, who more than 35 years ago published his study *Electricity in the 17th and 18th Centuries* – a monograph that is still the standard in the field. Heilbron points out at the very beginning of the chapter on the invention of the Leiden jar: "The circumstances surrounding the invention of the condenser should interest the philosopher as well as the historian of science. … Its invention … was a true discovery, the finding of something opposed to expectation, a piece of serendipity on the part of two unpracticed operators."[3]

1. A typical electrostatic generator in the mid-1740s consisted of a cylinder or sphere (in most cases from glass), a cushion, and a metallic prime conductor. The rotating glass was rubbed with the cushion, thus separating charges on the glass and the cushion. The charge from the glass was collected on the prime conductor, which was in most cases a metal cylinder or sphere. For a discussion of the technical development of electrostatic generators in the eighteenth century, see Willem D. Hackmann, *Electricity from Glass: The History of the Frictional Electrical Machine 1600-1850* (Alphen aan den Rijn: Sijthoff & Noordhoff, 1978); Heiko Weber, *Die Elektrisiermaschinen im 18. Jahrhundert* (Berlin: VWB, 2011).
2. Table 1 summarizes the analysis of primary sources.

This statement is typical of the accounts that are developed by historians as well as by philosophers of science concerning the invention of the Leiden jar.[4] The experiment contradicts the then-established rules of how to carry out electrical experiments. Thus, it is entirely unexpected and unpredicted; moreover, "the condenser flagrantly violated received principles of electricity. The electricians were no more able to explain the jar than was the general public who came to witness its powers. Their theories had ceased to predict the outcome of events … Frank admissions that the jar had shattered accepted theory appeared on every side."[5] Consequently, it was only possible for people not familiar with experiments in electricity to discover the effect.

Three central figures are related to this discovery: Ewald Jürgen von Kleist (1700–1748), Andreas Cunaeus (1712–88), and Pieter van Musschenbroek (1692–1761). Following the accounts by the historians, Kleist was the first to make this discovery. He was an enthusiast about electrical experimentation, but the "remoteness of his situation and the press of business, however, prevented him from ever quite mastering the subject, and so it was that, initially, he doubted the novelty and overlooked the importance of his discovery."[6] However, Kleist did communicate his findings a couple of weeks after the first experiments – at first to Johannes Nathaniel Lieberkühn, who was a member of the Berlin Academy of Sciences. After having learned through the response that the phenomenon was a novelty, Kleist introduced four other scholars. According to Heilbron,

> Kleist described his new power to at least five persons, of whom one was a veteran professor of experimental philosophy (J.G. Krüger) and one an able member of the Berlin Academy (J.N. Lieberkühn). None was able to reproduce his results. … He [Kleist] had forgotten to emphasize the counter-intuitive step that made a condenser from a nail in a bottle: he did not say that the experimenter must grasp the outside of the bottle and stand on the floor during electrification; he did not say that the bottle's exterior must be grounded.[7]

Additionally, according to Heilbron, Kleist's description caused more problems as he had not specified that the person holding the bottle is supposed to discharge it – when two people do this, the experiment does not work and this was another problem in the reproduction of the effect:

3. John L. Heilbron, *Electricity in the 17th and 18th Centuries: A Study in Early Modern Physics* (Mineola: Dover, 1999), p.309.
4. However, Hochadel argues that in the case of the Leiden jar the discovery was "literally in the air. … In this condensed atmosphere of rotating glass spheres and electrified jars, the discovery was just a question of time." Oliver Hochadel, *Öffentliche Wissenschaft: Elektrizität in der deutschen Aufklärung* (Göttingen: Wallstein, 2003), p.54.
5. Heilbron, *Electricity in the 17th and 18th Centuries*, p.315 (note 3). It has to be remarked though that Nollet, for example, did not see his theory being violated by the jar.
6. Heilbron, *Electricity in the 17th and 18th Centuries*, p.309 (note 3).
7. John L. Heilbron, *Elements of Early Modern Physics* (Berkeley; Los Angeles; London: University of California Press 1982), pp.183–4; see also Heilbron, *Electricity in the 17th and 18th Centuries*, p.311 (note 3). Among the other correspondents was Schwidlitzky, who was a member of the *Danziger Naturforschende Gesellschaft* and who communicated this letter to this Society.

> In the unsuccessful experiments, something stronger than usual must have been felt; but, owing to the small condenser and the poor grounding, nothing worthy of remark. Also, if two men discharge the jar, the shock passes through the arm, side, leg, and semi-insulating shoes, whereas if one man acts alone, it runs through both arms and across the breast, a much more sensitive path.[8]

A few months after Kleist's initial experiment, the effect was independently discovered in Leiden, Netherlands. There, Pieter van Musschenbroek carried out experiments in which he electrified water.[9] However, when Andreas Cunaeus, who was, like Kleist, an amateur, repeated the experiment he had seen at Musschenbroek's laboratory, things took a different turn: "He was alone; he was not an adept; he knew nothing of the Rule of Dufay. He electrified the water-filled jar in the manner most natural to him, holding it in his hand; lacking assistance, he drew the spark himself, and transformed [the initial experiment] into the terrible Leiden jar."[10] Cunaeus told Musschenbroek and his colleague Allamand about his experience – they were able to reproduce the same experience, and Musschenbroek wrote a letter to the Paris Academy of Science.[11] According to Heilbron, "Musschenbroek's very clear, professional account, very different from the murky letters of von Kleist, enabled any informed and courageous reader to reproduce Cunaeus' experiment."[12]

To summarize this account so far: two amateurs managed to get severe shocks and to create an effect that materializes itself in the Leiden jar in part due to their being amateurs and not knowing Dufay's Rule. Dufay's Rule stated that objects that were to be electrified must rest on 'electric' bodies (bodies that can be easily electrified by friction, for instance, glass and wax).

The first of these amateurs, Kleist, did not manage to communicate the crucial details of his experiment adequately; consequently, none of his correspondents were (initially) able to repeat the experiment. The second, Cunaeus, had the opportunity to show the experiment to Musschenbroek, who was able to repeat the experiment and to communicate it in a clear and professional mode to the Paris Academy.

According to historians of science, there were at least three central problems that caused difficulties for the practitioners in realizing the experience. First of all, it was necessary to ground the person who charged the jar. Second, how the jar was discharged was crucial – this had to be done by the same person who was holding the jar. Third, there was a conceptual problem – the jar violated Dufay's Rule.

Similar descriptions can be found in a number of publications that discuss or mention the invention of the Leiden jar.[13] H. Otto Sibum and Jörg Meya place particular emphasis

8. Heilbron, *Electricity in the 17th and 18th Centuries*, p.312 (note 3).
9. According to Heilbron, "G. M. Bose: The Prime Mover in the Invention of the Leyden Jar?" *Isis* 57 (1966): 264–7, 265, these experiments were based on an idea by Georg Matthias Bose: "the production of sparks with the help of water." As electricity was related to fire, drawing the matter of fire from water appeared an interesting approach.
10. Heilbron, *Electricity in the 17th and 18th Centuries*, p.313 (note 3).
11. On Cunaeus' role in the invention of the Leiden jar, see Heilbron, "G. M. Bose" (note 9).
12. Heilbron, *Electricity in the 17th and 18th Centuries*, p.314 (note 3).
13. For example, see Jessica Riskin, *Science in the Age of Sensibility: The Sentimental Empiricists of the French Enlightenment* (Chicago: University of Chicago Press, 2002); Allan Mills,

on the role of grounding in stating that the lack of success of Kleist's correspondents in reproducing the effect results from his failure in making grounding explicit.[14] Likewise, Sibum emphasizes that the grounding is the crucial step; according to his account, the reproduction of Kleist's experiment by the Danzig Academy had to fail: a person standing insulated was charging the jar; another person was trying to discharge it and got only a weak shock.[15] However, Sibum also emphasizes the role of the human body in the experiment, which had been insufficiently pointed out in Kleist's letter.[16]

In another classic study on the history of electricity, Roderick W. Home does not mention Kleist, but simply tells the story of Musschenbroek's invention and its role in the theoretical development of electrical research. Here, according to Home, the fact that the experimenter stood on the floor while holding the glass (that should be permeable to the electric fluid) caused a substantial problem.[17]

To summarize, two amateurs discovered the Leiden jar, and the necessity of grounding the experimenter while charging the jar posed a major problem in replicating the experience for the contemporaries, particularly for the recipients of Kleist's letters.

Confusing experiences

When we started with this research project, a particular aspect in our approach was the intended methodology. Similarly to the studies carried out with the replication method, we intended to use self-reflected experiences from re-enactments of experimental procedures with the aim of developing a more thorough understanding of experimental practices as well as of the difficulties in communicating the experience of the experiment.[18] To this end, we started working with small Leiden jars and a reconstruction of an early nineteenth-century electrostatic generator that had been designed for teaching purposes.

Initially, we began following the accounts of historians of science: ground yourself; charge the bottle (gently, to be frank) by drawing sparks from the prime conductor of the

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"Studies in Electrostatics Part 6: The Leyden Jar and Other Capacitors," *Bulletin of the Scientific Instrument Society* 99 (2008): 20–22; and Sara J. Schechner, "The Art of Making Leyden Jars and Batteries according to Benjamin Franklin," *eRittenhouse* 26 (2015): 1–11. An exception in this respect is Patricia Fara, *An Entertainment for Angels: Electricity in the Enlightenment* (Cambridge (UK): Icon Books, 2002), who does not mention grounding at all.

14. Heinz O. Sibum and Jörg Meya, *Das fünfte Element: Wirkungen und Deutungen der Elektrizität* (Reinbek bei Hamburg: rororo, 1987), pp.64–6.
15. Heinz O. Sibum, *Physik aus ihrer Geschichte verstehen* (Wiesbaden: DUV, 1990), pp.165–70.
16. Ibid.
17. Roderick W. Home, *The Effluvial Theory of Electricity* (New York: Arno Press, 1981), p.146.
18. For an example of studies based on the replication method see Peter Heering, Falk Riess and Christian Sichau (eds.), *Im Labor der Physikgeschichte: zur Untersuchung historischer Experimentalpraxis* (Oldenburg: Bis, Bibliotheks- und Informations system der Universität Oldenburg, 2000); Olaf Breidbach, Peter Heering, Matthias Müller and Heiko Weber (eds.), *Experimentelle Wissenschaftsgeschichte* (Munich: Wilhelm Fink Verlag, 2010), pp.13–72; and Klaus Staubermann, *Reconstructions: Recreating Science and Technology of the Past* (Edinburgh: National Museums Scotland, 2011).

electrostatic generator; and discharge it through one's body.[19] As everything worked as expected, we were discussing how to increase the strength of the charge and discharge, whether this was an issue for historical actors, and whether there could be some fear with respect to this experience (what we at that time called the 'coward effect'). To modify the experiment safely, we started with the experimenter standing on an insulating stool. Surprised, and literally shocked, we felt a significant concussion when discharging the bottle after it was charged without being grounded. Having repeated this experience a couple of times, always with the same result, we blamed the insulation and started improving it – but continued to feel strong effects. Apparently, and contradicting the initial expectation, it is possible to receive a significant shock with a Leiden jar held by an insulated person during the process of charging.

In this course of experiments, we used both small glass bottles that were filled with water and held in the hand as well as bottles of different dimensions that were covered from the inside as well as from the outside with tin foil, thus providing better control over the capacity. As insulation, we worked with an insulating stool that had glass rods as feet and, when in doubt whether this might be sufficient, also used a large cube of Styrofoam as well as insulting plates made of plastic. We worked in different rooms as well as in the open air, thus trying to control for unintentional insulations. We also worked barefoot, again to make sure that we were properly grounded.

In the course of our experiments, things got more and more complicated. We checked the quality of the insulation (as well as the quality of the grounding); we rated the effect of the discharge in terms of our physiological reaction; we tried to increase the effects while at the same time being scared of the blows. In some respects, the more we tried to structure our experimental experiences, the more confused we became. However, one detail remained indisputable: it was possible to get a shock that we rated as substantial from an electrified phial filled with water even when one was insulated while charging the bottle.

This result appeared to contradict what we thought we knew about the Leiden jar. With some effort, we were finally able to make sense out of these experiences from the current scientific point of view. From our understanding, the capacity of the insulated human body is large enough to provide sufficient charges in order to make the bottle work as a Leiden jar even when the body is insulated. However, as historians, we remained puzzled. Therefore, we decided to go back to the original sources.[20]

Introducing the phenomenon: Kleist and his bottle

None of Kleist's original letters could be located; however, some of his contemporaries published either these letters or at least a summary of them.[21] In his publication on the

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19. Drawing sparks from the generator instead of touching it directly with the metal rod was based on the idea that in this manner some control of the amount of electricity that went into the jar could be provided.
20. The primary sources we are using also form the basis of Heilbron's account. However, unlike Heilbron, we read these sources with the experience of working with the Leiden jar ourselves, and this has shifted emphasis and enabled us to develop a different perspective.
21. There are several publications which refer to different letters written by Kleist. The different versions do not contradict each other; however, the letters have a slightly different wording.

Leiden jar, which appeared in 1746, Johann Heinrich Winkler summarizes a letter he had received from Kleist and which dates May 15, 1746. In this letter, Kleist apparently gave a chronology of the events. According to Winkler's summary, Kleist had carried out the experiment for the first time on October 11, 1745. He then communicated it to Lieberkühn in Berlin on November 4 and December 16, to Schwidlitzky in Danzig on December 28 and February 24, to D. [sic] Krüger in Halle on December 19 and March 17, and to the Professors of the Lower Lusatian Ritterakademie on March 6.[22] However, Kleist had "by none of them received a response that the experiment had been working, until finally, Mr. Gralath from Danzig sent the desired message on April 10 saying that he had succeeded in the experiment."[23] According to Winkler's account, Schwidlitzky reported to Kleist that initially Gralath had failed to reproduce the effect as the latter had not communicated that the person who is supposed to experience the strong effect has to hold the bottle in his hand. Gralath had realized this omission fairly quickly and had succeeded in reproducing the experiment on March 5.[24]

Two publications help to understand what Kleist may have been doing (and communicating) – one by Johann Gottlob Krüger, who published two letters he had received from Kleist, the other by Daniel Gralath, who was another recipient of Kleist's letters.

In his 1746 monograph *Geschichte der Erde in den allerältesten Zeiten*, Krüger added some further electrical observations that were to be seen as additions to his previous monograph devoted to this field.[25] He concludes his monograph by reprinting Kleist's letters, "as they contain new experiments." [26]

In the first letter, Kleist described a series of eight experiments and documents a development that ends with what we would call the Leiden jar. Kleist starts [1] with a wooden reel that is placed in a small glass tube; when the reel is electrified, luminous

22. From Lieberkühn's response, Kleist learned that his findings were new; in the following letters he was trying to enable scholars to reproduce them.
23. Johann H. Winkler, *Die Stärke der elektrischen Kraft des Wassers in gläsernen Gefässen: welche durch den Musschenbrökischen Versuch bekannt geworden* (Leipzig: Bey Bernhard Christoph Breitkopf, 1746), p.3. According to Gralath's account, the first letter to Schwidlitzky, dated November 28th, 1745, in Daniel Gralath, "Nachricht von einigen Electrischen Versuchen," *Versuche und Abhandlungen der naturforschenden Gesellschaft in Danzig* 1 (1747): 506–34.
24. This account corresponds to the one published by Gralath, "Nachricht" (note 23). From Winkler's account it is unclear whether Gralath communicated the successful repetition of the experiment and then Schwidlitzky sent an additional communication describing the circumstances of this success, or whether the information of Gralath's success also resulted from Schwidlitzky's communication. Winkler's account can be found in Winkler, *Die Stärke*, p.4 (note 23).
25. Johann G. Krüger, *Geschichte der Erde in den allerältesten Zeiten* (Halle: Lüderwaldische Buchhandlung, 1746), Johann G. Krüger, *Zuschrifft an seine Zuhörer, worinnen er ihnen seine Gedancken von der Electricität mittheilet, und ihnen zugleich seine künftige Lectionen bekant macht* (Halle: Carl Herrmann Hemmerde, 1745).
26. According to Winkler's description, the letters published by Krüger date December 19th, 1745, and March 17th, 1746, Krüger, *Geschichte der Erde*, p.176 (note 25).

effects are visible (the visual aspect of luminous effects appears to be a central issue to Kleist).[27] He modifies this set-up [2] by inserting an iron nail in the reel; luminous effects are visible from the wood and the metal. Then he abandons the wood and [3] experiments with a small empty medical flask in which a nail is placed – when this is electrified and separated from the prime conductor, a brush of light is visible.[28] When the nail is strongly electrified, [4] it is possible to ignite alcohol (spirit of wine) or turpentine in the next room. [5] If an object or a finger or a metal bar is brought to the nail during the electrification, severe shock results. [6] An insulated metal tube can be electrified much more strongly with this apparatus than with the prime conductor. Likewise, alcohol can be ignited, and the same is possible with an insulated person [most likely the person cannot be ignited but strongly electrified]. When the metal cylinder is electrified in the usual manner, [7] Kleist holds the nail which is in the phial against the tube and continues electrifying, and the strength of electricity is significantly higher. [8] A metallic instrument is inserted into a glass sphere containing some liquid and is charged in the usual manner.[29] In this case, very strong electricity is also produced; one would not allow oneself to be subjected to the emitting shock more than once. Kleist notes that it is not possible to ignite alcohol as the spoon is knocked out of the hand, or the spirit gets spilled. If the instrument is charged with the tube, the same force is shown from the tube, as well as with a person on an [insulating] square.

Kleist remarks that it appears notable to him that the strong impact can only be produced in the hand. No alcohol can be ignited when the spoon is placed on the table. Even if the instrument is electrified vigorously and placed on the table, and a finger is held close, no spark can be observed. However, when Kleist takes the phial again in his hands without electrifying it anew, it shows the initial strength. In a postscript, he mentions that he had used a small sphere from a thermometer to carry out this experiment. He filled half of the sphere with water and placed a wire with a ball in the tube (see Figure 1).[30] When this ensemble is electrified, the convulsion is stronger than the one obtained with the medical flask. The shock is severe, and the phial can ignite alcohol easily.[31]

27. The emphasis on the luminous appearance is remarkable in the context of the German speaking community: Herr observed that, until the late 1730s, the electrical machine was limited to the experimental context of electrical luminous effects; see Wiebke Herr, *Spät und scheinbar plötzlich. Zu den Hintergründen des markanten Etablierungsverlaufs der Elektrizität (1730-1748)* (Laatzen: Wehrhahn, 2012), p.258.
28. Even though Kleist mentions that some mercury or alcohol in the flask would improve the effect, it does not seem that the nail is inserted in the liquid.
29. It is not clear from the text what he refers to by speaking of the metallic instrument; this might be what is later referred to as the nail.
30. It is not clear whether Kleist had included a sketch in his communication to Krüger or whether this image is based on Krüger's interpretation of the text.
31. Kleist, see Krüger, *Geschichte der Erde*, pp.177–81 (note 25). The letter Kleist had sent to Swietlicki is summarized in Daniel Gralath, "Geschichte der Electricität: Zweyter Abschnitt," *Versuche und Abhandlungen der naturforschenden Gesellschaft in Danzig* 2 (1754): 355–460, 407 – its content as well as its structure appears to be very similar to the one reproduced by Krüger.

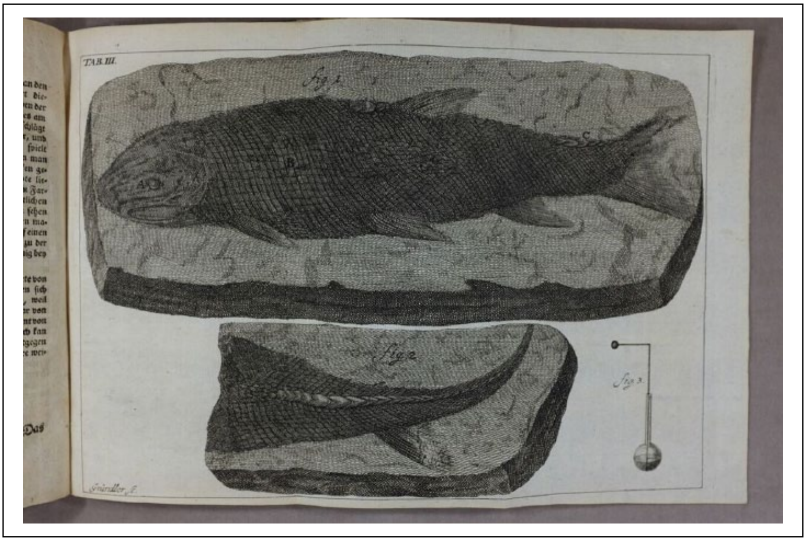

Figure 1. Krüger's representation of a sphere with water with a wire (with permission of The Bakken Museum, Minneapolis).

Krüger published a second letter Kleist had written to him. In this letter, Kleist mentioned that the Danzig Society had likewise not been able to repeat his experiments (which can be seen as an indication that Kleist got a similar response from Krüger). In the following, Kleist describes his electrical machine (to which an insulating stool belongs) and some experiments with the device he called an "electrical thermometer." He could ignite alcohol with this instrument, even in a room next door. However, Kleist stresses again that it is necessary to hold the jar in the hand while discharging.[32]

The other relevant publication to understand what Kleist had been communicating is from Daniel Gralath (1708–67), a central figure of the *Danziger Naturforschende Gesellschaft* (the Danzig Society mentioned above). Gralath himself had not been the addressee of Kleist's letters, but Swietlicki, who communicated these letters to the society. Gralath made several unsuccessful attempts to reproduce Kleist's experiment, the first one on December 14th, 1745.[33] In response to Gralath's request for more detailed information, Kleist pointed out that the experiment would work better if the tube of a thermometer half-filled with alcohol were used. In the end, it was during a joint experimentation on March 5, 1746, that one of Gralath's collaborators, the naturalist Gottfried Reyger (1704–88), managed to get the intended effect. He held with one hand the small medical bottle with the nail toward the electrified prime conductor and approached the nail with the other hand, thus finally solving the problem. Each person in the room repeated the experience and got the intended effect. However, when Gralath used a larger

32. Kleist, in Krüger, *Geschichte der Erde*, pp.181–4 (note 25).
33. Gralath, "Geschichte der Electricität", p.409 (note 33).

phial filled with water the effect was significantly stronger and hardly anyone dared to make the experience more than once.[34]

Kleist was informed about the results by Swietlicki on April 10, 1746; he responded in a letter on May 15 which contained a remark that irritated Gralath significantly: “I have not been able to report that only the one who is holding the glass in his hand feels the shock, as this is against my experience. This one as well as the one who is touching the wire or the sphere experience similar shocks.”[35]

However, at the time when Gralath finally succeeded in reproducing Kleist’s findings, Musschenbroek’s experiment was already known – Nollet responded to a communication from Gralath’s colleague Samuel Wolff that he is familiar with a similar experiment that “was at first made known in the French journals on April 1, [1746].”[36]

In summary, the analysis of Kleist’s letters reveals an evolution: starting with experiments on luminous discharge effects and ignition of liquids, Kleist concludes his series of experiments with a device that appears to be a Leiden jar without the water. However, the crucial effects were already detected according to these accounts when no water had been in the jar – the design of the jar as we connect it with Kleist is only added in a postscript to the first letter.

Above all, it is evident that Kleist’s correspondents did not blame him for omitting the necessity of the experimenter to ground the outer side of the jar while charging it. Instead, the central problem appeared to be that they were not aware of the necessity to touch the inside and the outside of the jar at the same time in order to discharge the jar and to create the shock (through touching the wire or the prime conductor if it is still connected to the wire).

Introducing the phenomenon: Musschenbroek’s letter

The Leiden jar became known to the scholarly world (and immediately also to the rest) from a letter (written in Latin) of Musschenbroek to Réaumur, dating January 1746. Quite remarkably, the reader of this letter might not get the impression that something spectacular is communicated as it starts with the phrase “As I see that this sheet … is not completely filled, I would like to tell you about a new but terrible experiment.”[37] In the following, Musschenbroek described the experiment (according to Heilbron’s translation, the main emphasis is laid on the necessity that one person carries out the experiment): “in my right hand I held the globe D, partly filled with water, into which the wire dipped; with my left hand E I tried to draw the snapping sparks that jump from the iron

34. Ibid.
35. Ibid., p.411.
36. Gralath, “Nachricht,” 512 (note 23). According to Gralath’s description, the results of these experiments were communicated immediately: Samuel Wolf wrote on March 9th to the Abbé Nollet, and received a confirmation that had been written almost two months later (May 9th) in which the Musschenbroek experiment was communicated (Gralath, “Geschichte der Electricität,” p.409 (note 33)).
37. Musschenbroek, translated in Heilbron, *Electricity in the 17th and 18th Centuries*, p.313 (note 3).

tube to the finger."[38] Then, other precautions were mentioned, among them grounding: "Suffice it that the man should stand directly on the ground, that the same one who holds the globe should draw the spark; the effect is small when two men participate, one grasping the globe and the other pulling the sparks."[39] It should be noted that, in their translation of the same sentence, Roller and Roller put a slightly different emphasis:[40] "The person who tries the experiment may simply stand on the floor, but it is important that the same man hold the flask in one hand and try to draw the spark with other; the effect is very slight if these actions were performed by two different persons."[41]

This difference appears to be just slight, yet it might be relevant for the difficulties we had in bringing together our experimental experiences and the account by historians of science. In retrospect, the translation by Roller and Roller appears to be the more appropriate one. Moreover, Nollet's translation of the letter corresponds more closely with this one than with the translation by Heilbron.[42] These different readings are to be kept in mind when we start analyzing the reactions of the mid-eighteenth century natural philosophers toward Musschenbroek's letter.

The Leiden jar in France

Musschenbroek's letter was immediately read at the Académie. A second reading took place three months later when its novelties were confirmed by Jean-Antoine Nollet, at that time the ultimate authority on electricity in France, at a public séance in April 1746. Nollet, with Le Monnier the Younger, investigated the effects and how to obtain them. Le Monnier read his findings in the public séance that took place on November 12, 1746. Each of them published independent papers in the 1746 edition of *Mémoires de l'Académie Royale des Sciences* (published with a five-year delay, in 1751) describing the experiment and how to proceed to obtain the dramatic effect.[43]

In his memoir, in the entry for April 20, 1746, Nollet referred to Réaumur's account of Musschenbroek's experiment and its results. He explained that he had been impatient to perform the experiment himself and could not wait for the German or Bohemian glass indicated by Musschenbroek as the only types that produced the amazing results. Therefore,

38. Ibid.
39. Ibid., p.314.
40. The relevant sentence in Musschenbroek's letter reads: "Sufficit ut homo stet tantum in solo; verum necesse est at idem homo manu capiat globum, et alteri mana eliciat scintillas." Musschenbroek to Réaumur. In: *Procès-verbaux de l'Académie royale des sciences Paris*, January 20th, 1746 (http://gallica.bnf.fr/ark:/12148/bpt6k55741q/f8.image.r=Proc%C3%A8s-verbaux%20T65%20Acad%C3%A9mie%20Royale%20des%20Sciences.langDE)
41. Duane E. Roller and Duane H. D. B. Roller, *The Development of the Concept of Electric Charge: Electricity from the Greeks to Coulomb* (Cambridge: Harvard University Press, 1957), p.594.
42. Jean Antoine Nollet, "Observations sur Quelques Nouveaux Phénomènes de l'Électricité," *Mémoires de l'Académie Royale des Sciences* (1746): 1–23, 2.
43. Nollet, "Observations" (note 44); Louis-Guillaume Le Monnier, "Recherches sur la Communication de l'Electricité," *Histoire de l'Académie Royale des Sciences* (1746): 477–64.

he tried the experience with ordinary glass, holding the flask with one hand and drawing the spark with the other and receiving a shock he considered as being undeniable.[44]

Nollet has attributed Musschenbroek's difficulties in obtaining the results with some types of glass to the humidity of the glass above the water. This region had to be extremely dry according to Nollet – Musschenbroek did not mention any relevance of this detail. Thus, it seemed a plausible explanation for Nollet that Musschenbroek had not paid attention to this detail and wrongly attributed the missing effect to the glass instead of the humidity. According to Nollet, the relevant condition for obtaining strong effects is that the employed vase had to be dry, clean, and well closed.[45]

The French electricians tested different liquids inside the bottle, being unsuccessful with oily liquids and alcohol, and finding water as the most appropriate. Nollet also tested vases of various materials, sizes, and forms, concluding that they should be made of glass or porcelain, and of no more than four or five inches in diameter.[46] Nollet noted that the jar is electrified when it is not insulated; however, he does not mention that grounding is necessary to the success of the experiment. In this same year, Nollet published *Essai Sur l'électricité des Corps*, approved by the *Académie* on August 20, 1746.[47] The book is devoted to revealing Nollet's theory of electricity and to explaining the electrical phenomenon known in that period as the Leiden experiment. Nollet describes the Leiden experiment, saying that when a person holding in one hand a charged bottle of glass or porcelain filled with water suspended from a charged metal approaches the other hand to the rod to obtain a spark, he feels a violent and sudden commotion in his arms, chest, innards, and, often, throughout his body.[48] In his publication, a demonstration of the experiment is shown in one of the plates (see Figure 2). The grounding is invisible from this plate as the person is not fully depicted. However, when comparing this plate to the one shown in the account of the Paris Academy (see Figure 3), it is striking that Nollet's emphasis is placed only on the process of discharging. Corresponding to this emphasis in the visual representation, Nollet also does not mention in his monograph the grounding of the experimenter as a necessary condition for obtaining impressive effects with the charged bottle.

In another paper in the same volume, Le Monnier describes the Leiden experiment, making clear that he held the bottle with one hand and drew the "luminous brush, accompanied by whistling" with the other, immediately feeling the "concussion of the Leiden experience."[49] Like Nollet, Le Monnier does not mention the necessity of the person who is charging the bottle to be standing on the floor. Le Monnier remarks that the success of the experiment depends on setting a connection between the inside and outside of the bottle. The shape and length of the connection do not matter, but it needs to be a non-electric body (human bodies or metals). To emphasize the role of the links in the discharging process, he describes experiments with chains of men and long wires acting as a connection.[50]

44. Nollet, "Observations," 4 (note 44).
45. Ibid., 5–6.
46. Ibid.
47. Jean Antoine Nollet, *Essai sur l'électricité des corps* (Paris: Chez les freres Guerin, 1746).
48. Ibid., pp.193–4.
49. Le Monnier, "Recherches sur la Communication de l'Electricité," 448 (note 45).
50. Ibid., 449–53.

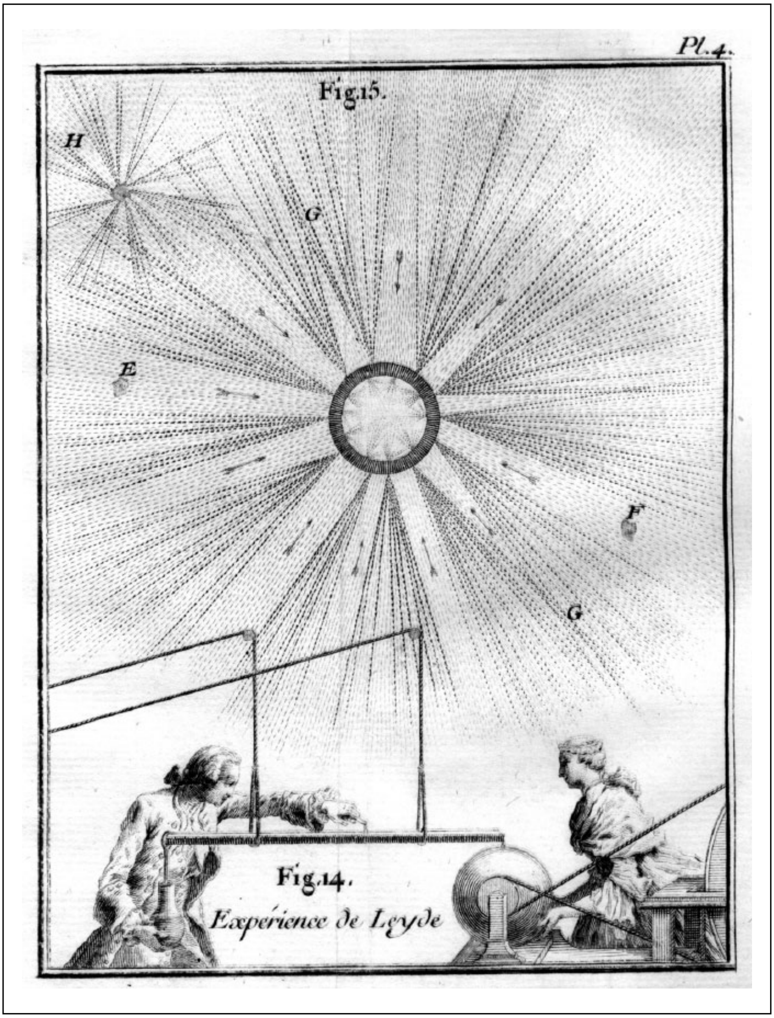

Figure 2. Nollet's representation of the Leiden experiment in his *Essai* (dating 1746), with emphasis on the discharging process (with permission of The Bakken Museum, Minneapolis).

From the conceptual perspective, Le Monnier recognizes that the jar experiment violates Dufay's Rule and describes several situations illustrating this relevant and intriguing aspect of the Leiden experiment. For instance, the jar does not receive a significant amount of electrical virtue when placed on a glass stand that is dry or suspended by a silk thread. To receive the electrical virtue, the part of the phial below the surface must communicate to a non-electric material; it is evident by the fact that, when it is touched by the finger or with a piece of metal while resting in a stand of glass, it immediately becomes electrified, but not when touched with a dry glass tube.[51] However, he

51. Ibid., 453.

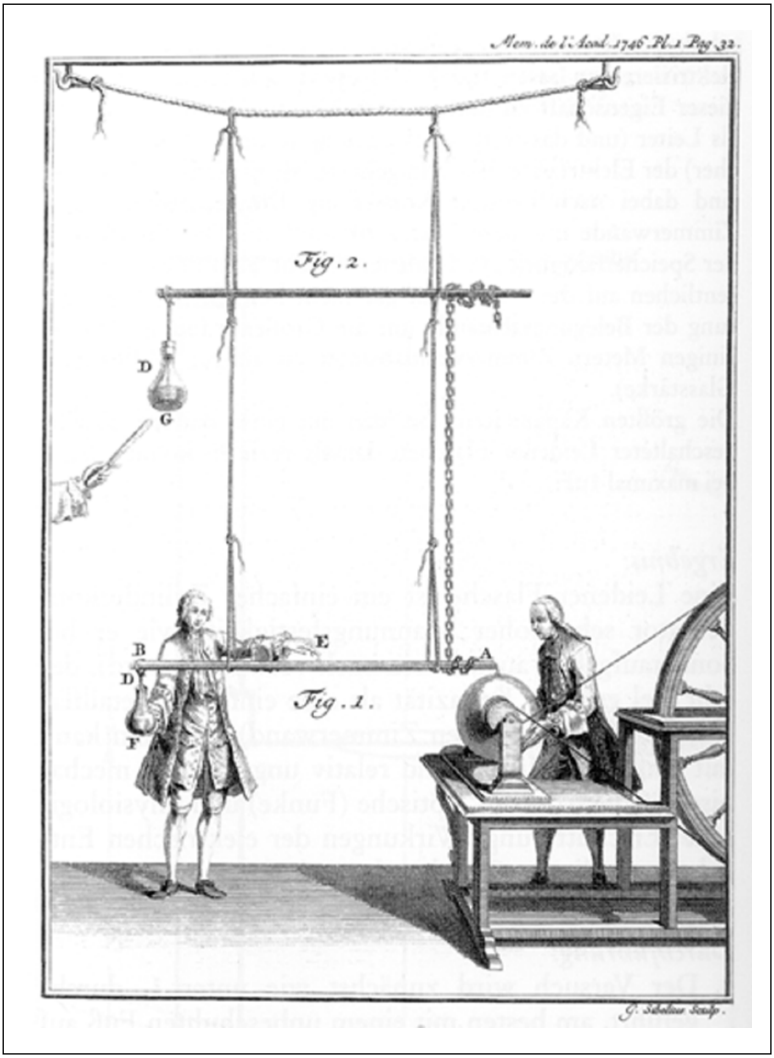

Figure 3. Nollet's illustration of the Leiden experiment in the *Mémoires de l'Académie* (published 1751).

does not see it as an indication that grounding is an important condition for the success of the experiment.

For the purposes of this paper, it is important to summarize that both Nollet and Le Monnier are clear in saying that it is necessary to set an electric body between the inside and outside of the charged bottle to obtain a strong effect. At the same time, they do not even mention whether the experimenter stands on the floor or an isolated stool. Therefore, one can speculate that they did not consider grounding as a critical condition for performing the experiment.

The Leiden jar in Britain

The first announcement of the Leiden experiment came to the Royal Society in a letter sent by Abraham Trembley, who was traveling in the Netherlands and visited Musschenbroek.[52] Trembley describes some experiments on electrical effects in tubes with mercury and then turns to the Leiden experiment:

> There is an Experiment that Mr. l'Allamand has tried; he electrify'd a tin Tube, by means of a glass Globe; he then took in his left Hand a Glass full of Water, in which was dipped the End of a Wire; the other End of this Wire touched the electrified tin Tube: He then touch'd, with a Finger of his right Hand, the electrified Tube, and drew a Spark from it, when at the same Instant he felt a most violent Shock all over his Body. … It is to be remarked that in this Experiment he stood simply upon the floor, and not upon the Cakes of Resin. It does not Succeed with all Glasses; and tho' he has tried several, he has had perfect Success with none but those of Bohemia. He has tried English Glasses without any Effect. The Glass with which it best succeeded was a Beer Glass.[53]

This account contains all the relevant information: an experimenter standing on the ground (instead of being insulated) holds a glass of water in hand while it is electrified; concomitantly, the other hand is used to contact the inner side. This procedure results in a violent shock. Moreover, the mention of different glasses indicates that this account is closely related to the one which had arrived in Paris a few weeks earlier.

Despite this seeming clearness, the experiment was evidently not understood as we would perform it nowadays: two weeks after Trembley's letter had been read at the Royal Society, a letter by Henry Miles was read in which he describes an experiment that was intended to be a modification of the Leiden experiment, narrated by l'Allamand.[54] While standing on a wax cake he filled a china basin with water, held it in his hand, and approached the basin to a metal tube suspended with a silk fiber from the ceiling. After being electrified, Miles dipped the metal tube into the water. Afterward, another person approached holding a spoon containing alcohol, which was ignited. At the same time, Miles received a pungent stroke in one of his fingers that held the basin. Remarkably, Miles interprets this experiment significantly differently: "I think there can be no Doubt, but that Water is as good a Medium of Communication to the Effluvia, as any Subject whatever."[55] Moreover, he carried out the experiment while standing on a resin cake. In other words, it is evident that the 'necessity' of grounding to perform experiments similar to the Leiden one has not become clear to Miles from Trembley's account.

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52. Abraham Trembley, "Part of a Letter from Mr. Trembley, F.R.S. to Martin Folkes, Esq; Pres. R. S. concerning the Light Caused by Quicksilver Shaken in a Glass Tube, Proceeding from Electricity," *Philosophical Transactions of the Royal Society (1683-1775)*, 44 (1746–7): 58–60. This letter dates February 4th, and was read February 13th 1746.
53. Ibid., 59.
54. Henry Miles, "A Letter from the Rev. Dr. Miles, F. R. S. to Mr. Baker, F. R. S. concerning the Electricity of Water, *Philosophical Transactions of the Royal Society (1683-1775)*, 44 (1746–7): 91–3.
55. Ibid., 92.

The next communication appeared in the March issue of the *Gentlemen's Magazine*, where a letter from Paris summarized Musschenbroek's experiment. The procedure is discussed in detail, again referring to the right hand holding the bottle and a finger of the left hand touching the prime conductor in order to receive the shock.[56] Additionally, Nollet and Le Monnier are said to have "ventur'd to make the same experiment, and in like manner found the concussion very terrible."[57] Notwithstanding the emphasis is still laid on the procedure, and the reproducibility of experiences established by electrical researchers is also pointed out, there is no mention of the grounding.

On May 29, 1746, again some information reached the British electricians from the continent, this time in the form of a letter by Johann Heinrich Winkler, one of the researchers who had been (though in his case belated) in direct contact with Kleist. Winkler emphasized his physiological experiences (and the ones of his wife) when discharging the Leiden jar. Moreover, he mentioned experiments with animals and the fact that a spark gap can be used to discharge the jar. From the account, it appears that it was not fully understood what Winkler is communicating as a footnote refers to a letter submitted by Bose in the previous year which described a very brisk discharge from a particular electrostatic generator.[58] Consequently, it is not too surprising that this communication received no significant attention.

Things changed only in October, when a letter written in Paris by John Turberville Needham on July 4 was read. The first part of this letter describes Le Monnier's newly designed electrical machine, which appears to be extremely efficient, and some experiments carried out with it. The main part of this letter is devoted to the experiment "of Mr. Musschenbroek, improved by Monsieur Le Monnier."[59] Following this description, the

> Phial is … to be electrified by the Operator, who takes hold of the Body of the Bottle, and applies to the electrifying Spheroid the bent Extremity of that Wire, which passes from near the Bottom of the Phial through the Cork…. The Operator must take care not to touch the Wire itself, while he endeavors to electrify the Phial, otherwise he would be in the Case of one, who should aim to electrify himself, without standing upon some one of the Bodies that are Electrics per se.[60]

However, when the phial is charged, it is not merely discharged by touching the wire, but the wire is used to suspend the bottle from a chain that is connected to the prime conductor. At the same time as the prime conductor is still electrified, the person who discharges the bottle grasps its bottom and touches the prime conductor. Even though the

56. "Extract of a Letter from Paris, March 25", *Gentlemen's Magazine*, 1746, p.163.
57. Ibid.
58. Georg Matthias Bose, "Abstract of a Letter from Monsieur De Bozes [sic], Professor of Experimental Philosophy, at the Academy of Wirtemberg, to Monsieur De Maizau. Communicated by Mr. Baker from Mr. Ellis, and Translated out of the Latin by Mr. Baker," *Philosophical Transactions of the Royal Society (1683-1775)* 43 (1743): 419–21.
59. Turberville Needham, "Extract of a Letter from Mr. Turbervill Needham to Martin Folkes, Esq; Pr. R. S. concerning Some New Electrical Experiments Lately Made at Paris," *Philosophical Transactions of the Royal Society (1683-1775)*, 44 (1746–7): 247–63, 252.
60. Ibid., 253.

strength of the discharge is substantial (and Needham recommends not charging the phial completely), for him the most remarkable aspect is that the phial does not lose its efficacy within a few minutes and can keep it for up to 36 hours.[61]

In the following, Needham describes several experiments with the Leiden jar, two of which are notable in the context of this paper. A jar is held in hand in a darkened chamber, "the Wire inserted in it is perceived to emit a Stream of Fire at its Extremity without any Discontinuance; but if it is suspended by a silken Thread, the fiery Eruption instantly ceases."[62] Even though this might be seen as the indication that grounding is required, there is no mention of it in Needham's account. In another experiment, Needham describes that a phial placed on a glass tray does not receive electricity unless "the Finger of some one in the Company is approached very near to the Phial itself: But, in that Case, it receives it visibly from the Finger; insomuch that, if the Chamber is darkened, you will see the electrical Fire streaming out of the Finger, and entering into the Water, through the Body of the glass Phial."[63] Two aspects are noteworthy in this account: Needham stresses that from this experience it becomes evident that glass does not exclude the "power of electricity," that is, the glass permits the passage of the electrical fluid – a clear violation of the Dufay's Rule. At the same time, Needham seems to attribute the relevant role in the Leiden jar not to the grounding but the human body instead. Moreover, there is another aspect that makes Needham's account significant: he is pointing out that the electrical shock is augmented. It appears to be a new quality in the descriptions of the Leiden jar – in the initial descriptions the authors stressed the severe effect of the jar, but did not interpret this as a sort of amplification.

Just one week after Needham's letter was read, John Watson claimed to have discovered several of the experiments carried out by Le Monnier prior to them being communicated. According to Watson, the phial is suspended with a wire from a gun-barrel (which serves as the prime conductor), then after it is charged "a Man grasps the Phial with one Hand, and touches the gun-barrel with a Finger of the other. Upon which he receives a violent Shock."[64] Moreover, Watson continues by identifying the criteria that are relevant for the outcome of the experiment: "This Experiment succeeds best, *cæteris paribus*,

1. When the Air is dry.
2. When the Phial containing the Water is of the thinnest Glass.
3. When the Outside of the Phial is perfectly dry.
4. In Proportion to the Number of Points of non-electric Contact. ...
5. When the Water in the Phial is heated ..."[65]

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61. Ibid., 255.
62. Ibid., 257.
63. Ibid., 259.
64. William 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," *Philosophical Transactions of the Royal Society (1683-1775)*, 44 (1746–7): 704–49, 709.
65. Ibid, 709f.

Again, grounding is not considered a crucial condition for the success of the Leiden experiment. Furthermore, in the continuation of the paper, Watson describes an experiment which indicates that he is operating the Leiden jar without grounding: "a person placed upon Originally-electrics" is standing insulated and holding two jars; if a second person standing on the floor touches this person, "a very light Stroke only is perceived. However, if the second Person, while the Globes are in Motion, places one of his Fingers upon the Hand, or any Part of the naked Body of the first, and at the same Time touches the Gun-barrel with his other Hand; both feel a Shock."[66] From this experiment, it seems that, at least for Watson at that time, the Leiden jar can be charged even when the person who is holding it is not grounded. The unawareness of the need for grounding is more evident when Watson highlights the conditions for success: "In this Experiment, it is not necessary that the Outside of the Glasses held in the Hands should be dry, as in the former Experiments; because whatever by the Moisture is communicated to the Man, is stopped by the Original-electrics upon which he is placed."[67]

However, if grounding is apparently not a requirement for the operation with the jar, it is in other experiments with the electrical machine. Watson describes that the sphere in the machine is only producing electricity when parts of the machine are grounded.[68] Watson carried out several experiments in this respect which led him to conceive "that the electrical Power was not inherent in the Glass, but came from the Floor of the Room."[69] This result is then used by Watson to propose an explanation for the violent effect of the jar: when a man holding a highly electrified phial touches the prime conductor

> …instantaneously parts with as much of the Fire from his Body, as was accumulated in the Water and Gun-barrel; and he feels the effects in both Arms, from the Fire of his Body rushing through one Arm to the Gun-barrel, and from the other to the Phial. … As much Fire as the man then parted with, is instantaneously replaced from the Floor.[70]

Thus, to Watson, grounding is apparently necessary for the process of discharging the phial, but not during the charging.

Watson's conceptual understanding is not limited to the role of grounding in the discharge process. From several experiments, he concludes "that the electrical Force always describes a Circuit."[71] At the same time, it is evident (and made explicit) that the jar is particularly efficient in accumulating electricity: "The Phial of Water of Musschenbroek seems capable of a greater Degree of Accumulation of Electricity than anything we are at present acquainted with."[72]

The violation of Dufay's Rule by the Leiden jar turned out to be a conceptual question that was intensely discussed. Six weeks after Watson's paper was read, Le Monnier's

66. Ibid., 714.
67. Ibid.
68. In this respect, Watson is referring to Bose's experiments.
69. Watson, "A Sequel to the Experiments and Observations," 716 (note 66).
70. Ibid., 742.
71. Ibid., 718.
72. Ibid., 730. This notion of Watson's is similar to one advocated by Benjamin Martin in a monograph printed in 1746: "If a Phial of Water be provided, and well cork'd, and a Wire bended on the Top be pierced thro' the Cork, and thrust down near the Bottom of the Phial, leaving

letter (which had been announced by Needham) was read to the society.[73] In this letter, Le Monnier made evident that the Leiden jar violates Dufay's Rule because a phial held in the hand (a non-electric) is electrified. Moreover, all objects that are in the circuit of discharge receive electricity, even though they are not placed upon electrics. Furthermore, discharges of the Leiden jar can even go through the water of a basin, again demonstrating the exception to the rule. Different evidence presented by Le Monnier for this exception lies in the way the Leiden jar is charged: when it is placed on dry glass, no signs of charge can be detected. However, when something non-electric touches the glass, then it is charged. Watson disagrees with Le Monnier's conclusion about the violation of Dufay's Rule by the Leiden jar and insists that it can be explained without being an exception to the rule. He argues that the charged water is placed on an electric (glass), and the fact that the glass is placed on a non-electric (hand) does not influence the charging process.[74]

To summarize this development so far: the first news from the continent did not lead to immediate responses. This may in part be due to the problem that the communication could be misinterpreted. Only when Needham's letter was read did British researchers start immediately to publish their findings and interpretations. In their discussion, the role of the human body and the violation of Dufay's Rule were crucial; the grounding played no role in this respect. Instead, the concept of the electrical circuit became relevant for the discussion.

German reactions to the 'Leiden experiment'

Beside the reproduction of Keist's letters by Krüger, there are two main publications which discuss the Leiden jar.[75] Possibly the most important one is a monograph

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the upper Part standing about two or three Inches above the Bottle, then Laying this Wire on the Globe in Motion, the Wire will receive the Electricity from the Globe, and the Water will be impregnated therewith, the more as the Wire is kept longer on the Globe; then the Person thus holding the Phial in one Hand, is to approach a Finger of his other hand near the middle Part of the Globe, and he will receive the Electric Eruption of Fire with a very considerable Snap and Force, greater by much than what proceeds from the Barrel alone; the Reaction is because all the Electricity running thro' the Wire into the Water, is there condensed as it were, and confined by the Electrical Substance of Glass, and so acts in a greater Quantity, and therefore with greater Force, than when it issues from the Barrel unconfined" (Benjamin Martin, *An essay on electricity : being an enquiry into the nature, cause and properties thereof, on the principles of Sir Isaac Newton's theory of vibrating motion, light and fire ... with some observations relative to the uses that may be made of this wonderful power of nature*. (Bath: Printed for the author 1746), 31f.). Note that again grounding is not an issue.

73. Le Monnier, "Recherches sur la Communication de l'Electricité" (note 45).
74. 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," *Philosophical Transactions of the Royal Society (1683-1775)* 44 (1746): 388–95, 389.
75. Krüger, *Geschichte der Erde* (note 25), There are also several announcements in public journals which describe the Leiden experiment or the attempts to develop an understanding of it. See e.g. *Neue Zeitungen von gelehrten Sachen* 88, 751 (October, where Krüger's account of Kleist's experiments is mentioned) and 812f. (November, where Nollet's account is described).

published by Winkler (who, in May 1746, addressed a letter to the Royal Society London).[76] The dedication in this monograph dates September 6, 1746, thus it is likely that this study had been published before the discussion in the Royal Society.

Quite remarkably, Winkler points out in the preface what he considers to be the major understanding that he has achieved through his experiments: "After many experiments, I finally realized that the main reason for the amplification of the electricity results from the glass of the bottle in which the water was electrified. The glass of the bottle gets itself electrified from the water which is electrified in the bottle."[77]

In his description, Winkler quickly moves further from having a person holding the bottle. Instead, he uses chains and wires to connect the inside of the bottles with the prime conductor and the outside with a round metal piece that is placed below the prime conductor. This modification was meant to overcome the 'nasty effects' of the experiment, though at the same time Winkler was eliminating the human body from the experiment, which is a rather unusual step at this time.[78] Grounding has no explicit role in these experiments. Instead, Winkler indicates that the shock is weaker when the bottle is placed on a wooden stand.[79] However, the approach toward the question of grounding is not coherent: among other "curious phenomena," Winkler describes that a person holding the bottle while being insulated gets electrified himself but cannot draw a spark from the bottle. Only when someone approaches the person and draws sparks out of him does the bottle also give sparks.[80] In another experiment, Winkler steps with a charged bottle onto a silk square and touches the wire in the bottle; as a result, he gets charged and can draw sparks from people standing nearby.[81]

From the description of the experiments, it is evident that Winkler lacked (at least for some time) a conceptual understanding: he is varying the bottle, the liquid in the bottle, the way the bottle is charged and discharged, he uses a bottle that is placed in a vacuum, and so forth. By varying the experimental conditions, Winkler generates a substantial number of particular cases which he is describing and analyzing. This analysis also indicates that his conceptual understanding does not focus on the importance of grounding: in the second part of the explanatory part, he discusses the increase of the electrical force of water in glass vessels; only in the next part does he address the effect of touching the outside of the vessel. Apparently, these two aspects are not necessarily connected; consequently, the aspect of grounding does not play a major role in the discussion. On the contrary: in the second part, Winkler interprets experiments where no (intentional) grounding took place.

The second account is published by Gralath in the first volume of the *Versuche und Abhandlungen der naturforschenden Gesellschaft* in Danzig in 1747.[82] Like Krüger,

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76. Johann H. Winkler, *Die Stärke der elektrischen Kraft des Wassers in gläsernen Gefässen: welche durch den Musschenbrökischen Versuch bekannt geworden* (Leipzig: Bey Bernhard Christoph Breitkopf, 1746).
77. Ibid., Preface.
78. Ibid., p.7.
79. Ibid., p.8.
80. Ibid., p.15
81. Ibid., p.45.
82. According to his account, central experiments were carried out in April 1746.

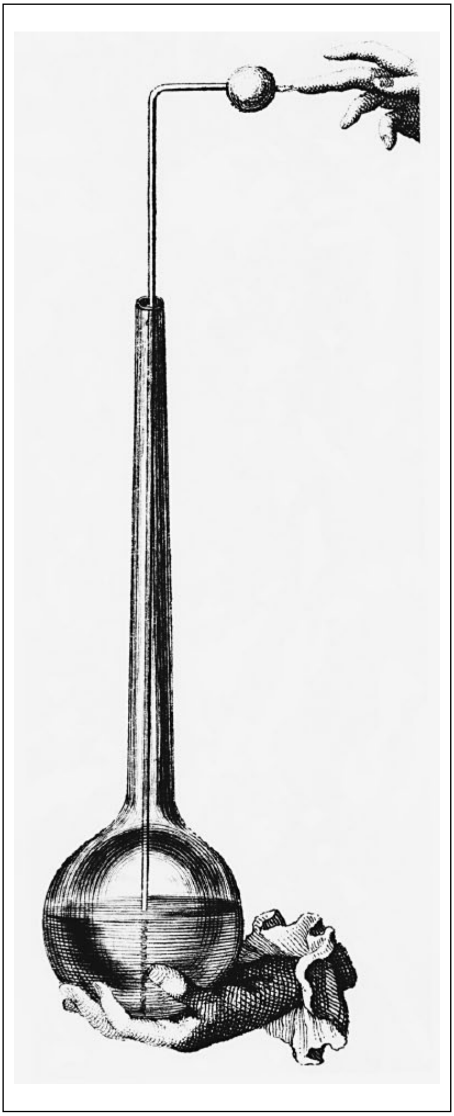

Figure 4. Gralath's illustration of the jar only depicts the discharge process (with permission of the Deutsches Museum, Munich).

Gralath gave a brief outline of the historical development and illustrated this with a phial shown on a plate (see Figure 4).

From his account, it is evident that he varied the experiment in several ways, and that he also carried out the experiment with numerous other people. From his experiences with the Leiden jar he can give several specifications that are required for the success of the experiment – grounding is not among them. Instead, he points out that the crucial aspect (and thus the deficit in Kleist's report) is something completely different:

> As Mr. von Kleist did not report that only the one experiences the severe action who is holding the glass or phial in one hand, and approaches the wire or the tube with a finger of the other hand, the experiment had in the beginning not the intended success, until I became aware that this circumstance is decisive, as this one finally went well for the first time on March 5th, 1746.[83]

Even though Gralath emphasizes a number of precautions (the outside of the phial has to be dry, one has to hold the phial where the water is, a crack makes the phial useless), there is no discussion of the necessity of grounding.

In the course of his paper, Gralath describes experiments which can be summarized in two groups: In the first series of experiments, he is describing those where he is modifying the discharging circuit. In the second series, he described experiments which aim at killing animals through the discharge of the Leiden Jar. He wants to produce and examine the biological effects caused by a discharge and to analyze the electrocution of animals. Here, he is describing in a detailed manner what attempts he undertook before he finally succeeded in electrocuting a siskin.

In comparison, Winkler and Gralath differ significantly in their experimental treatment of a new device and the related understanding. While Winkler described and discussed a broad variety of experiments in an exploratory manner, Gralath's approach appears to be more theory-oriented.[84] He aims on the one hand at identifying parameters that support his understanding of the process of electrical conduction in the discharge of the Leiden jar. On the other hand, he uses the Leiden jar for experiments that no longer aim at understanding the behavior of the device. Instead, he uses the device as it provides a larger amount of electricity that he can use to examine the biological effects of this amount of electricity. In this respect, he treats the Leiden jar as an already established device in the inventory of an electrical researcher.

Another aspect appears to be remarkable in this early discussion of the Leiden jar in the German-speaking community: despite the fact that Winkler has apparently been in contact with Kleist, he uses Nollet as his main reference. At the same time, Winkler appears to be central, if not the central person in the German-speaking community of electrical researchers. Consequently, Nollet's account seems to be the most relevant one for the subsequent discussion. It is therefore not that relevant whether Musschenbroek stressed grounding, but whether Nollet did so (which he did not). The only exception in this respect may be Gralath, who seems to work independently and starts his experimentation with the account from Kleist.

Explaining the jar and shifting the emphasis toward grounding

The person to provide the widely accepted explanation of the Leiden jar was Benjamin Franklin. As there is vast literature about Franklin and his interpretation of the Leiden jar,

83. Gralath, "Nachricht," 512 (note 23).
84. It has to be noted though that Gralath's account was printed sometime after the initial events; consequently, this impression might be due to his way of summarizing his findings.

we will not discuss his conceptual interpretation in detail.[85] Yet, with respect to the focus of our paper, there is one detail in Franklin's explanation which is crucial: this explanation, which is using the one-fluid theory, is based on the idea that "whatever quantity of electrical fire is thrown in at top, an equal quantity goes out of the bottom."[86] Franklin emphasizes in this letter the necessity of establishing an equilibrium between the amount of electricity put into the phial, and the amount that is removed from the outside.[87] However, in this explanation, he does not explicitly put the emphasis on grounding the bottle:

> As no more electrical fire can be thrown into the top of the bottle, when all is driven out of the bottom, so in a bottle not yet electrified, none can be thrown into the top, when none can get out at the bottom; which happens either when the bottom is too thick, or when the bottle is placed on an *electric per se*.[88]

The necessity of grounding is made explicit in the following letter, where Franklin states: "Besides, the phial will not suffer what is called a *charging*, unless as much fire can go out of it in one way, as is thrown in by another. A phial cannot be charged standing on glass or wax, or hanging on the prime conductor, unless a communication be formed between its coating and the floor."[89]

Historians have emphasized that Franklin's success in explaining the Leiden jar with a description that was based on the one-fluid theory has been crucial for the wide acceptance of this theory. Even though he mentions the necessity of grounding and uses it in his conceptual description, what appears to be crucial is the quantitative, economically influenced approach that enabled an explanation of the effects experienced so far. Consequently, we may ask when grounding was ascribed the importance that we find in modern historians' text on the early history of the Leiden jar. This is going to be discussed in the final section of this paper.

Historical perspective

When looking at the sources, it appears that some details of the historians' traditional story about the Leiden jar do not correspond to the information in the primary sources.

85. Apart from the standard monographs we have already referred to, also see Bernard S. Finn, "An Appraisal of the Origins of Franklin's Electrical Theory," *Isis* 60 (1969): 362–9, and Jerome B. Cohen, *Benjamin Franklin's Science* (Cambridge: Harvard University Press, 1990).
86. This quotation originates from a letter by Franklin to Collinson, dating September 1, 1747. For Franklin's letters, Benjamin Franklin, *Experiments and Observations on Electricity, Made at Philadelphia in America* (London: David Henry, 1769). Reprinted for The Classics of Science Library (New York: Gryphon Editions, 1996), p.12. In a footnote, Franklin added, "What is said here, and after, of the top and bottom of the bottle, is true of the inside and outside surfaces, and should have been so expressed."
87. Heinz O. Sibum, "The Bookkeeper of Nature: Benjamin Franklin's Electrical Research and the Development of Experimental Natural Philosophy in the 18th Century," in Joseph A. Leo Lemay (ed.), *Reappraising Benjamin Franklin: A Bicentennial Perspective* (Newark, N.J.: University of Delaware Press, 1993), pp.196–220, had already stressed the relevance of economic considerations in Franklin's electrical theory; therefore, we will not go deeper into this argumentation.
88. Franklin, *Experiments and Observations*, p.14 (note 89).
89. Ibid., p.24.

Most relevant in this respect is the issue of grounding. Actually, in the early period of the development of what became known as the Leiden jar, grounding was not the central issue. Neither Krüger nor Gralath saw it as the key problem of Kleist's account of the experiment. Likewise, neither Musschenbroek nor the early recipients of his letter emphasized the necessity of being grounded. What appears to be something very natural for people currently versed in electrical practices was the main concern of the philosophers working with and about the Leiden jar: the need that the same person who touches the metal rod holds the phial. The conceptual idea of the electrical circuit was only developed out of practice with the Leiden jar. Before this development, a second one discharged a charged object or person. Now it was necessary to connect the inside of the Leiden jar with its outside by forming a circuit. The lack of this knowledge turned out to be the major difficulty in reproducing the effects Kleist had described, at least from the retrospective narration communicated by Gralath. Table 1 summarizes some of the contributions of the early experimenters with the jar in different communities.

An aspect related to this reinterpretation is the status of the experimenters, namely Kleist and Cunaeus. Both are typically characterized as amateurs who were not really versed in the field and therefore could accidentally discover the Leiden jar by not being grounded and by violating the Dufay's Rule. It has become evident that Kleist's work can be seen as a systematic approach to the field of electrical research that is related to what had been typical in the German-speaking regions.[90] Moreover, it can be questioned whether they actually violated Dufay's Rule. The (initial) Leiden experiments, at least, aimed at electrifying water – and the water was placed in an 'electric per se' – the glass of the phial. Consequently, these experiments can be seen as obeying Dufay's Rule. This notion changes only when the 'epistemic thing' changes from the water to the jar.[91] As a result, the emphasis of the discovery lies in our reading not of the dilettante, who does not know Dufay's role, but in the unintentional connection of the inner and outer coating of the jar that forms the closing of the circuit.[92]

Following the successful replication of the effect described by Kleist and Musschenbroek, natural philosophers started to analyze and characterize the phenomenon

90. This is not to say that there is a particular national style in experimenting. However, there appear to be what can be termed 'thought collectives' in the sense of Ludwik Fleck, and they both have a similar style of experimenting and a common national background. However, there may be more than one collective within a particular national context; this aspect needs further elaboration. On Fleck's epistemology, see Ludwik Fleck, *Genesis and Development of a Scientific Fact* (Chicago: University of Chicago Press, 1979).

91. Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Palo Alto: Stanford University Press, 1997).

92. From this perspective, Heilbron's statement that "No one who accepted the Rule of Dufay – as all practiced electricians did – could intentionally have invented the Leiden jar" (Heilbron, *Electricity in the 17th and 18th Centuries*, p.235 (note 3)) is not to be put into question. However, the reading is changing – the problem is not holding the jar in the hand but connecting the inside with the outside. This manipulation was not part of the electrician's procedures or conceptual understanding.

Table 1. A summary of some of the contributions of early experiments in Germany, France, and England.

Experimenter	When	Where	Remarkable aspects	Attention to grounding	Interpretation of how the jar was used
Ewald Jürgen von Kleist	October 11, 1745	Pomerania	Evolution from luminous effects to what we would call the Leiden jar. The effect is only produced when the bottle is held in the hand.	No	Production of effects.
Daniel Gralath	December 14, 1745	Danzig	Failure to reproduce the effect.	No	Replication and stabilization.
Daniel Gralath and Gottfried Reyger	March 5, 1746	Danzig	One should hold the bottle in one's hand instead of placing it on a table. The larger the phial, the stronger the effect.	No	Replication and stabilization. Systematical analysis.
Daniel Gralath	April 1746	Danzig	Production and examination of biological effects caused by a discharge. Modifications of discharging circuit. Experiments aiming at killing animals using the Leiden jar as an already established device.	No	Black box.
Johann Heinrich Winkler	May 29, 1746	Leipzig/ London	Emphasis on physiological experiences and reproduction of the effect and experiments with animals.	No	Black box
Johann Heinrich Winkler	September 6, 1746	Leipzig	Human body is no longer part of the experiment. Variations of the experimental conditions.	No	Systematical analysis.
Pieter van Musschenbroek	January 1746	Leiden	It is necessary that the same person holds the flask in one hand and draws the spark with other.	No	Replication and stabilization.
Jean-Antoine Nollet	April 20, 1746	Paris	Testing the relevant condition for obtaining strong effects is that the employed vase had to be dry, clean, and well closed. Reproduction and test of different glasses and liquids.	No	Replication and stabilization.

(Continued)

Table 1. (Continued)

Experimenter	When	Where	Remarkable aspects	Attention to grounding	Interpretation of how the jar was used
Jean-Antoine Nollet	August 20, 1746	Paris	It is necessary that the same person holds the flask in one hand and draws the spark with other.	No	Replication and stabilization.
Le Monnier the Younger	November 12, 1746	Paris	The success of the experiment depends on setting a connection between the inside and outside of the bottle. Experiments with chains of men and long wires acting as a connection.	No	Systematical analysis.
Abraham Trembley	February 4, 1746	London	The experimenter must stand on the floor instead of on an insulated stool. It is necessary that the same person holds the flask in one hand and draws the spark with other.	Yes	Replication and stabilization.
Henry Miles	March 1746	London	No explicit mention of the necessity that the same person holds the basin and touches the metal wire.	No	Replication and stabilization.
John Turbervill Needham	October 1746	London	The charged phial keeps its charge for days, the glass permits the passage of the electrical fluid, and the jar augments the electricity.	No	Systematical analysis.
John Watson	October 1746	London	Identification of the criteria that are relevant for the outcome of the experiment. Apparently, grounding is necessary for the process of discharging the phial, but not during the charging. The Leiden jar is an accumulator. Electricity describes a circuit.	No/yes	Systematical analysis.

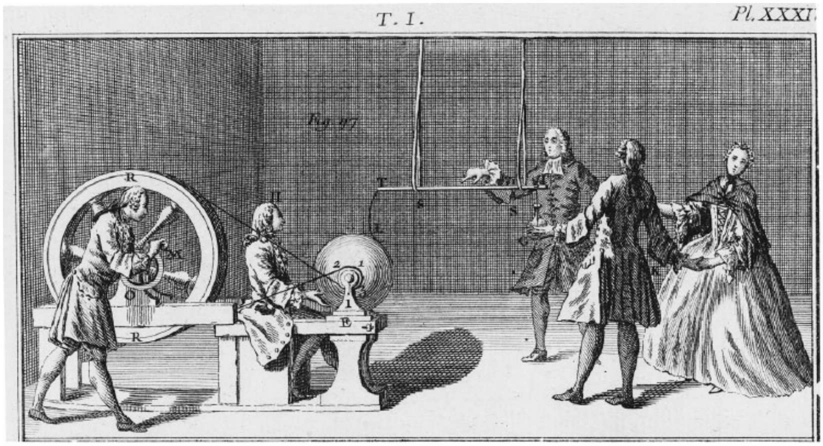

Figure 5. Discharging the Leiden jar through a chain formed by human bodies (1753) (with permission of the Deutsches Museum, Munich).

that was quickly becoming prominent. In this respect, we can see a shift in the work with the jar: the device is no longer an item of research but becomes part of the typical periphery in electricity. Working with the jar results quickly either in electrocuting animals or in forming discharge circles – here it is the collective experience that is meaningful in the context of the Enlightenment (see Figure 5).[93]

Epistemological perspective

When analyzing the experiments carried out with the Leiden jar in France and England, at least three different approaches can be distinguished, as summarized in Table 1: some researchers are fascinated by Musschenbroek's account and start to make their own experiences – in some sense, they are attempting to replicate and potentially stabilize the experimental findings. Then we have researchers who analyze the Leiden jar systematically. Two different reasons can be ascribed to this approach: some scholars intended to modify and thus improve the jar (for example by increasing the efficiency, reliability, strength of the effects, etc.), while others analyzed the jar to develop an explanation of its behavior. Finally, we find researchers who use the Leiden jar as a sort of black box: they are not aiming to understand its behavior but to benefit from its amplifying effect with respect to their experimental (or therapeutic) purposes.

The stabilization of the standard experimental procedure with the Leiden jar (experimenting while standing on the ground and the necessity of discharging the jar through a circuit which could even be formed by several persons) was a process that took several

93. On the role of collective experiences in the Enlightenment culture see in particular Alice N. Walters, "Conversation Pieces: Science and Politeness in Eighteenth-Century England," *History of Science* 35 (1997): 121–54.

months to be completed. This appears to be a situation where the existing theories were considered to be useless in explaining the new phenomenon and where an alternative was lacking. Practical experiences were no longer guided by theoretical understanding in the field. In this respect, the situation could be considered one of exploratory experimentation.[94] This concept has been established by Steinle to describe situations where researchers came across new phenomena and had to free themselves from their initial understanding in order to develop a new one that is based on experimental investigations. These experiments were not unstructured; however, they were systematized by controlling and modifying potential factors and thus played a role in developing a new theoretical understanding. Consequently, exploratory experimentation takes place on the level of the individual researcher, yet, in the case of the early Leiden jar, we have a number of natural philosophers who are in similar situations and seem to use this approach in particular ways. This is evident, for example, in Winkler's descriptions, as he gives several examples where he noticed an unanticipated effect that he found curious, and then analyzed this effect though controlled modification of the circumstances.

At the end of this period, there were standard procedures. Shortly afterward, with Franklin's interpretation of the jar, there was also a conceptual understanding that was generally accepted. Central to this was the notion that electricity from the outside of the bottle was conducted into the ground. As long as there was still electrical fluid on the outside of the bottle, it was possible to continue charging. Once the entire charge had been taken from the outside, it was not possible to charge the bottle any further. This understanding had become part of what Thomas Kuhn identified as the first paradigm in electricity.

> Those first experiments did not, however, provide electricians with the Leyden jar. That device emerged more slowly, and it is again impossible to say just when its discovery was completed. The initial attempts to store electrical fluid worked only because investigators held the vial in their hands while standing upon the ground. Electricians had still to learn that the jar required an outer as well as an inner conducting coating and that the fluid is not stored in the jar at all. Somewhere in the course of the investigations that showed them this, and which introduced them to several other anomalous effects, the device that we call the Leyden jar emerged. Furthermore, the experiments that led to its emergence, many of them performed by Franklin, were also the ones that necessitated the drastic revision of the fluid theory and thus provided the first full paradigm for electricity.[95]

The interesting part here is the question raised (and in some senses answered) by Kuhn: When was the discovery of the Leiden jar completed? Following his argumentation, it is the conceptual understanding by Franklin that formed this completion, and thus Franklin's interpretation (and the emphasis on grounding) has to be part of the epistemic

94. Friedrich Steinle, *Explorative Experimente: Ampère, Faraday und die Ursprünge der Elektrodynamik* (Stuttgart: Steiner, 2005), translated in Friedrich Steinle, *Exploratory Experiments: Ampère, Faraday, and the Origins of Electrodynamics* (Pittsburgh: University of Pittsburgh Press, 2016).
95. Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1970), p.62.

objects labeled 'Leiden jar'. However, as we have shown, the label was ascribed much earlier by the historical actors; it was already used by Nollet in 1746 – and here the emphasis on grounding was not that relevant to the discussion. In this respect, Franklin's interpretation and its dominant role in the electrical research of the second half of the eighteenth century may have had a similar function. As this version became dominant, it covered the previous discussion, and as a result the understanding of the early phase is interpreted through the comprehension of the Franklinist description of the jar, in which grounding fulfills a central role, not only on the conceptual but seemingly also on the practical level.

Thus, it was only by introducing ourselves again to the experiments that we noted a discrepancy between the common image of the development of the Leiden jar and our practical experiences. Moreover, it was this difference that caused us to go back to the sources and recognize that grounding was not the central aspect (and problem) in initially reproducing the effect of the jar. This research procedure contributed in clarifying experimental accounts described by the historical actors and the process of the development of conceptual understanding toward the Leiden jar as an epistemic object.

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