



## Nollet and the Leyden Jar: conceptions of electric fluid, materials, and explanations of 18th-century electricity

Nollet y la botella de Leyden: concepciones del fluido eléctrico, los materiales y las explicaciones de la electricidad en el siglo XVIII

Nollet e a garrafa de Leyden: concepções de fluido elétrico, materiais e explicações para a eletricidade no século XVIII

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### ABSTRACT

The Leyden jar, constructed in the mid-18th century, became a central theme in debates about electricity, contributing to different interpretations of its functioning. This article discusses how the Frenchman Jean-Antoine Nollet (1700–1770) understood the nature of electricity and explained the phenomena of electrification and discharge of the jar, based on his theoretical and experimental concepts. Through an analysis of primary sources, in dialogue with modern historiography of science, we seek to highlight how his propositions regarding electrical phenomena fit into the experimental practices of the period. Considering the context and research methods of the time, we also reflect on the limits and scope of these propositions. By adopting this historical episode as our object of study, we highlight its didactic potential, particularly for rethinking the teaching of and about science from a more critical, historical, and investigative perspective that values the processes of scientific knowledge construction in specific contexts.

**Keywords:** history of science, 18th-century electricity, Leyden jar.

### RESUMEN

La botella de Leyden, construida a mediados del siglo XVIII, se convirtió en uno de los temas centrales de los debates sobre la electricidad, lo que dio lugar a diversas interpretaciones sobre su funcionamiento. Este artículo analiza cómo el francés Jean-Antoine Nollet (1700–1770) comprendía la naturaleza de la electricidad y explicaba los fenómenos de electrización y descarga de la botella, a partir de sus concepciones teóricas y experimentales. Mediante el análisis de fuentes primarias, en diálogo con la historiografía contemporánea de la ciencia, se busca evidenciar cómo sus propuestas sobre los fenómenos eléctricos se inscriben en las prácticas experimentales de la época. Considerando el contexto y los métodos de investigación del período, se reflexiona asimismo sobre los alcances y las limitaciones de dichas proposiciones. Al adoptar este episodio histórico como objeto de estudio, se destacan sus potencialidades didácticas, especialmente para repensar la enseñanza de las ciencias y sobre las ciencias desde una perspectiva más crítica, histórica e investigativa, que valore los procesos de construcción del conocimiento científico en contextos específicos.

**Palabras clave:** historia de la ciencia; electricidad; siglo XVIII; botella de Leyden.



## RESUMO

A garrafa de Leyden, construída em meados do século XVIII, tornou-se um dos temas centrais dos debates sobre eletricidade, o que resultou em diferentes interpretações sobre seu funcionamento. Este artigo discute o modo como o francês Jean-Antoine Nollet (1700-1770) compreendia a natureza da eletricidade e explicava os fenômenos de eletrização e descarregamento da garrafa, com base em suas concepções teóricas e experimentais. A partir da análise de fontes primárias, em diálogo com a historiografia moderna da ciência, buscou-se evidenciar como suas proposições sobre os fenômenos elétricos se inserem nas práticas experimentais do período. Considerando o contexto e os métodos de investigação da época, reflete-se ainda sobre os limites e os alcances dessas proposições. Ao adotar esse episódio histórico como objeto de estudo, destacam-se suas potencialidades didáticas, sobretudo para repensar o ensino de e sobre ciências, a partir de uma perspectiva mais crítica, histórica e investigativa, que valorize os processos de construção do conhecimento científico em contextos específicos.

**Palavras-chave:** história da ciência; eletricidade; século XVIII; garrafa de Leyden.

## INTRODUCTION

The dissemination of electrical experiments through shocks, discharges, and other visual effects not only aroused curiosity among spectators in the 18th century but also contributed to the popularization of studies on electricity and the development of new experimental apparatuses (Heilbron, 1979; Jardim; Guerra, 2017). It was in this context that the Leyden jar was built in Europe around 1745. It was a device capable of storing electricity and producing discharges more intense than those produced by the electrification methods used until then (Silva; Heering, 2018).

The jar's capacity to store electricity for long periods, as well as the intensity of the sparks it produced, quickly piqued the interest of European and American natural philosophers during the first half of the 18th century. Thus, it became one of the central themes in discussions on electricity at the time, mobilizing a set of scientific practices of the period, ranging from experimental investigations to the circulation of ideas through letters and printed publications (Jardim; Guerra, 2017)<sup>1</sup>.

The device raised questions at the time, as the knowledge established to that point about electricity could not explain the mechanism of operation, the role of the materials that made up the jar, or the phenomena of electrification and unloading, which prompted several scholars. Among them was the Frenchman Jean-Antoine Nollet (1700-1770), whose contributions occupied a prominent place in the experimental natural philosophy of the period.

Given the centrality of the Leyden jar in the debates about electricity and the active role of Nollet in its interpretation during the first half of the 18th century, this article discusses how this natural philosopher understood the nature of electricity, interpreted the operation of the device, and explained the phenomena of electrification and discharge, based on his theoretical and experimental conceptions. For this, we analyzed the author's primary sources (Nollet, 1745, 1746a, 1746b), considering the assumptions of the modern historiography of science. This is a meta-scientific study, which seeks to understand the epistemological conditions that make certain scientific interpretations possible in specific historical contexts (Martins, 2004, 2022). Therefore, when analyzing Nollet's (1746a, 1746b) propositions about the Leyden jar, we also reflect on the limits, questions, and scope of their interpretations, avoiding anachronistic judgments and recognizing the role of other scholars to discuss the device.

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<sup>1</sup> To understand the importance of the means of scientific dissemination in the eighteenth century, we suggest Jardim and Guerra (2017).

As Jardim and Guerra (2017) highlight, understanding the scientific work of the eighteenth century entails recognizing it as a culture located across different branches of knowledge, in which several experimenters engaged with the theme of electricity. From this perspective, this article presents a relevant theme for the teaching of physics by bringing the historical discussion about Nollet, a natural philosopher who, although influential in the European scientific scenario of the 18th century and with important contributions to the explanation of the operation of the Leyden jar and the popularization of electricity, is little remembered in books and manuals and rarely mentioned in Portuguese-language productions.

Therefore, it is an original and innovative article in this regard, presenting characters that have not been fully explored to date. Moreover, the work analyzes the problems in Nollet's arguments and recognizes the tentative and provisional character of science. This interpretative effort values the understanding of the processes of construction and validation of scientific knowledge—as opposed to the justification and reinforcement of empiricist and positivist views of science that admit its “evolution”—; and the interests involved and their implications for society and education, in order to open room for a questioning posture and contribute to the didactic potential of historical episodes such as this.

## NOLLET AND THE EXPERIMENTAL NATURAL PHILOSOPHY — HISTORICAL CONTEXTUALIZATION

Since its creation in 1745, the Leyden jar had been the subject of discussion among scholars of electricity (Silva; Heering, 2018). In France, it attracted the attention of several experimenters, among them the abbot<sup>2</sup> Jean-Antoine Nollet (1700-1770). Nollet was born on November 19, 1700, in Pimprez, a small village north of Paris. Coming from a peasant family, he showed an early interest in studying. His talent was noticed by the local priest, who convinced his parents to support his education. With much effort, he was sent to study at Clermont and, later, at Beauvais, with the initial intention of pursuing an ecclesiastical career (Fouchy, 1773; Lecot, 1856).

His manual skills in instrument making soon caught the attention of French academic circles. In 1728, he joined the Société des Arts, where he began to get along with scholars such as Charles Du Fay (1698-1739), with whom he collaborated on investigations into electricity between 1731 and 1733. His competence was also recognized by René-Antoine de Réaumur (1683-1757), who, in 1732, appointed him to direct his laboratory. During that time, Nollet worked on improving instruments, such as the thermometer, and developing an improved darkroom and a lens polishing machine, both approved by the Académie des Sciences in 1733, which consolidated his reputation as one of the most promising experimenters in the Parisian scientific scene (Fouchy, 1773; Maluf, 1985).

In 1734, Nollet went to London, where he met John Desaguliers (1683-1744) and was elected a Fellow of the Royal Society. Two years later, he went to the Netherlands, where he met Pieter van Musschenbroek (1692-1761). In 1738, he published a work on electricity, which received a good reception, leading to increased interest in his lectures and experimental demonstrations in Europe. The following year, he was appointed adjunct to the Académie des Sciences, and his growing influence led, in 1744, to his appointment as the prince's instructor in Versailles (Silva, 2011).

Nollet's interest in electrical phenomena intensified after he read a report on Professor Bose's experiments around 1745. A few months later, he presented his work, entitled

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<sup>2</sup> Abbot (from the French *abbé*) is an ecclesiastical title granted to members of the Catholic clergy, usually linked to religious orders or administrative functions in monasteries.

Conjectures sur les causes de l'électricité des corps [Conjectures on the causes of the electricity of bodies] (Nollet, 1745), to the Académie Royale des Sciences, in which he laid the foundations of his ideas about the nature of electricity. Bose in Germany and William Watson (1715-1787) in England (Silva, 2011) promptly recognized his propositions.

With an already consolidated reputation in the European scientific community, Nollet deepened his investigations in 1746 (Nollet, 1746a) and, with the publication of the book *Essai sur l'électricité des corps* [Essay on the electricity of bodies] (Nollet, 1746b). In this work, he expanded on the ideas formulated in the previous year, discussing, among other aspects, the<sup>3</sup> effluent and affluent currents of electric fluid. The propositions presented generated controversies in Europe, leading him to defend and expand them in a book published in 1749 (Nollet, 1749). This brief biography shows that Nollet was important in the experimental studies of electricity and, therefore, reinforces the importance of this work in which we discuss his ideas.

## THEORETICAL DISCUSSION ON ELECTRICITY: NOLLET AND THE LEYDEN JAR PHENOMENON

In *Conjectures*, Nollet is strongly influenced by Professor Bose's experiments, described in *Tentamina Electrica In Academiis Regiis Londinensi Et Parisina Primum Habita* [Electrical experiments first held at the Royal Academies of London and Paris], published in 1744. Among other experiments, the device capable of electrifying bodies by means of rotating glass globes, driven by a mechanical wheel, caught Nollet's attention. These globes, as shown in Figure 1, provided a more intense and consistent friction than the glass tubes previously used to produce<sup>4</sup> electrical phenomena (Nollet, 1745).

Based on the hypothesis of a single type of electrical fluid and other experiments, Nollet investigated the effects of electrical matter, its origin, its mode of action, and the mechanisms responsible for the phenomena of electricity. He considered electrical matter as the main agent of electrical phenomena, which, according to his analysis, were divided into two large groups: "1st Those alternating movements that received the names of attraction and repulsion; 2nd The phenomena that are accompanied by light or inflammation [...]" (Nollet, 1745, p. 137).

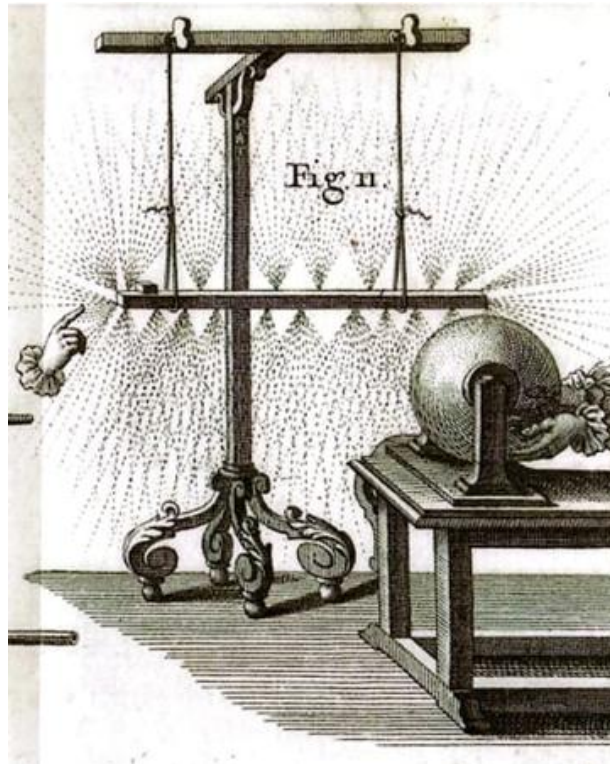
Nollet attributes to electrical matter<sup>5</sup> the characteristics of a subtle fluid, present everywhere, as well as those of fire, establishing a relationship among electricity, fire, and light. In *Conjectures* (Nollet, 1745), he proposes seven properties common to the matter of fire and the matter of electricity, reinforcing the idea that this fluid is not only a consequence of electrical phenomena.

**Figure 1** – Representation of glass globes being rubbed and producing effluent and affluent currents of electrical fluid

<sup>3</sup> The idea of effluent and affluent currents of electrical fluid was built based on the two types of electricity, glassy and resinous, a model proposed years earlier by Du Fay.

<sup>4</sup> One of the phenomena carried out from this experiment was the ignition of alcohol vapors inside an electrified jar, caused by the sparks generated by the glass globes (Silva, 2011).

<sup>5</sup> Nollet (1745), in a footnote, refers to electrical matter with the term "electrical fire", referring to light emissions, or the sparks that explode with them, capable of igniting/firing the vapors and flammable liquids close to them.



Source: Nollet (1746a, plate 3)

The existence of this electrical fluid was indisputable, according to Nollet (1745), and played an essential role in the manifestation of electrical phenomena rather than being a secondary consequence of the process. Thus, he establishes seven propositions related to the characteristics of electrical matter, based on the experimental observations reported in *Conjectures*, which will serve as a starting point for explaining other electrical phenomena.

Friction electrification and communication electrification differ in their characteristics, but both can produce similar electrical effects. Some objects, such as living bodies, metals, and, in general, all matter that cannot be easily electrified by friction, or that are limited, acquire electrical matter more easily and intensely when they come into contact with electrified bodies. These materials are more receptive to electricity by communication (Nollet, 1746a).

On the other hand, materials such as glass, sulfur, resins, wool, and gums, which are more easily electrified by friction, have a very limited ability to receive electricity by communication. However, Nollet (1746a) notes that the effects of electrification, whether by friction or by communication, seem to be essentially the same. Although friction electrification has its value, he considers communication electrification a more effective means of producing electrical effects.

### Effluent and affluent currents

Based on the behavior of electrical matter as a subtle and elastic fluid, Nollet (1745) proposes a system composed of the existence of two currents<sup>6</sup> of electrical matter, which he later names effluent current and affluent current. He explains that electrical matter projects in a progressive, perceptible movement to a certain distance, moving from the inside to the

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<sup>6</sup> These currents in Nollet (1745) are analogous to water flood, as part of the matter that fills everything and that assumes a specific meaning. Thus, the effluent and affluent currents would be opposite "floods," generating a conflict of matter.

outside of the electrified bodies. Moreover, he believes that a similar matter propagates from all directions to the electrified body. This matter comes not only from the surrounding air, but also from all nearby bodies, including the densest and most compact.

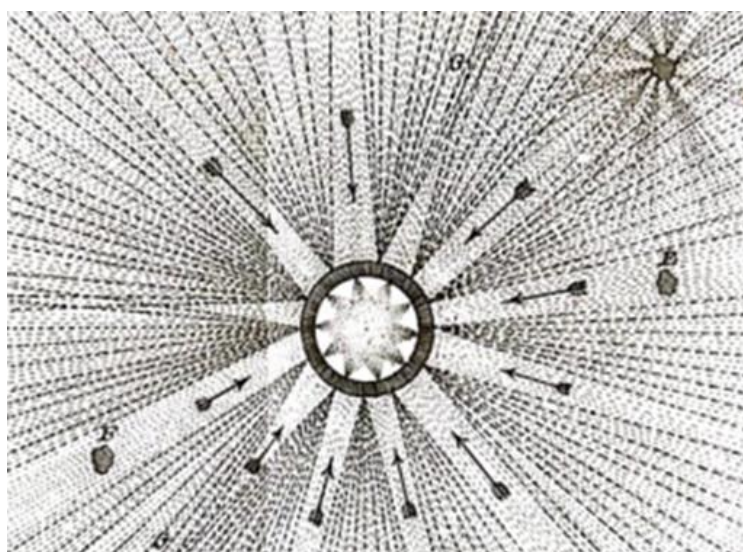
In the interaction between two people, one electrified and the other not, Nollet (1745, p. 124-125) proposes that:

When an electrified person approaches their finger to another who is not electrified, both feel the same sting, and often a strong sensation of pain spreads, reaching the arm of both as if this double impression comes from two flows or currents of elastic matter, moving in opposite directions, whose shock caused them to take opposite directions to those they had before [...] when an electrified body approaches another that is not electrified, simultaneously emanates from both [bodies] a flow of [electrical] matter that feels on both sides like a light breeze, while the two bodies are at a certain distance from each other [...].

He uses the propositions established in the third part of *Conjectures* (Nollet, 1745) to explain how the output and entry of this electrical matter occur in the electrified bodies responsible for the phenomena of attraction and repulsion. From the annular portion of an electrified glass tube, as shown in Figure 2, the electrical matter present in its structure is pressed by friction and agitated by its reaction and by the reaction of the glass that contains it. This causes the matter to move towards the outer surface, propagating outward until it loses velocity.

However, when crossing the glass pores, the air resistance hinders its direct passage, causing the fluid of this electrical matter to spread in different directions in the form of divergent beams, creating a circle of greater or lesser extent according to the intensity of the electrification of the electrical body and the amount of electrical matter involved in the process. As this electrical matter detaches from the electrified body, it leaves small voids in the glass structure, quickly filled by a fluid of the same nature present in the environment (Nollet, 1745).

**Figure 2** - Annular portion of the electrified tube



**Source:** Nollet (1746a, plate 4)

**Note:** The arrows represent the affluent (inlet) currents, and the divergent beams represent the effluent (outlet) currents of electrical fluid.

Nollet compares this phenomenon to that of a perforated vessel submerged in a river: if the water inside the vessel is somehow removed, the surrounding water will flow in, reestablishing the balance of this fluid. The author concludes that

Thus, electrical matter moves in two opposite directions, forming, as it were, two currents, one of which leaves the tube by divergent lines, while the other goes to it by convergent directions: let us call the first of these currents effluent matter, and name the last of affluent matter (Nollet, 1745, p. 139).

These conceptions are important to understand how Nollet interpreted the phenomena observed in the Leyden jar. The distinction between effluent and affluent currents allows us to understand the processes of entry and exit of electrical matter in electrified bodies, offering a coherent explanation of the mechanisms of electrification and discharge in the device. From this interpretation, Nollet will seek to understand the effects of the jar's discharge and the material conditions that enable its operation, aspects that will be discussed in the next topic.

### Electrification and discharge: The “Leyden experience”

On April 20, 1746, three months after reading M. de Réaumur, in the Académie Royale des Sciences, about the Leyden jar experiment described by M. Musschenbroek, Nollet reports to the Academy, through the letter entitled *Observations*, that both he and Pierre Le Monnier (1715–1799) had already carried out a large number of experiments with the objective of observing and analyzing the different aspects that make up the phenomenon of electrification and discharging of the jar (Nollet, 1746b). Nollet is surprised and enthusiastic about the intensity of the excitement caused<sup>7</sup> by the phenomenon presented in Leyden's experiment<sup>8</sup>. His impatience led him not to wait until he could obtain German or Bohemian glass, as recommended in Musschenbroek's letter, before conducting the Leyden jar experiment, and he ended up using an ordinary glass (Nollet, 1746b).

Contrary to what Nollet (1746b, p. 4) imagined, the ordinary glass vial served to carry out the experiment:

This vial, in which I had little confidence, served me beyond what I expected: on the very first attempt, I felt in my chest and bowels a commotion that made me involuntarily bend my body and open my mouth, as occurs in accidents in which breathing is interrupted. The index finger of my right hand, which pulled the spark, received a shock or an extremely violent sting; my left arm was shaken and repelled from top to bottom, to the point of making me drop the half-filled glass of water I was holding.

From there, Nollet could perform Leyden's experiment with an English glass and a Lorraine glass<sup>9</sup>, used in the manufacture of chemical containers. As he succeeds in varying the glasses of different regions, Nollet (1746b, p. 5–6) concludes that Musschenbroek made a mistake regarding the quality of the glass:

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<sup>7</sup> The term "commotion" used here is a physical shock caused by the passage of fluid or electrical fire from one body to another. According to Nollet (1746b), the sudden passage of this fluid, resulting from the flow of effluent and affluent currents, is what causes the electrical commotion, as demonstrated throughout this writing.

<sup>8</sup> When we refer to the “Leyden experiment” in the context of Nollet, we mean the phenomenon of electrically charging and discharging the Leyden jar. We chose this term because Nollet, in his works, referred to the phenomenon in this way.

<sup>9</sup> Region located in Northeastern France.

He [Musschenbroek] must have used, by chance, a Bohemian glass that was quite dry, and, in carrying out a similar experiment with other damp or poorly wiped glasses, obtained distinct results. The expected effect [jar electrification] failed in the latter [English or Dutch glass] and was successful in the former [German glass]; which led him to conclude, based on the type of the glass, something that, in fact, he should have attributed to another cause undoubtedly, and more accurately, he would have attributed this difference to the current state of the vials [...].

Thus, Nollet (1746b) postulates that one essential condition for the electrification phenomenon to occur is that the jar be completely clean and dry, both inside and outside, especially in the empty region above the water. Care should be taken to clean and dry the flask used in the Leyden experiment well, because, according to Nollet, the glass attracts all the vapor particles around it when it becomes electric due to the immersion of the metallic wire in the water contained in the flask. Because of this condition, Nollet informs in the letter that hot water should not be used, as the steam would be attracted by the electrified glass. The optimal element is cold and pure water.

For Nollet, the transparency of the liquid used in Leyden's experiment favors the free movement of the electric fluid into the flask, allowing it to adhere perfectly to its internal surface and transmit electricity with intensity to the glass. As water does not have the opacity of mercury, iron filings, and sand, or the unctuousness of oils, it proves to be the most suitable liquid to carry out the experiment. Besides the observations on the humidity of the glass, the temperature, and the transparency of the liquid used in Leyden's experiment, Nollet (1746b) notes two issues that influence electrification, which we will discuss below.

The first consideration concerns the shape and dimensions of the vial used. Nollet (1746b) notes that the disturbance was less intense the smaller the vial. For him, this is because smaller containers hold less water, resulting in a smaller contact area between the metal rod immersed in the vial and the liquid. Thus, he concluded that he could control the intensity of the disturbance by varying the size of the containers used in the experiment. This phenomenon reinforces a principle that Nollet had proposed in *Conjectures* in 1745. According to him, electrical matter gains strength as it passes through denser bodies than air. Water, in particular, seemed to be the most suitable substance to facilitate this movement of electric fluid, as demonstrated by the experiments.

The second consideration concerns the materials that could or could not replace the glass to carry out the Leyden experiment. Nollet (1746b) repeats the experiment with different materials, concluding that only porcelain, which he considered a semi-divided material, could replace the glass vial. As Nollet observed that only glass and porcelain worked to carry out Leyden's experiment, he considered replacing them with a wax or sulfur container, since these materials were considered electrical bodies. However, when repeating the electrification process with these materials, nothing happened, leading Nollet (1746b) to question the particularity of the new electrification phenomenon observed in the glass vial presented.

As Nollet did not believe in the existence of the two types of electricity, glassy and resinous, he built a sulfur globe to replace the glass globe used in the electrification of bodies. Then he repeated Leyden's experiment, using the sulfur globe to electrify the glass, wax, and sulfur vials, producing sparks only with the glass container. The only difference was the intensity of the commotion: the sulfur globes electrified the bodies less than the glass globe did.

By observing the electrification of the glass vial from the sulfur globe, Nollet (1746b) concluded that the wax and sulfur containers were less suitable than the glass vial to be electrified by communication. He conjectures that, in Leyden's experiment, the vessel

containing water must, at the same time, electrify itself by communication and retain the electricity acquired, even when supported or touched by non-electrical bodies. In addition, it states that only glass and semi-dividers have this double property.

Until then, there was the rule established by<sup>10</sup> Du Fay that an electrified body, either by communication or by friction, lost its electrical virtue when touched or handled by non-electrical bodies. However, for Nollet (1746b), glass should be excluded from this general rule, as it had the double property of being electrified by communication and retaining this electrification. His considerations regarding Du Fay's rule were corroborated by experiments conducted by Le Monnier.

Le Monnier (1746), in a work sent to the Academy at the same time, conjectures that it is not always necessary to place on electrical bodies the objects that one wishes to electrify, concluding that some objects receive electricity on any material, regardless of their nature. In his letter, he further reports that Leyden's experience is not the only exception to the rule established by Gray and Du Fay. He also notes that the electrification of the glass vial apparently intensifies when it is in contact with the hand or other non-electrical body. Thus, he questions whether these materials could provide any substance to the vial that would favor the electrification process.

Unlike Le Monnier, who directly confronts Du Fay's rule, Nollet (1746b) seeks to explain Leyden's electrification phenomenon in terms of the previously mentioned properties of glass. He uses the principles of electricity previously reported to the Academy, which he considers well-founded and less dependent on conjecture, to explain the new phenomenon.

Nollet (1746b), both in *Observations* and in his book *Essai sur l'électricité* [An essay on electricity] (Nollet, 1746a), published in the same year, acknowledges Le Monnier's observations. Why, then, did Nollet not seek to answer the contradiction presented by Leyden's experience regarding Du Fay's rule? Was it out of respect for Du Fay or the fact that he had already published *Conjectures* a year earlier?

He apparently avoided explicitly disagreeing with the propositions already established by Du Fay and chose to reinterpret the phenomenon presented in Leyden's experience. This stance may also be related to the publication of *Conjectures*, in which Nollet (1745) had just presented his propositions on the effluent and affluent currents of electrical fluid, i.e., his own theory of electricity.

Instead, Nollet (1746a) integrated Leyden's experience into his propositions about the nature of electricity, presented in *Conjectures* (Nollet, 1745) and later in his book *Éssai* (Nollet, 1746a), attributing to glass particular properties that justified its distinct behavior in experience. Thus, he explains that both the output of the effluent flood and the input of the affluent flood, which constituted the flow in opposite directions and, consequently, the electrification, do not happen when a person places the electrified vial on a piece of resin. In carrying out Leyden's experiment, Nollet (1746a) repeats the mechanism necessary for electrification and extraction of sparks from the flask. First, he holds in one hand a glass or porcelain jar, partially filled with water, where the end of an electrified metal rod is dipped. Then, when the other hand is brought closer to the metal rod to cause a spark, a violent and sudden commotion in both arms (and, often, also in the chest, in the bowels, and in the whole body in general) is felt.

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<sup>10</sup> Du Fay made it a rule that for a body to be electrified, it needed to be supported on a thick electrical material, i.e., insulated. According to him, this experimental configuration would prevent the electrical matter acquired during the electrification process from dissipating (Heilbron, 1979).

Observing a sudden light in the flask filled with water and an internal pain (inside the body) when performing the experiment, both under similar circumstances, he conjectures that the person extracting the spark from the electrified flask also possesses a certain amount of a subtle fluid. The repercussion of this electrical fluid is felt with greater or lesser intensity, more or less deeply, in proportion to the force of the shock received (Nollet, 1746a).

He states that if the shock is double, occurring simultaneously at two points and being significantly stronger on both sides than usual, it may, instead of just causing stings and small localized jerks in the experimenter, result in a more intense and probably generalized commotion in the subject performing the experiment. This is the case when carrying out the Leyden experiment:

[...] a strongly electrified mass is held with one hand, while a spark is caused with the other; the electrification manifests itself simultaneously at two opposite points on a very subtle fluid, which transmits its impact to the entire person who is impregnated with it. If I am mistaken in this conjecture, here, at least, are facts that are certain and that, however, seem to be their consequences. When I interrupt the continuity of this fluid, on which I suppose the electrification acts at the same time at two points, the commotion becomes incomparably weaker, as if the fluid were less pressed and more free to escape from this double impact. If I reestablish its continuity through diaphanous bodies<sup>11</sup>, the commotion returns to its original intensity and manifests itself by a luminous brightness. We will be able to better judge the value of these results when I report the experiences as I carried them out (Nollet, 1746b, p. 17).

Thus, for Nollet (1746b), the spark and the commotion felt in Leyden's experience are the result of the encounter of two flows of currents that move in opposite directions: an effluent and an affluent one. For him, the spark perceived in the experiment is born from the junction of these two flows, and their interaction can cause a repercussion similar to that of two rows of elastic bodies that collide. This repercussion of the electrical fluid, which Nollet called an electrical impulse, acts simultaneously at two opposite points of the same body/object, propagating itself as a fluid that transfers its movement to the other parts of the same matter. Nollet (1746a, p. 195) compared this effect to what occurs in a liquid-filled barrel: "The walls of a barrel are usually compressed when pressing the liquid it contains; and if this pressure occurs at two points on the liquid, all solids in contact with it are affected even more intensely." Figure 3 shows the representation of the comparison performed by Nollet.

To test the propositions related to the observation of internal shock in diaphanous materials through luminosity, the repercussion of electrical fluid in a body, and the double shock, which occurs simultaneously at two points, Nollet (1746a) performs three experimental arrangements.

**Figure 3** – Representation of the comparison performed by Nollet

<sup>11</sup> It is a body/material that allows the passage of light almost totally; a transparent, clear body; an ordinary glass (without impurities or textures, for example).



**Source:** Prepared by the authors, 2025

**Note:** A represents one person's hand, B represents another person's hand. C and D represent the internal parts of the barrel that are taking an impact and transferring the pressure to the liquid.

The first experiment investigated whether the commotion generated from the Leyden experiment could be observed in diaphanous containers. Nollet (1746a) states that if the electric fluid, when compressed, tends to become luminous, then the commotion generated could be observed when crossing these containers. The author performs an experimental arrangement in which two people hold the ends of a glass jar filled with water, while one of them causes the spark:

To this end, instead of using only one person [for spark extraction], I use two: one holds the vessel full of water, while the other causes the spark, and I have each one hold, by one end, a glass tube full of water<sup>12</sup>. When the explosion occurs, and the two living bodies feel the commotion, the intermediate tube that unites them glows with a luminous glow as sudden and short-lived as the shock that hits the two people subjected to this experience. Isn't it more than likely that we would see the same [glowing] effect on ourselves if we were transparent like glass and water? (Nollet, 1746a, p. 196-197).

Nollet (1746a) does not make clear how the two bodies are connected to form a circuit through their interaction. This leads us to assume that they are directly connected, as illustrated in Figure 4.

According to Nollet (1746a), the matter/body subjected to the shock must be continuous and uninterrupted, and this is an indispensable condition for the success of Leyden's experiment. If this conjecture is true, as he supposes, the resulting commotion in the experiment is transmitted and distributed uniformly to all parts of the matter affected by means of the electric fluid, after the double repercussion. The second experiment carried out

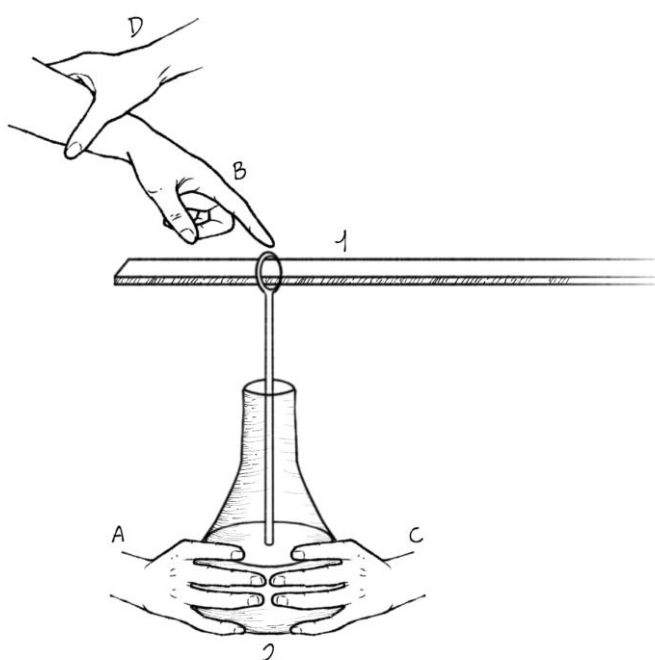
<sup>12</sup> This excerpt appears as follows in the original: “& je leur fais tenir à chacune par un bout un tube de verre rempli d'eau”. We understand that there is an error in this section of Nollet (1746a, 196–197), because the glass tube does not need to be full of water for the phenomenon to occur. All Nollet's phenomena represent a glass tube that serves as a mean, water has no role in the described process.

by Nollet (1746a) aims to observe the effect of commotion when two people do not touch each other directly:

I interrupted it, therefore, on purpose, making the experience, as before, with two people, but who, instead of being united by an intermediate solid body, did not touch each other at all; the result was as I expected, the internal commotion failed, and the effect was reduced to a very violent sting for the one who caused the spark, and to a very strong shake, but which did not pass into the hand of those who held the vessel full of water (Nollet, 1746a, p. 197–198).

Figure 4 shows the representation of the first arrangement.

**Figure 4** – Representation of the first arrangement

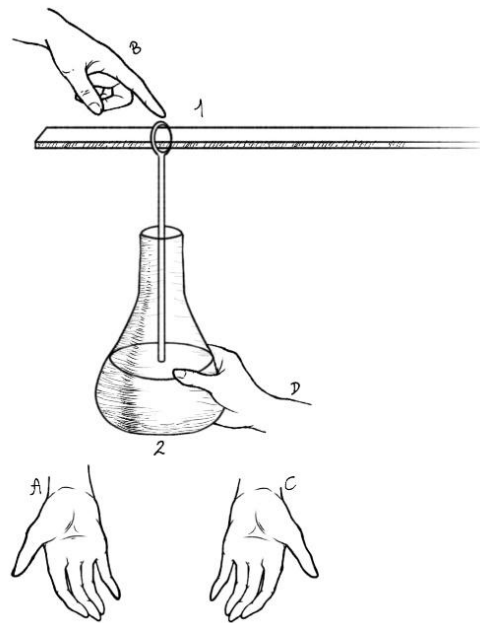


**Source:** Prepared by the authors, 2025.

**Note:** Hands A and B belong to the same person, and hands C and D belong to the second person. In this representation, what Nollet mentions can happen.

Nollet (1746a) observes what he had speculated at first. Internal commotion does not occur, and the effect is reduced to an intense sting for the person who causes the spark and a localized shake/commotion for the other person holding the jar of water, as shown in Figure 5. Therefore, he concludes that the continuity of electrical matter is essential for the commotion to propagate through the body.

**Figure 5** – Representation of the second arrangement

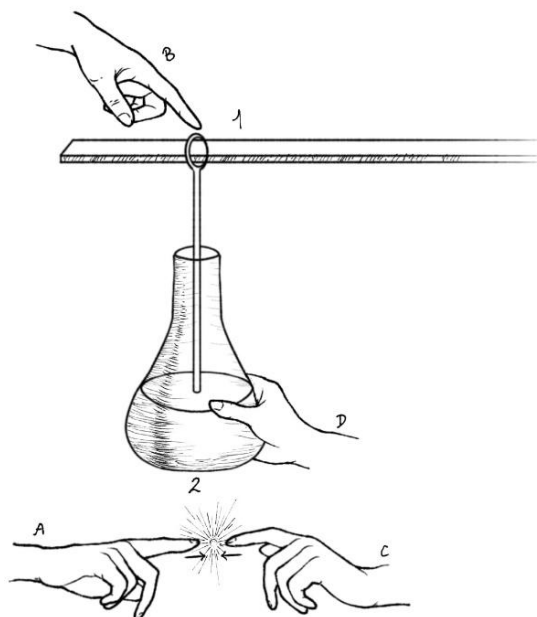


**Source:** Prepared by the authors, 2025

**Note:** A and B represent the hands of the first person, C and D the hands of the second person. In this configuration, people do not touch each other, so a circuit is not formed.

Finally, Nollet (1746a) performs a third experiment, shown in Figure 6, to verify whether, at the moment of the spark, a wire or a radius of internal electrical matter is struck by two extremes, producing a double shock that occurs simultaneously at two opposite points. This phenomenon reinforces his conception that the commotion in Leyden's experience results from the interaction and simultaneous repercussion of the electric fluid throughout the human body.

**Figure 6** – Representation of the third arrangement



**Source:** Prepared by the authors, 2025.

**Note:** A and B represent the first person, C and D the second person. In this configuration, the first person extracts sparks from the metal rod, while the second person holds the glass vial. As they approach the ends of the fingers of the other hand, they will observe a spark preceded by a subtle glow that represents the encounter between the two currents, effluent and affluent, of electrical fluid.

We can conclude that Nollet (1746a, 1746b) believes the phenomenon of electrification in Leyden's experiment is a system composed of: experimenter-glass flask-primary source. That is, the person holding the vial with one hand, while electrifying the water in it, acts as a double-flow agent for the opposing electrical currents: the effluent and affluent currents. The affluent flood travel from the outside of the jar to the experimenter, from the hand holding the jar, while the effluent flood exits the experimenter's body towards the jar.

By touching the metal rod contained in the vial (that is connected to the primary source) with the other hand, a new, more intense, double flow is established between the metal rod and his body. This creates an electrical circuit using the body's own electrical fluid. Thus, at this very moment, the experimenter is hit simultaneously by the affluent currents of the jar and the primary source, which forces the internal expulsion of the effluent currents from his body.

It is, therefore, the sudden compression of the electric matter/fluid present in the arms, chest, and other regions of the body that generates the violent and painful electric commotion characteristic of Leyden's experience and the consequent bright spark at the end of the finger that touches the metal rod from the simultaneous exit and entry of the opposite currents, i.e., from the encounter between them at the end of the finger and the metal rod.

### Considerations regarding Nollet's observations and propositions

In our work, we saw that Nollet sent *Conjectures* to the Académie in 1745 and *Observations* in early 1746; in other words, his propositions about the nature of electricity. He answers the questions presented by Leyden's experiment, integrating the new phenomenon into his conceptions/propositions about the causes and nature of electricity, published in the book *Essai*, approved by the Académie on August 20, 1746.

In his works, particularly in *Essai* (1746a), Nollet explains the various ways he used Leyden's experiment, exploring different arrangements to answer 17 questions about the characteristics and nature of electricity. In addition to the issues already discussed throughout this writing, we note that Nollet uses Leyden's experiment to corroborate the propositions presented in both *Conjectures* and *Observations*, establishing an analogy between fire, light, and electricity:

Through the experiences and observations reported in this question, it seems that the matter that causes electricity, or that operates its phenomena, is the same as that of fire and light. Would a matter that burns, that enlightens, and that has so many common properties with which it ignites bodies and makes us see objects something other than fire, something other than light itself? (Nollet, 1746a, p. 134–137).

Although quite elucidatory, Nollet's (1746a) propositions are open to question. If an electrified body loses its electrification when touched by a non-electrical body, why, when holding the vial with the hand (a non-electrical body), does it not prevent the loading of the Leyden jar? On the contrary, this condition seems to intensify the effect. Nollet (1746a) attributes to glass particular properties that justify its distinct behavior from other electrical bodies, such as the ability to be electrified by communication and retain this electrification

simultaneously. However, his propositions are fragile when it comes to explaining this phenomenon consistently.

Also, if materials like sulfur and wax were considered electrical bodies at the time, why didn't they work in Leyden's experiment? Nollet (1746a) only conjectures on the subject, without offering a clear explanation of why glass and porcelain have properties more suitable for electrification by communication, while materials such as sulfur and wax, even though electrified by friction, are less susceptible to this type of electrification.

Why can some bodies hardly be electrified if they are not supported on a non-electrical body/material or in contact with that body? In his proposition, Nollet (1746b) agrees with Le Monnier's hypothesis, according to which the experimenter's hand could provide a substance to the jar, facilitating its electrification. However, Nollet does not present an explanation for the mechanisms involved, merely stating that this condition contradicts the rule previously proposed by Du Fay. Such a lack of clarification reveals a fragility in its propositions.

Another question that arises is: what exactly causes the spark and the sensation of commotion in the body? Nollet (1746b) proposes that the spark is the result of the double shock between two flows of electrical matter, the effluent and affluent currents, which move in opposite directions. And the electric commotion is due to the double repercussion of the electric fluid throughout the experimenter's body. However, Nollet's explanation of Leyden's experience is based on his propositions, presented in *Conjectures* (Nollet, 1745), of affluent and effluent currents.

We can conclude that, despite his efforts to incorporate the new phenomenon presented in Leyden's experience into the propositions formulated in *Conjectures*, fundamental questions remained unclear. Instead of directly investigating these gaps, Nollet (1746a, 1746b) chooses to reaffirm his previous hypotheses, even when they demonstrate evident weaknesses in the face of new experimental evidence.

Nollet's propositions, widely disseminated in Europe, did not escape criticism. His ideas about affluent and effluent currents, as well as his interpretation of the Leyden jar's functioning, sparked debate among the natural philosophers of his time. His theory was met with controversy, which led him to publish, in 1749, another work in which he sought to defend and expand his hypotheses (Nollet, 1753). In the same period, new interpretations about the nature of electricity began to circulate.

It was in this context that the hypothesis of the American Benjamin Franklin (1706–1790) began to gain prominence, according to which electricity would be constituted by a single fluid, capable of manifesting itself in positive (excess) and negative (deficiency) states. His book, published in London in 1751, quickly resonated in France, in part thanks to the translation of Thomas-François Dalibard (1709–1778), carried out at Buffon's encouragement. The absence of mention of Nollet in the preface of this translation and the success in repeating Franklin's experiments marked a period of intellectual tension (Torlais, 1956).

Nollet responded by publishing a series of letters, some addressed to Franklin himself, in which he challenged the US polymath's ideas, reaffirmed his own, and defended his approach to the investigation of electrical phenomena in the eighteenth century<sup>13</sup>. Franklin's hypothesis also had gaps, both in the jar's functioning and in other explanations, according to Moura (2018, 2019). Still, it became better known—and better recognized—than Nollet's. Franklin was not as well recognized by the Academy in the eighteenth century, nor did he have as many practical skills as Nollet, yet he was better known. It is in this sense that studies, through the History of

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<sup>13</sup> For a more detailed explanation, we suggest reading Morais (2025).

Science, of not very well-known episodes and characters can elucidate our knowledge of the way science is done.

## FINAL CONSIDERATIONS

From a historiographical point of view, the historical episode analyzed exhibits characteristics of the scientific practices of the eighteenth century, marked by the formulation of hypotheses and experimental investigation aimed at interpreting phenomena still poorly understood. When we return to Nollet's (1745, 1746a, 1746b) propositions about the nature of electricity and the phenomena linked to the Leyden jar, with their attempts to explain based on effluent and affluent currents, we show that phenomena can present different interpretations and concepts change meaning over time and space. In addition, questions that the character did not answer, as highlighted in the text, illustrate the efforts to interpret a new and challenging phenomenon at the time.

To analyze the phenomenological problem in the historical episode, it was necessary to conduct an experimental investigation in replicas of the Leyden jar. This investigation demonstrated its formative potential, as the different theoretical and practical aspects involved constitute a fertile field for the development of didactic-pedagogical proposals in school contexts, promoting dialogue between the history of science and the teaching of physics. Thus, when studying episodes in the history of science such as this, we advocate the incorporation of investigative practices to understand hypotheses and results. From this perspective, the teacher and the student are faced with situations that, considering the knowledge about electricity and matter in the eighteenth century, seemed unexplained.

Finally, the analysis of Nollet's (1746a, 1746b) propositions on the electrical phenomena associated with the Leyden jar reinforces the importance of historical case studies and the production of didactic materials that break with reductionist and decontextualized approaches to science.

## AUTHORSHIP CONTRIBUTION STATEMENT

**Conceptualization; Formal analysis:** Morais, T. B.; **Research:** Morais, T. B.; Silva, A. P. B.; Pinto, A. F.; **Methodology:** Morais, T. B.; Pinto, A. F.; **Project administration:** Morais, T. B.; Silva, A. P. B.; Pinto, A. F.; **Supervision:** Silva, A. P. B.; Pinto, A. F.; **Writing - Preparation of the original draft:** Morais, T. B.; **Writing - Review and editing:** Morais, T. B.; Silva, A. P. B.; Pinto, A. F.

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Not applicable

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