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REVIEW ARTICLE

Priestley, Scheele, Lavoisier, and the Burning Lenses

Priestley, Scheele, Lavoisier y las lentes ardientes

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ABSTRACT

The purpose of this article was to familiarize readers with burning lenses, which were used by 18th century by some English and French chemists as a means of reaching high temperatures. However, not all experiments have given satisfactory results. The failures in the melting platinum using various burning lenses led Lavoisier to develop a new method of melting platinum using oxygen. In addition, in this article a literature was reviewed, including books on chemistry and the history of chemistry published in various countries to discuss the problem of oxygen discovery by Joseph Priestley (1733-1804), Carl Wilhelm Scheele (1742-1786) and Antoine Laurent Lavoisier (1743-1794).

Keywords: Burning lenses; J. Priestey; C.W. Scheele; A. L. Lavosier; Platinum.

RESUMEN

El propósito de este artículo era familiarizar a los lectores con lentes ardientes, que fueron utilizados por algunos químicos ingleses y franceses en el siglo XVIII como un medio para alcanzar altas temperaturas. Sin embargo, no todos los experimentos han dado resultados satisfactorios. Las fallas en el fundido de platino usando varias lentes ardientes llevaron a Lavoisier a desarrollar un nuevo método para fundir platino usando oxígeno. Además, en este artículo se revisó una literatura, incluidos libros sobre química y la historia de la química publicados en varios países para discutir el problema del descubrimiento de oxígeno por Joseph Priestley (1733-1804), Carl Wilhelm Scheele (1742-1786) y Antoine Laurent Lavoisier (1743-1794).

Palabras clave: Lentes ardientes; J. Priestey; C.W. Scheele; A. L. Lavosier; Platino.

INTRODUCTION

The use of a burning lens by Priestley to obtain dephlogisticated air

A burning lenses were used in the 18th century by some chemists as a means of reaching high temperatures. One of them was the English chemist Joseph Priestley (1733-1804). He was a gases researcher. Priestley discovered, among others, dephlogisticated air (today's oxygen) by heating by means of a burning lens red oxide of mercury (mercuric oxide - HgO). Here is a description of the feelings he experiences about this experiment. "But having afterwards procured a lens of twelwe inches[1] [30.48 cm] diameter, and twenty inches [50.80 cm] focal distance, Iproceeded with great alacrity to examine, by the help of it, what kind of air a great variety of substances, natural or factitious,...With this apparatus, after a variety of other experiments, an account of which will be found in its proper place, on the 1st of August, 1774, I endeavoured to extract air from mercurius calcinatus per se [HgO]; and I presently found that, by means of this lens, air was expelled from it very readily... But what suprized me more than I can well express, was, that a candle burned in this air with a remarkably vigorous flame, " (Priestley, 1776, pp. 33-34). "My reader will not wonder, that, after having ascertained the superior goodness of dephlogisticated air by mice livin in it,...I should have the curiosity to taste it myself. I have gratified that curiosity, by breathing it,...The feeling of it to my lungs was not sensibly different from that of common air. I fancied that my breast felt peculiary light and easy for some time afterwards. Who can tell but that, in time, this pure air maybecome a fashionable article in luxury. Hitherto only two mice and myself have had the privilege of breathing it" (Priestley, 1776, p.102).

Scheele's request to Lavoisier to conduct an experiment using burning lens

On September 30, 1774, the Swedish chemist Carl Wilhelm Scheele (1742-1786) wrote a letter to French chemist Antoine Laurent Lavoisier (1743-1794) in Uppsala. Édouard Grimaux (1835-1900), professor at the Polytechnic School in Paris, published on January 15, 1890, the original French version of this letter in the article with the title *Une lettre inédite de Scheele à Lavoisier* (An unpublished letter from Scheele to Lavoisier). In the letter, Scheele[2] asks Lavoiser to carry out an experiment involving the purchase of an "fire air" (oxygen) by means of burning lens. Scheele also asks for Lavoisier to inform him about the results of this experiment (Grimaux, 1890, pp. 1-2).

A fragment of Scheele's letter to Lavoisier translated from French to English, is as follows: "Sir, …Although I do not have the honor of being known by you, I am taking the liberty of thanking you very humbly. I desire nothing with as much ardor as to be able to show you (*sic*) my gratitude. … Because I do not have a big burning glass, please try it with yours this way. Dissolve silver in nitrous acid and precipitates it with alkaline tartrate [potassium carbonate], wash this precipitate, dry it, and reduce it [silver carbonate] with the burning glass in your machine fig.8; but because the air in this bell jar is such that the animals die in it and a part of the fixed air separates from the silver in this operation, it is necessary to put some quick lime [calcium oxide] in the water where one has putt the bell, so that this fixed

1 The French inch was equal to 2.7 cm, the English inch was 2.54 cm" (Smeaton, 1987, p. 265). In the article the conversions have been made from French or English inches, respectively.

2 In the introduction of the letter, Scheele wrote a few words of thanks for a book which Lavoisier sent him. "When Lavoisier published his *Chemical Opuscules*, which appeared in January 1774, he sent copies to a large number of scientists: Bergman, Scheele, Franklin, Guyton de Morveau, Priestley, etc., as well as to the French and foreign Societies" (Grimaux, 1890, p. 1).

air [carbon dioxide] joins faster with the lime. It is by this mean that I hope that you will see how much air is produced during this reduction, and whether a lighted candle can sustain the flame and the animals live within it. I will be infinitely obliged if you let me know the result of this experiment. I have the honor to be always with great esteem, Sir, Your very humble servant. At Upsale, September 30, 1774. **C.W. Scheele**" (Grimaux, 1890, pp. 1-2).

Jean-Pierre Poirier in his *Lavosier. Chemist, Biologist, Economist,* briefly described the contents of this letter using modern chemical language: "On September 30, 1774 Scheele thanked Lavoisier for the book and sugested a protocol for producing a large quantity of fire air using burning glasses. It required dissolving silver in nitric acid, precipitating it by using potassium carbonate, washing and drying the precipitate of the silver carbonate and then subjecting it to the fire of the burning glass, taking the precaution of placing a little quick lime under the ball jar to absorb the fixed air discharged during the operation" (Poirier, 1998, pp. 77-78). He also informed the reader that Scheele's letter remained unanswered. "Lavoisier received Scheele's letter on October 15, 1774, but he did not answer it. … He was undoubtedly very busy, but it sems to be a weak excuse for a man who was usually so punctual in his correspondance. The Swedish historians of sciences have still not forgiven him for what was much more than simple rudeness. It is difficult to disagree with them", wrote Poirier (1998, p. 78).

Lavoisier and the burning lenses

Figure 8, which Scheele mentions in his letter to Lavoisier, is among many other drawings, at the end of the book by Lavoisier, with the title *Opuscules Physiques et Chimiques* (Lavoisier, 1774, p. 491*)*. It illustrates the experiment carried out by Lavoisier with the minium [red lead, oxide of lead][3] (Lavoisier, 1774, pp. 256-265). Lavoisier used in this experiment, the big burning lens, made by Tschirnhaus[4], belonging to Count Théophile Malo Correct de la Tour d'Auvergne (1743-1800) (Lavoisier, 1774, p. 257). It was about 33 inches (89 cm) in diameter (Poirier, 1998, p. 54; Smeaton, 1987, p. 266). In the years 1772-1773, Pierre Joseph Macquer (1718-1784), Louis Claude Cadet de Gassicourt (1731–1799), Antoine L. Lavoisier and Mathurin Jacques Brisson (1723–1806) used this lens in their experiments along with another Tschirnhaus lens[5], belonging to the Royal.

3 Lowry, 1915, p. 229.

4 Ehrenfried Walther von Tschirnhaus (1651–1708), Lord of Kieslingswalde and Stolzenberg was born on April 10, 1651 in Kieslingswalde in Saxony (now, Sławnikowice, Poland), on the estate, which his family had owned for 400 years. In the years 1676-1679, Tschirnhaus first went to France and then to Italy. During this period of his life, he was particularly interested in using mirrors and lenses to produce high temperatures necessary for the melting of metals and minerals. Most of the time he participated in joint experiments with François Villette (1621-1698) in Lyon (Smeaton, 1987, p. 265), Athanasius Kircher (1602-1680) in Rome and Manfredo Settala (1600–1680) in Milan. In the years 1679-1692, the Tschirnhaus was in a family estate. His passion at the time was mathematics. He also devoted a lot of time to the production of large burning glasses. He also carried out experiments using these glasses (Eloge de M. De Tschirnhaus, 1709; Kracht, & Kreyszig, 1990, pp. 21-22; Sztejnberg, 2016).

5 This lens had a diameter of 33 inches (89 cm). It were used by Guillaume (Wilhelm) Homberg (1652-1715) and Etienne-François Geoffroy (1672-1731) in the first decade of the 18th century as a means of reaching high temperatures. It was bought by Philip II of Bourbon-Orleans (1674-1723), Duke of Orléans, who gave it to the Paris Academy of Sciences (Smeaton, 1987, p. 265). Homberg and Geoffroy used it to examine the effect of heat on some metals. Homberg, thanks to his experiments showed "that gold and silver are volatile metals in the fire of the Sun, like other metals in the fire of our furnaces" (Homberg, 1702, pp. 141-142). Geoffroy in his paper entitled "Experiments on Metals, Made with the Burning Glass of the Royal Palace" described his observations of four

Academy of Science of Paris (*L'Académie Royale des Sciences de Paris*). They worked with both lenses from August 14 to October 17, 1772, and conducted 192 experiments during which they heated many substances. Melting experiments were performed, including, among others, diamonds, iron, platinum, gold, tin, silver, zinc, and cobalt. The second series, 28 experiments, were carried out from March 14 to August 14, 1773. During this period, experiments on heating were carried out with diamond powder, mercury, manganese, and carbon. For, example, mercury from the cinnabar [mercuric sulfide, HgS], put in a hard porcelain dish, evaporated in its entirety without any residue (Lavoisier, 1865a, pp. 284-348).

In October 1774, a experiments on heating of various substances were carried out by using a new lens, which was presented to the Academy by Jean Charles Philibert Trudaine de Montigny (1733-1777), president of the Academy in 1773. The lens (fig.1) called the Great Burning Glass of Mr. Trudaine (*du Grand Verre Ardent de M. Trudaine*). It "consisted of two segments of a glass sphere of 8 feet (2.60 m) radius, sealed together to leave a space 4 feet (1.30 m) in diameter and 6 5/12 inches (17 cm) thick filled with alcohol. With an 8-inch (22 cm) auxiliary lens of solid glass it brought the sun's rays to a focus less than an inch (2.7cm) in diameter, it was hoped, a higher temperature than any previous instrument" (Smeaton, 1987, pp. 267-268). Trudaine de Montigny, Macquer, Cadet, Lavoisier, and Brisson worked with this lens in the *Jardin de l'Infante* (Garden of the Infante), near the Louvre, where the Academy was then housed. On October 5, 1774, it took about half a minute to melt *d'un gros sou de cuivre* (a big copper penny). On October 15, 1774, Pedro Pablo Abarca de Bolea, comte d'Aranda (1719-1798), Spanish ambassador to France in 1773-1784, placed to the focus of the sun's rays some French silver coins. It turned out that the piece of 3-pound coin (*3 livres*) was melted in a few seconds, and the 6-pound (*6 livres*) coin took a little longer to melt (Trudaine de Montigny, Macquer, Cadet, Lavoisier, & Brisson, 1774, pp. 68-70).

The Great Burning Glass of Mr. Trudaine turned out to be a very useful instrument. According to researchers, "it is very superior to anything we've ever done in this genre. We look at his performance as a beautiful monument of advances in optics and industry. This is an essential service that Mr. Trudaine has rendered, not only to the Academy, but to anyone interested in perfection sciences and arts" (Trudaine de Montigny et al., 1774, pp. 71-72).

Platinum and the burning lenses. Lavoisier's new method of melting platinum using oxygen

Among the metals with which Lavoisier, Macquer, Cadet, Brisson, and Trudaine de Montigny experimented in 1772-1774, platinum was extremely resistant to melting tests with burning lenses.

In a letter to Priestley of June 7, 1782, Benjamin Franklin (1706-1790) informed him of the melting of platinum[6] by Lavoisier. The day before, Franklin was present at the Academy. Lavoisier in the presence of the Count Du Nord[7] demonstrated the melting of platinum in an oxygen blast. A fragment of Franklin's letter to Priestley, is as follows: "Yesterday the Count du Nord was at the Academy of Sciences, when sundry Experiments were exhibited for his

metals: iron, copper, tin and lead (Geoffroy, 1709, pp. 162-176). The English version of this article has been published in *Philosophical Transactions* (Geoofroy, 1708/1709, pp. 374-386).

6 In the article written by William Arthur Smeaton (1925-2001), the reader finds information about earlier attempts to melt platinum (Smeaton, 1984).

7 The Count du Nord, later Emperior of Russia (Tsar) Paul I (1754-1801) was the only son of Catherine II (1729-1796), Empress of Russia.

entertainment; among them, one by M. Lavoisier, to show that the strongest fire we yet know, is made in a Charcoal blown upon with dephlogisticated air. In a Heat so produced, he melted Platina presently the fire being much more powerful than that of the strongest burning mirror" (Duveen & Klickstein, 1955, p. 119).

Leslie B. Hunt in his article, *The First Real Melting of Platinum,* briefly described Lavoisier's platinum melting experiment. In his "spectacular experiment", Lavoisier directed "the stream of oxygen into a hollowedout piece of charcoal in which he had placed a small quantity of the metal" (Hunt, 1982, p. 85).

In an article published in November 1782, Lavoisier described the construction and use of the apparatus, which proved to be very helpful in melting platinum. In addition, wishing to emphasize his success, he recalled earlier failures. He wrote: «*On sait que jusqu'ici on n'avoit encore trouvé aucun moyen de fondre la platine brute; M. le Baron de Sickingen & M. le Comte de Milly étoient parvenus à la ramollir & à la forger, mais ils n'avoient pu la faire couler; enfin la grande loupe de M. Trudaine ne l'avoit pas même amollie; j'étois donc déjà assuré par cette seule expérience, d'être en possession d'un moyen de produire une chaleur beaucoup plus forte qu'aucune de celles qu'on eût employées jusqu'ici...».*

The translation of the French text is the following: "We know that so far we have not found any way to melt the platinum raw; Mr. Baron de Sickingen and Mr. Count de Milly were able to soften and forge it, but they could not make it flow; lastly, the big magnifying glass of Mr. Trudaine had not even softened it; I was already assured by this experience alone, to be in possession of a way to produce a much stronger than any of the hitherto used..." (Lavoisier, 1782, p. 460).

In a short article entitled "Note on Platinum Fussion", which was published in *Oeuvres de Lavoisier,* IV, Lavoisier highlighted the importance of his discovery of the method of melting platinum. "A French chemist has an important secret which he thinks he ought to pay homage to the government. By adding new experiences to those already made on platinum, he found a way to make this malleable metal, to form bars, and the processes which it employs to fill this object are neither more difficult nor more complicated than those which one employs to extract the iron of its mines in the large works...Platinum treated and purified by its process ... it is likely to extend, to take all the forms that it is considered appropriate to give to it, to be used in jewelry, in crockery, in kitchen utensils, coins and medals; it is indestructible and unalterable to fire like gold, and is infusible by every degree of fire known; and lastly, it is not attackable by any of the acids which enter into the composition of food" (Lavoisier, 1868, p. 470).

Was Lavoisier the discoverer of oxygen, like Scheele and Priestley, or should he be considered a reformer of chemistry?

In 1789, a book written by Lavoisier entitled *Traité Élémentaire De Chimie* (Elementary Treatise Of Chemistry) was published. Lavoisier wrote in this book, that he is the discoverer of oxygen, like Priestley and Scheele. The translation from French into English is as follows: "This air, which we have discovered almost at the same time, Mr. Priestley, Mr. Scheele, and myself, has been named by the first, with a air déphlogistiqué [*dephlogisticated air*]; by the

second, air empiréal [fire air]. I first gave him the name of d'*air éminemment respirable* [eminently respirable air]: since then, it has replaced that of d'*air vital* [vital air]" (Lavoisier, 1789, p. 38).

A book entitled *A Chemico-Medical Essay to Explain the Operation of Oxigene, or the Base of Vital Air on the Human Body* was published in 1797, in Philadelphia. The author of this book, Benjamin De Witt (1774-1819), expressed his attitude towards Pristley's discovering of "dephlogisticated air" or "pure air", as well as Scheele's discovering of "empyreal air" and Lavoisier's discovering of "vital air". "Mr. Scheele, it is said, made the discovery also nearly about the same time, though he did not know of Dr. Priestley's experiments. Lavoisier says he also discovered it; but it is more probable, that he received the hint in a conversation with Priestley when in France" (De Witt, 1797, p. 9).

Baron Henry Brougham (1778-1868), was another person who did not like that Lavoisier considered himself an oxygen discoverer. He expressed his opinion on this subject in the book entitled *Lives of Philosphers.* "Priestley is the undoubted discoverer of oxygen. He was the first who communicated a knowledge of it to Lavoisier, at Paris, soon after he had made the discovery; nor can anything be more disingenuous than that celebrated person's afterwards affirming that he, Priestley, and Scheele, had all discovered it "about the same time." He never discovered it until Priestley discovered it to him" (Brougham, 1855, p. 76). Further, in the text of the same book, Brougham gave the reader information about the exact date of Priestley's oxygen discovery and that Priestley and Scheele did not discover oxygen, almost at the same time. "Now I begin this statement by observing, that as to the precise time of Dr. Priestley's discovery there is no doubt; no "presqu'en même tems;" it was the first day of August, 1774. Scheele, without knowing of his discovery, made the same the year after, 1775. So far then the statement of Lavoisier is incorrect; Priestley and Scheele did *not* discover oxygen, "presqu'en même tems." (Brougham, 1855, p. 304).

Albert Landenburg (1842-1911) had the same opinion as Brougham. "Lavoisier also wrote a treatise on oxygen, but Priestley states that he had previously informed Lavoisier of his discovery, although the latter makes no mention of this. ... It is to be deplored, but unfortunately it seems to be established, that Lavoisier repeatedly tried to appropriate to himself the merits of others. I do not enter further into this matter here, because I regard it as inessential in the history of the development of chemistry. A man's own period is concerned with his personal qualities, and history with his works. Lavoisier paid with his life both for faults which he committed and for faults which he did not commit. His own time judged him. Posterity may regard him with admiration and indulgence" (Landenburg, 1911, p. 17).

The British chemist Sir Thomas Edward Thorpe (1845-1925), was the author of the book entitled *Essays in Historical Chemistry* that was published in London in 1894. Thorpe strongly disagreed that Lavoisier had discovered oxygen. He gave many interesting facts about this in his book (pp. 119-121). He referred, among other things, to the book written by French chemist Marcellin Pierre Berthelot (1827-1907) with the title *La Révolution Chimique: Lavoisier; ouvrage suivi de notices et extraits des registres inédits de laboratoire de Lavoisier* (The Chemical Revolution: Lavoisier; book followed by records and excerpts from Lavoisier's original laboratory records) (Berthelot, 1902). "If any further evidence is required to prove that Lavoisier was not only not "the true and first discoverer" of oxygen, but that he has absolutely no claim to be regarded even as a later and independent discoverer, it is supplied by M. Berthelot himself. Not the least valuable portion of M. Berthelot's book, as an

historical work, is that which he devotes to the analysis of the thirteen laboratory journals of Lavoisier, which have been deposited, by the pious care of M. de Chazelles, his heir, in the archives of the Institute. M. Berthelot has given us a synopsis of the contents of almost every page of these journals, with explanatory remarks, and dates when these could be ascertained. As he well says, these journals "are of great interest because they inform us of Lavoisier's methods of work and of the direction of his mind – I mean the successive steps in the evolution of his private thought" (Thorpe, 1894, p. 121).

German chemist August Wilhelm Hofmann (1818-1892), in the eighties of the twentieth century, in his book *Berliner Alchemisten und Chemiker* (Berlin Alchemists and Chemists) identified the names Scheele and Priestley with the discovery of oxygen, while the name Lavoisier with his "immortal work" that "have relevated the essence of burning" (Hofmann, 1882, p. 57).

Albert Landenburg considered Lavoisier a reformer of chemistry, not an oxygen discoverer. On page 16 of his book entitled *Lectures on the History of the Development of Chemistry since the Time of Lavoisier* wrote: " … the history of chemistry itself furnishes proof of the fact, inasmuch as Priestley and Scheele were the discoverers of oxygen, while Lavoisier was the reformer of chemistry" (Landenburg, 1911, p. 16).

In 1981, Daniel L. Gilbert (1925-2000), scientist from the Laboratory of Biophysics at National Institutes of Health, Bethesda (Maryland, USA), in a book with the title *Oxygen and Living Processes. An Interdisciplinary Approach*, regarded Scheele and Pristley as independent codiscoverers of oxygen while Lavoisier was "the discoverer of the mechanism of oxidation" (Gilbert, 1981, p. 10). In addition, he pointed out that Scheele: "actually discovered oxygen before Priestley" (Gilbert, 1981, p. 12).

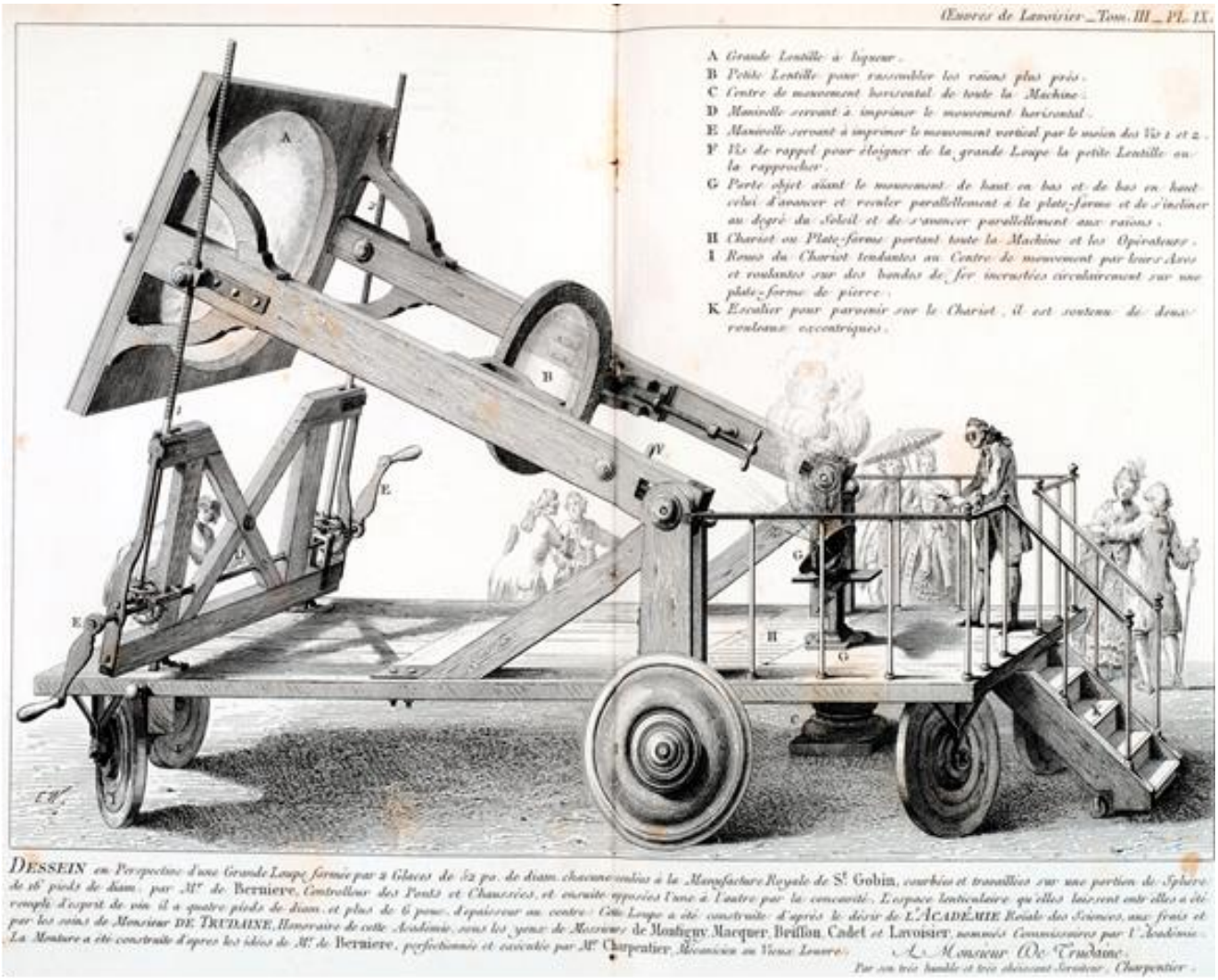

Fig. 1. The Great Burning Glass of Mr. Trudaine (Lavoisier, 1865b).

CONCLUSION

Some burning lenses were used in experiments carried out by some English and French chemists in the 18th century. Priestley used a burning lens to get dephlogisticated air (oxygen). Scheele asked Lavoisier to obtain oxygen using a burning lens available at the Academy, according to the Scheele method. The failures in the melting platinum using various large burning lenses led Lavoisier to develop a new method of melting platinum using oxygen. An analysis of literature shows that some chemists considered Lavoisier as a chemistry reformer, not an oxygen discoverer. He did not discover this chemical element at the same time as Priestley. Scheele discovered oxygen earlier than Pristley. The merits of three prominent chemists (Scheele, Priestley, and Lavoisier) for the development of chemistry are enormous. Their names were forever written in gold letters in the history of chemistry.

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