# Rediscovery of the Elements

## Phlogiston and Lavoisier

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**The Birth of Phlogiston.** Georg Ernst Stahl (1660–1734) adopted an ancient idea of combustibility ("phlogiston")[1] and expanded the concept to embrace all of chemistry (Note 1). According to Stahl, *phlogiston* was released from burning objects, from respiring animals, and from calcining (corroding) metals; and to avoid saturation of the atmosphere, plants reabsorbed phlogiston. Charcoal seemed to possess phlogiston, because when heated with a calx the charcoal could regenerate the original metal. Simple, and yet profound, the idea of phlogiston linked together diverse chemical phenomena in chemical theories and applied crafts, such as mining, dying, smelting, glassmaking, and tanning. Scientists universally adopted this theory, which appeared to permit a comprehensive system of theoretical chemistry. Phlogiston served chemists well for most of the 18th century.

Stahl, who obtained an M.D. at Jena, took an appointment at the University of Halle, Germany, in 1687; he departed in 1716 to become body-physician of Frederick I, King of Prussia until his death in 1734. His work on phlogiston was performed and published in 1718 at Halle.[2] The original university building still stands (Figure 1).

*Figure 1. This building (N 51° 28.99; E 11° 57.88) on the Saale River is the original Friedrichs Universität (precursor to the University of Halle), founded in 1642, where Georg Ernst Stahl was professor. At the neighboring modern chemistry building, the portrait of Stahl is displayed prominently among those of the other chemists of the University.*

**The Antiphlogistic Theory.** Antoine Laurent Lavoisier (1743–1794) through years of careful and imaginative work developed his antiphlogistic theory,[3] culminating in his *Traité* in 1789.[4] His choice of correct experiments and brilliant interpretation of the observations allowed him to recognize the flaws of phlogiston and to substitute a theory that is the basis of modern chemistry. He rejected the four Aristotelian elements (fire, earth, water, and air) and substituted the true elements, including oxygen and hydrogen, which he named. With this new view of chemistry, he and other Parisian colleagues went on to propose a new nomenclature based on composition instead of appearance. Today we still use this method of nomenclature; for example, "corrosive icy oil of tin" and "flowers of zinc" are now called "stannic chloride" and "zinc oxide," respectively.

To visualize the appearance of Paris during Lavoisier's time, one can survey the maps of Louis Bretez, better known as the *Plan de Turgot*.[5] Commissioned by Louis XV to promote better city planning, this work produced a three-dimensional picture of Paris in incredible detail. For example, Figure 2 shows the portion of the *Plan de Turgot* relating to Lavoisier's latter work at the "le Petit Arsenal," where he established his famous laboratory at the height of his fame (during the period 1775–1792). By studying the *Plan de Turgot*, one can locate other sites significant in Lavoisier's life. Figure 3 displays a sketch of modern Paris with these important locations identified.[6]

Much has changed since the days of Lavoisier; however, as one wanders the streets of Paris, occasionally one finds neighborhoods that preserve the atmosphere of former times, such as Lavoisier's birthplace (Figure 3, A) on rue Pecquet (Figure 4) and l'Eglise Saint Merri (Figure 3, B) where he was christened (Figure 5). Lavoisier lived at Pecquay until the age of 5, when his mother died. The family moved to his grandmother's residence on rue du Four-St. Eustache (Figure 3, C) until he attained the age of 28. It was during this period of life that Lavoisier was educated at the Mazarin College (Figure 3, D; it still stands, now housing the Institut de France). Lavoisier was introduced to the charm of chemistry by Guillaume François

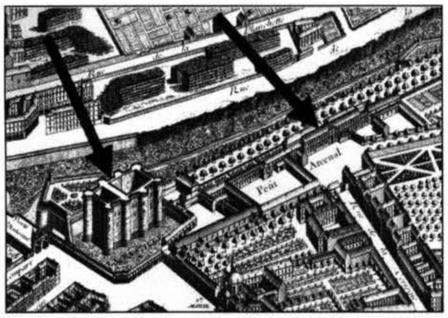


*Figure 2. This portion of the 1739 Plan de Turgot presents the eastern edge of Paris. The view is southeast, with the Seine river immediately to the right (and out of view). The Bastille (left arrow) is to the north of le Petit Arsenal (right arrow); Lavoisier enjoyed his famous laboratory in the southern (right) end of le Petit Arsenal. Today none of this remains. The Bastille (dating from 1370) was demolished in 1791 and today in its stead stands la Place de la Bastille with its lofty 50-meter Colonne de Juillet ("Column of July"). Along the long row of le Petit Arsenal now runs Boulevard Bourdon with its modern buildings.*

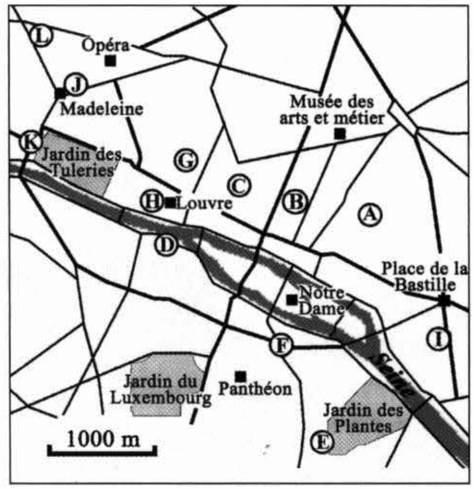


*Figure 3. Notable events occurring during Lavoisier's life occurred at these locations: (A) birthplace and home, 1743-1748, rue Pecquay (N 48° 51.59; E 02° 21.36); (B) St Merri church, where Lavoisier was christened (78, rue Saint Martin; N 48° 51.55; E 02° 21.02); (C) home after mother's death on rue du Four-St. Eustache, now rue de Vauvilliers, (N 48° 51.69; E 02° 20.60); (D) College Marazin, now the Institut de France, on the south bank of the Seine (N 48° 51.44; E 02° 20.24); (E) Jardin des Plantes, where Rouelle performed his public chemistry demonstrations (N 48° 50.55; E 02° 21.33; see Note 2: this is not the present-day amphitheatre); (F) Rouelle's apothecary, where he taught Lavoisier mineralogy and chemistry (45 rue Jacob; N 48° 51.36; E 02° 19.97); (G) residence upon marriage, at rue des Bons-Enfants, 1771-1774 (N 48° 51.96 E 02° 20.40); (H) the Academy of Science, now the Louvre (N 48° 51.57; E 02° 20.29); (I) le Petit Arsenal, the site of Lavoisier's famous laboratory, 1775-1792 (N 48° 51.05; E 02° 22.03); (J) residence on rue de la Madeleine 1792-1794 (N 48° 52.17 E 02° 19.54); (K) Place de la Révolution, formerly Place Louis XV and now Place de la Concorde, where Lavoisier was guillotined (N 48° 51.88; E 02° 19.23); (L) rue Lavoisier, now on the site of rue d'Anjou where the widowed Mme. Lavoisier moved (N 48° 52.42; E 02° 19.35).*

*Figure 4. Rue Pecquay, where Lavoisier was born, was originally a cul-de-sac; the northern end now opens up onto rue de Rambuteau (in the distance). This view is the southern end (looking north), which still retains the original narrow street and buildings of Lavoisier's time (N 48° 51.59; E 02° 21.36).*

*Figure 5. Saint Merri, the church where Lavoisier was christened (looking west). In the foreground is the famous automated Fontaine Stravinsky (beside Centre Pompideau Art Museum, to the left and not in view). One may enter the church from the other side and appreciate the beautiful gothic architecture, which dates from 1500. Saint Merri was patterned after Notre Dame and is sometimes called "the little Notre Dame."*

Rouelle (1793–1770) at the Jardin des Plantes (Figure 3, E) and was privately tutored on chemistry and mineralogy at Rouelle's apothecary on rue Jacob (Figure 3, F). As demonstrator at the Jardin des Plantes, Rouelle attracted large crowds of nobles and dignitaries to his flashy and boisterous chemical shows. Rouelle was the first to elucidate salts as the neutralization products of acids and basis, but he seldom published and is not well known today.

While living at his Four-St. Eustache residence, Lavoisier wrote his first paper, on plaster of Paris (gypsum), where he showed it to be a product of chalk and sulfuric acid.[7] Numerous scientific contributions brought him recognition at the Royal Academy of Sciences in Paris.[7] The energetic Lavoisier seemed to be always available to the Academy for advice, and his opinion was highly regarded. He wrote articles on city lighting; the transmutation of water into earth (he proved it did not); fireworks; potable water for Paris; mineralogy and geology (he

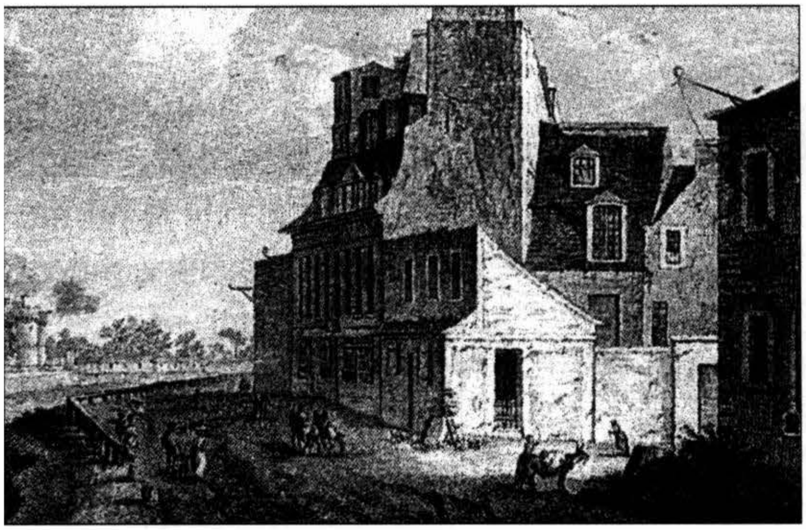

*Figure 6. View of Arsenal and gunpowder magazine in the latter 1700s (looking north; compare with Figure 2). (Portion of print by Simon Mathurin Lantara, 1729-1778. Courtesy, Musée Carnavalet, 23, rue de Sévigné, Paris.)*

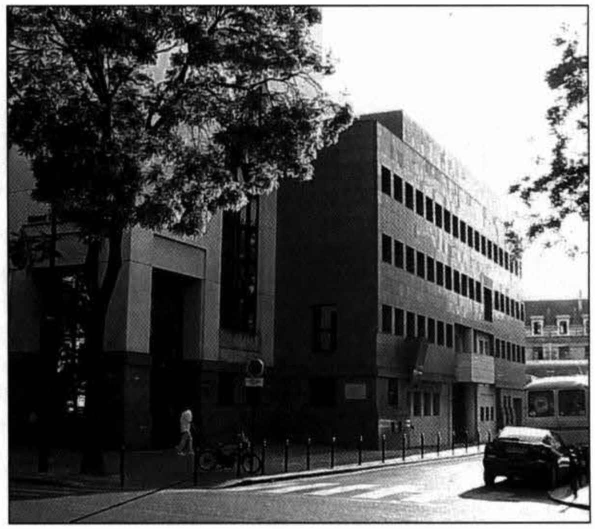

*Figure 7. This is the corner of rue Bassompierre (straight ahead) and Boulevard Bourdon (crossing left-right); N 48° 51.05; E 02° 22.03), where le Petit Arsenal stood, the home of Lavoisier's famous laboratory (looking west). A plaque on the wall (center) is viewed in the next figure. The entrance to le Petit Arsenal was originally at rue de la Ceraisie, 100 meters north (to the right); and the famous Bastille was located 300 meters north (to the right).*

suggested that differentiation of fossils in different strata indicated a mutable planet); public works, and scores of other subjects. He became a member of the Academy in 1768. Ominously, as an investment to secure his financial future, he joined the General Farm and became a tax collector the same year.[7]

Lavoisier married Marie Anne Pierrettte Paulze in 1771, moving to a new residence on rue des Bons-Enfants (Figure 3, G); this portion of the site is now occupied by le Banque France. Mme. Lavoisier was a common visitor to his laboratory, and she initiated careful note-taking,[8] which was continued throughout her husband's career. It was at this residence, and at the Academy of Science (now the Louvre; Figure 3, H), that Lavoisier performed his studies on the oxidation of phosphorus and sulfur, observing that they gained weight upon reaction with the air.[9] Upon his recommendation, the huge Tschirnhausen lenses, which could be used to concentrate the sun's rays, were taken out of the Academy's storage area in order to conduct high-temperature experiments in glass jars. This enabled phenomena to be visualized and monitored, in contrast to the old manner of dropping test objects into a roaring hearth. The classic Tschirnhausen experiments included diamonds, showing they could combust; and a mixture of minium ($Pb_3O_4$) and charcoal while measuring the amount of elastic fluid (carbon dioxide) that was produced as the elemental lead was regenerated. These experiments were performed in the Jardin de l'Infante on the south side of the Louvre, usually gathering large crowds of curious onlookers. It was during this time that Lavoisier began to understand that air functioned not as an inert medium during combustion, but as a *reactant*, accounting for the increase of weight of all substances that are burned or calcined.[9] The portion of the

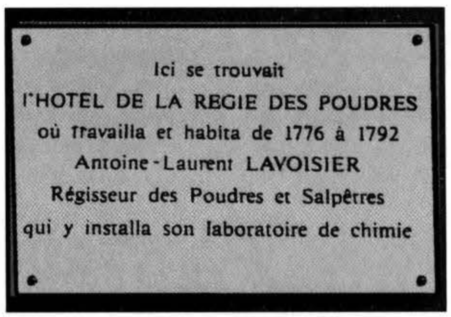


*Figure 8. Lavoisier's plaque (see previous figure) translates: "Here was located the Administration Office of Gunpowder, where Antoine-Laurent Lavoisier worked and lived 1776-1792, manager of gunpowder and saltpeter, who here constructed his chemical laboratory." This plaque is not included in the listing of commemorative plaques[14] and was discovered by the authors serendipitously.*

Louvre where the Academy held its meetings now corresponds to the part of the Sully wing (southeast section of the Louvre), where the Etruscan, Greek, and Roman antiquities and French paintings[7] are now exhibited. The terrace of Jardin de l'Infante today occupies the narrow strip of land between the Louvre and the Seine.

In 1775, Lavoisier was placed in charge of the Gunpowder Commission and he moved to le Petit Arsenal, near the Bastille (Figures 2; 3, I). He served the State well by improving dramatically the yield and quality of gunpowder. His famous laboratory was established in the attic of his new residence (Figure 6), which became "the center of all science in Paris."[8] Hundreds of celebrities visited this laboratory, including not only European visitors of distinction but also the "famous scientist from America," Benjamin Franklin (Mme. Lavoisier painted a portrait of Franklin, which is now lost). Here Lavoisier formulated his antiphlogistic theory and proposed his list of the true elements in his *Traité*.[4] Today the appearance of the Arsenal neighborhood is totally altered; a visitor would have no hint of the location of le Petit Arsenal were it not for a plaque at the original site (Figures 7-8).

In the summer of 1789, the very same year that Lavoisier's *Traité* was published, the Bastille was stormed, and the French political revolution was underway. By 1792 the situation worsened as public hostility towards the government deepened. The Farmer-General Lavoisier, cursed by his role of tax collector, fled his residence at the Arsenal to set up residence on rue de la Madeline (Figure 3, J; this residence no longer exists), and the famous laboratory which had witnessed the genesis of modern chemistry was dismantled. Lavoisier's tragic end came on May 8, 1794, when he was guillotined at le Place de la Révolution (Figure 3, K). A plaque currently resides at this site announcing the execution of Louis XVI and Marie Antoinette—with no specific mention of Lavoisier or any of the other 2,700 "enemies of the state" who were put to death in Paris during the Reign of Terror.

The widowed Madame Lavoisier moved to a fashionable suburb northwest of Paris, on a site where a street named in the honor of Lavoiser now runs (Figure 3, L). Today, nothing remains of the memory of Lavoisier on this street except a hotel and a few shops bearing his name (Figure 9).

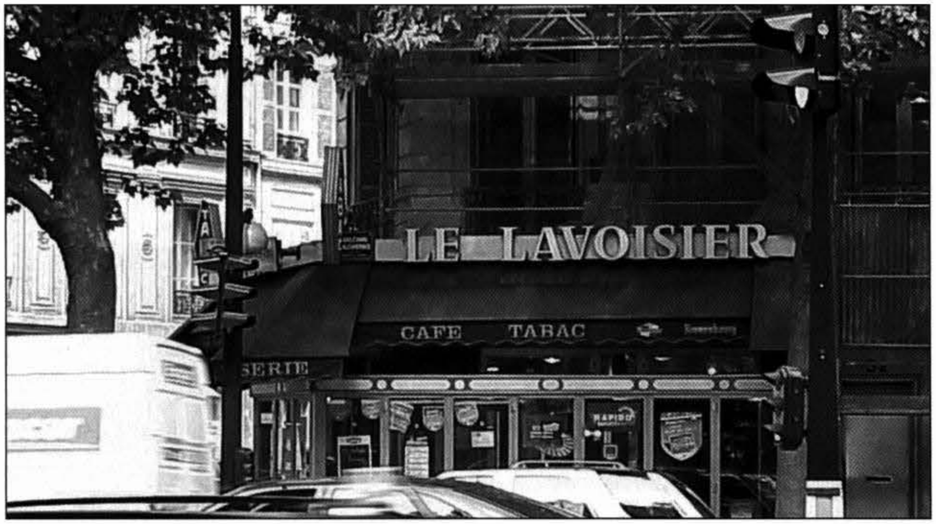


*Figure 9. This scene, at the busy of corner of rue Lavoisier and Blvd. Malesherbes (N 48° 52.43; E 02° 19.23), is located in the once fashionable Faubourg St-Honoré, where Madame Lavoisier moved after her husband's execution in 1794.*

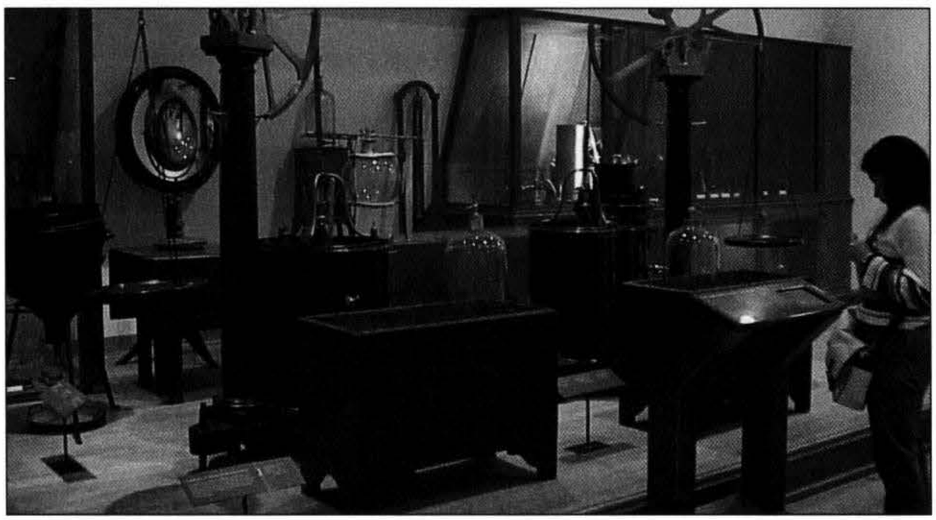

*Figure 10. Inside the Musée des arts et métier (corner of rues Vaucanson and Reaumur; N 48° 51.94; E 02° 21.34), an elaborate and beautiful exhibit on Lavoisier may be viewed. In this figure the classic experiment is recreated where hydrogen and oxygen are reacted to form water in a quantitative study. To the left and right, respectively, are the ponderous but delicate scales to weigh hydrogen and oxygen; in the center is the spark reaction flask where the explosive mixture was ignited to produce water.*

**Lavoisier's Legacy.** One can visit the Musée des arts et métier[10] where a fascinating display on Lavoisier may be viewed (Figure 10). The display includes the elaborate apparatus where Lavoisier weighed specific amounts of hydrogen and of oxygen, sparked the gaseous mixture, and weighed the product, water. Lavoisier, probably the first scientist to invoke the law of conservation of mass in a critical experiment, established water as a *compound* and not one of the four Aristotelian elements.

Almost immediately upon Lavoisier's pronouncement of his new theory in 1789, the French embraced it. The British and the Swedes soon followed, and Germany finally accepted the theory when Martin Heinrich Klaproth (1743–1817), perhaps the best analytical chemist of the day, convinced the Berlin Academy when he reproduced the key experiment in 1792—showing the transformation of mercury calx to mercury and oxygen is quantitative.[11] Thus the French chemical revolution—from Lavoisier's *Traité* in 1789 to general acceptance of the antiphlogistic theory—took a scant three years. To the woe of Lavoisier and to the scientific community, the French sociopolitical revolution took much longer to run its course.

## Notes.

1. The term "phlogiston" (from the Greek word φλογιστὸν, "inflammable") has been used intermittently since Aristotle (384–322 B.C.) to denote "combustibility." Johann Joachim Becher (1635–1682), the predecessor of Stahl, used "phlogiston" to denote a combustible principle in sulphur.[12]

2. The actual building where Rouelle presented his demonstrations at the Jardin des Plantes no longer exists; it was located near the present front entrance on rue Geoffroy-St. Hilaire.[13] This amphitheater was replaced by "le grand amphithéâtre de Verniquet" dating from 1788, which still stands and has just been renovated for tourists' visits. (This latter amphitheatre is 50 meters south of the Cuvier house, where Henri Becquerel discovered radioactivity in 1896.)

## References

1. J. R. Partington, *A History of Chemistry*, **1961**, Vol. 2, Macmillan, London, 653–690.

2. "Zufällige Gedancken und nützliche Bedencken über den Streit von dem sogenannten Sulphure, und zwar sowohl dem gemeinen verbrennlichen oder flüchtigen als unverbrennlichen oder fixen." **1718**, Halle (see ref 1).

3. Partington, *op. cit.*, Vol. 3, 363–495.

4. A.-L. Lavoisier, *Traité Élémentaire de Chimie*, **1789**, Paris.

5. Le Plan de Paris de Louis Bretez dit Plan de Turgot, 1739. Copies of this famous work are available, e.g., 1989, Verlag Dr. Alfons UHL, Nördingen, Germany. Wall maps may be purchased from various sources in Paris, e.g., the book shops in the Louvre and at the Musée Carnavalet.

6. An invaluable source detailing the original sites pertaining to Lavoisier's life and work is D. McKie, *Antoine Lavoisier. Scientist, Economist, Social Reformer*, **1952**, Henry Schuman, New York.

7. J.-P. Poirier, *Lavoisier. Chemist, Biologist, Economist*, **1996**, University of Pennsylvania Press, Philadelphia.

8. M. Berthelot, *La Révolution Chimique. Lavoisier*, **1890**, Félix Alcan (Éditeur), Paris.

9. H. Guerlac, *Lavoisier—the Crucial Year*, **1961**, Cornell University Press, Ithaca, New York.

10. A special issue of the official journal of le Musée des arts et métiers is devoted to Lavoisier: *La revue*, Comité Scientifique, No. 6, March, 1994.

11. K. Hufbauer, The Formation of the German Chemical Community (1720–1795), **1982**, University of California Press, Berkeley, 126; T. Thomson, *The History of Chemistry*, Vol. 2, **1830**, Henry Colburn and Richard Bentley, London, 136.

12. Partington, *op. cit.*, Vol 2, 637-686.

13. Personal communication, Philippe Jaussaud of l'École Nationale Veterinaire de Lyon, France, who is author of *Pharmaciens au Muséum*, **1997**, Muséum national d'Histoire naturelle, Paris.

14. M. Hénocq, *Les Plaques Commémoratives des Rues de Paris*, **1984**, La Documentation Française, Paris.