

AN INTERNATIONAL HISTORIC  
CHEMICAL LANDMARK

# THE CHEMICAL REVOLUTION

PARIS, FRANCE, JUNE 8, 1999



AMERICAN CHEMICAL  
SOCIETY

ACADEMIE DES SCIENCES  
DE L'INSTITUT DE FRANCE

SOCIETE FRANCAISE  
DE CHIMIE



Lavoisier with his disciples, from a bas-relief by Louis Barrias. (Musée des Beaux-Arts de Grenoble.)

**T**his booklet commemorates the designation of the chemical revolution, initiated by Antoine-Laurent Lavoisier, as an International Historic Chemical Landmark. The designation was conferred jointly by the American Chemical Society and the Société Française de Chimie, learned societies whose

aims are to promote the interest of chemists and chemistry and to serve the public interest. A plaque marking the event was presented to the Académie des Sciences de l'Institut de France on June 8, 1999. The inscription reads:

In these buildings, then "Collège Mazarin" or "des Quatre-Nations," Antoine-Laurent Lavoisier (1743—1794) studied from 1754 to 1761. He was elected to the Royal Academy of Sciences in 1768, where he presented his important studies on oxygen in chemistry. These began with a "pli cacheté" of Nov. 2, 1772, and, after he experimentally proved the chemical composition of water by the quantitative method, culminated in his abandoning of the phlogistic theory in 1785. In 1787, he proposed the principles of a new *Méthode de Nomenclature Chimique*, in collaboration with the chemists Guyton de Morveau, Berthollet, and Fourcroy and with the help of the mathematicians Monge and Laplace. The publication of his *Traité Élémentaire de Chimie* two years later convinced French and foreign chemists of his theories. His papers, stored in the Archives of the Academy of Sciences, bear witness to the conception and maturing of his revolutionary ideas, which are at the foundations of modern chemistry.

**On the cover:**

Portrait of M. and Mme Lavoisier by Jacques Louis David, 1788, the Metropolitan Museum of Art, purchase, Mr. and Mrs. Charles Wrightsman gift, in honor of Everett Fahy, 1977. Photograph © 1989, the Metropolitan Museum of Art.

**Background:** Entry from Lavoisier's journal proposing the revolution in chemistry, Feb. 20, 1773.

**Acknowledgments:**

The American Chemical Society gratefully acknowledges the assistance of those who helped prepare this booklet. It was written by James J. Bohning, Wilkes University with assistance from Patrice Bret, Comité Lavoisier, and Christiane Demeulenaere-Douyère, Archives de L'Académie des Sciences de Paris. It was produced by the Office of Communications, American Chemical Society. Design: Dalhman/Middour Design. Photographs courtesy of the Académie des Sciences and the Metropolitan Museum of Art.

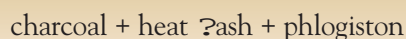
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# THE CHEMICAL REVOLUTION

“The importance of the end in view prompted me to undertake all this work, which seemed to me *destined* to bring about a *revolution* in . . . chemistry. An immense series of experiments remains to be made.” When he wrote these words in his laboratory notebook on Feb. 20, 1773, a confident Parisian, Antoine-Laurent Lavoisier, stood poised to forever change the practice and concepts of chemistry. For the next 16 years, never doubting that his prophecy would be fulfilled, the indefatigable Lavoisier forged a new series of laboratory analyses that would bring order to the chaotic centuries of Greek philosophy and medieval alchemy, leading future generations to regard him as the framer of modern chemistry.

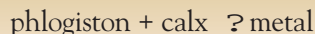
## The Chemical Heritage of Antoine-Laurent Lavoisier

When the 17-year-old Lavoisier left Mazarin College in Paris in 1761, chemistry could hardly be called a true science. Unlike physics, which had come of age through the work of Isaac Newton a century earlier, chemistry was still mired in the legacy of the Greek philosophers. The four elements of Aristotle—earth, air, fire, and water—had been slowly modified by the medieval alchemists, who added their own arcane language and symbolism. Thrown into this mix was the concept of phlogiston. Developed by the German scientist Georg Ernst Stahl early in the 18th century, phlogiston was a dominant chemical concept of the time because it seemed to explain so much in a simple fashion. Stahl believed that every combustible substance contained a universal component of fire, which he named phlogiston, from the Greek word for inflammable. Because a combustible substance such as charcoal lost weight when it burned, Stahl reasoned that this change was due to the loss of its phlogiston component to the air:



It followed that the less residue a substance left on burning, the greater its phlogiston content. Turning from organic substances to metals, Stahl knew that a metal calx heated with charcoal formed

the original metal. He proposed that the phlogiston of the charcoal had united with the calx:



Therefore, metals, which were thought to contain phlogiston, were also classified as combustibles. The difficulty with this scheme was the reverse reaction. When metals were strongly heated in air, the resulting calx weighed *more* than the original metal, not less, as would be expected if the lead had lost

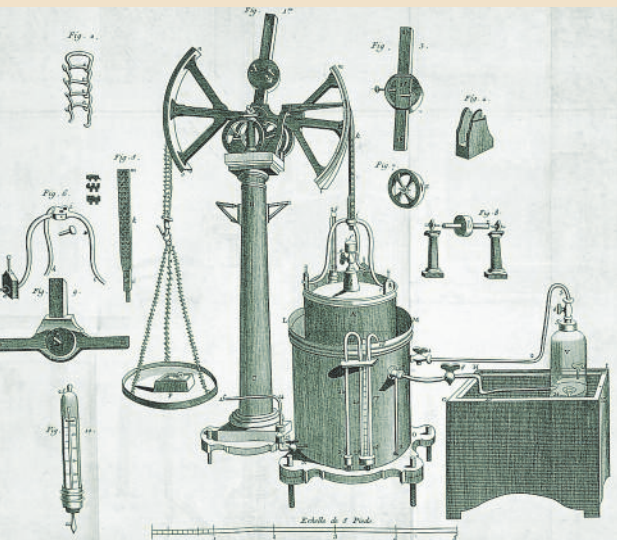


The School of the Four Nations, later Mazarin College, where Lavoisier studied as a young man. These buildings now house the Académie des Sciences de l'Institut de France.

the phlogiston component. This inconsistency caused some phlogistonists to suggest that phlogiston might even have a negative weight. Lavoisier was introduced to phlogiston by Guillaume François Rouelle, whose lectures he attended while pursuing a law degree. By 1772, having abandoned law to pursue a career in science, Lavoisier turned his curiosity to the study of combustion.

## Combustion and the Attack on Phlogiston

In experiments with phosphorus and sulfur, both of which burned readily, Lavoisier showed that they *gained* weight by combining with air. With lead calx, he was able to capture a large amount of air that was liberated when the calx was heated. To a suspicious Lavoisier, these results were not explained by phlogiston.



The gasometer used by Lavoisier as illustrated in the *Traité Élémentaire de Chimie*, plate VIII.

Although Lavoisier now realized that combustion actually involved air, the exact composition of air at that time was not clearly understood. In August 1774, the eminent English natural philosopher and phlogistonist Joseph Priestley met with Lavoisier in Paris. He described how he had recently heated mercury

calx (a red powder) and collected a gas in which a candle burned vigorously. After returning from Paris, Priestley found that a mouse could breathe this air and live much longer than a mouse that breathed “common air.” At the time, respiration was thought to involve the exhalation of phlogiston, which eventually saturated the common air. Thus, in a confined space, candles were extinguished and mice died. Priestley believed his “pure air” enhanced respiration and caused candles to burn longer because it was free of phlogiston. For this reason, he called the gas that he obtained from decomposing mercury calx *dephlogisticated air*.

In Paris, the intrigued Lavoisier repeated Priestley’s experiment with mercury and other metal calces. He eventually concluded that common air was not a simple substance. Instead, he argued, there were two components: one that combined with the metal and supported respiration and the other an asphyxiant that did not support either combustion or respiration. By 1777, Lavoisier was ready to propose a new theory of combustion that excluded phlogiston. Combustion, he said, was the reaction of

a metal or an organic substance with that part of common air he termed “eminently respirable.” Two years later, he announced to the Royal Academy of Sciences in Paris that he found that most acids contained this eminently respirable air and, therefore, was calling it *oxygène*, from the two Greek words for acid generator.

Lavoisier began his full-scale attack on phlogiston in 1783, claiming that “Stahl’s phlogiston is imaginary.” According to biographer Douglas McKie, the paper Lavoisier read before the Academy of Sciences “exposed . . . the many weaknesses of the accepted chemical philosophy” and “reveals . . . Lavoisier’s great powers of reasoning and exposition.” Calling phlogiston “a veritable Proteus that changes its form every instant,” Lavoisier asserted that it was time “to lead chemistry back to a stricter way of thinking” and “to distinguish what is fact and observation from what is system and hypothesis.” As a starting point, he offered his theory of combustion, in which oxygen now played the central role. Lavoisier did not expect his ideas to be

## Lavoisier’s American Legacy

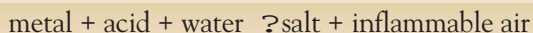
Pierre-Samuel du Pont was a close friend of Antoine Lavoisier. The two first met when Lavoisier was collecting taxes at the Ferme Générale and du Pont was gaining a reputation as a political writer and economist. He was elected to the Constituent Assembly in 1789 as a delegate from the third estate of Nemours. During the French Revolution, du Pont, who supported a constitutional monarchy, volunteered to help guard Louis XVI when a mob attacked the palace in 1792. Eventually arrested, du Pont was spared death at the guillotine because of the fall of Maximilien Robespierre, the architect of the Reign of Terror. Du Pont sought a new life in the United States in 1799, because there, “persecuted men can find safety . . . [and] fortunes can be rebuilt.” Having learned the newest methods of gunpowder manufacturing from Lavoisier, du Pont’s son Eleuthère Irénée opened a powder works near Wilmington, DE, in 1802. He wanted to call the business Lavoisier Mills, to show his “gratitude to the person whose kindness toward me was the primary cause of my undertaking.” His father, however, had other ideas, and it was organized under the name “du Pont de Nemours and Company.”

adopted at once, because those who believed in phlogiston would “adopt new ideas only with difficulty.” Lavoisier put his faith in the younger generation who would be more open to new concepts. He was not disappointed.

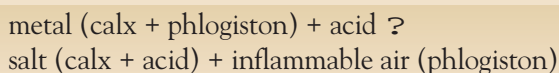
## A New Chemistry Emerges

In 1766, Englishman Henry Cavendish isolated a gas that he called “inflammable air” because it burned readily. For Lavoisier, combustion meant combining with oxygen; however, until he could explain the combustion of inflammable air, some would still doubt his new chemistry. Priestley noted that when inflammable air and common air were ignited with a spark in a closed vessel, a small amount of “dew” formed on the glass walls. When Cavendish repeated the experiment, he found that the dew was actually water. Cavendish explained the results in terms of phlogiston and assumed the water was present in each of the two airs before ignition. In June 1783, Lavoisier learned of the Cavendish experiment and immediately reacted oxygen with inflammable air, obtaining “water in a very pure state.” He correctly concluded that water was not an element but a compound of oxygen and inflammable air, or hydrogen as it is now known. To support his claim, Lavoisier decomposed water into oxygen and inflammable air.

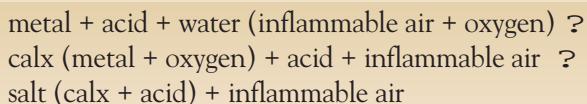
The last objection to discarding phlogiston could now be eliminated. It was known that when a metal dissolved in an aqueous acid solution, it produced a salt and inflammable air:



which Cavendish believed was phlogiston:



Now that the composition of water was known, Lavoisier offered a different interpretation:



For example, when zinc reacts with an acid, it combines with the oxygen of the water to form a calx, which then reacts with the acid to form a salt. The other component of the water, hydrogen, is released as a gas. According to McKie, “This was a new Lavoisier . . . raining down upon the

[defender’s] heads a destructive fire of incontrovertible chemical fact.”

To Lavoisier, it was time “to rid chemistry of every kind of impediment that delays its advance” with a reform that included a new language. Louis Bernard Guyton de Morveau, Claude Louis Berthollet, Antoine François Fourcroy, and Lavoisier adopted the long-neglected idea of an element as originally proposed by Robert Boyle more than a century earlier. “We shall content ourselves here with regarding as simple all

the substances that we cannot decompose.” They retained the names from the past of many of these simple substances, or elements. But when an element combined with another element, the compound’s name now reflected something about its chemical composition. For example, a calx was the combination of a metal and oxygen, therefore, zinc calx became zinc oxide. Lavoisier and his colleagues predicted that if the new system was “undertaken upon sound principles . . . it will naturally adapt itself to future discoveries.” Withstanding the test of time, the basic system is still in use today.

Lavoisier’s new system of chemistry was laid out for everyone to see in the *Traité Élémentaire de Chimie (Elements of Chemistry)*, published in Paris in 1789. As a textbook, the *Traité* incorporated the foundations of modern chemistry. It spelled out the influence of heat on chemical reactions, the nature of gases, the reactions of acids and bases to form salts, and the apparatus used to perform chemical experiments. For the first time, the Law of the Conservation of Mass was defined, with Lavoisier asserting that “. . . in every operation an equal quantity of matter exists both before and after the operation.” Perhaps the most striking feature of the *Traité* was its “Table of Simple Substances,” the first modern listing of the then-known elements.

A contentious Lavoisier would later proclaim: “This theory is not, as I hear it called, the theory of the French chemists. It is mine. It is a right that I lay claim to by the judgment of my contemporaries and at the bar of history.” Two years later, in 1791, the results were obvious. “All young chemists,” he mused, “adopt the theory, and from that I conclude that the revolution in chemistry has come to pass.” His legacy endures more than 200 years later.



Drawing by Mme Lavoisier of M. Lavoisier conducting a respiration experiment. Mme Lavoisier is pictured recording the laboratory proceedings.

# THE LIFE OF ANTOINE-LAURENT LAVOISIER (1743–1794)

“Lavoisier was a Parisian through and through and a child of the enlightenment,” wrote biographer Henry Guerlac. The son of Jean-Antoine and Émilie Punctis Lavoisier, he entered Mazarin College when he was 11. There, he received a sound training in the arts and classics and an exposure to science that was the best in Paris.



Forgoing his baccalaureate of arts degree, Lavoisier yielded to the influence of his father and studied law, receiving a law degree in 1763. But his interest in science prevailed, kindled by the geologist Jean-Étienne Guettard, whom he met at Mazarin. After graduation, he began a long collaboration with Guettard on a geological survey of France.

Lavoisier showed an early inclination for quantitative measurements and soon began applying his interest in chemistry to the analysis of geological samples, especially gypsum. Because of his flair for careful analyses and his prodigious output, he was elected to the Academy of Sciences at the age of 25. At the same time, Lavoisier used part of the fortune he had inherited from his mother to buy a share in the Ferme Générale, a private group that collected various taxes for the government. This fateful decision would later cost him his life at the height of his intellectual powers.

He married Marie Anne Pierrette Paulze on Dec. 16, 1771; he was 28, she was 14. “The marriage was a happy one,” according to McKie. “Mme Lavoisier was possessed of a high intelligence; she took a great interest in her husband’s scientific work and rapidly equipped herself to share in his labors. Later, she helped him in the laboratory and drew sketches of his experiments. She made many of the entries in his laboratory notebooks. She learned English and translated a number of scientific memoirs into French.”

Lavoisier became further involved in public life in 1775, when he was appointed one of four commissioners of the Gunpowder Commission, charged with reforming and improving the production of gunpowder. Lavoisier moved his residence and laboratory to the arsenal in Paris, where for almost 20 years it drew many distinguished visitors. He devoted several hours every day and one full day a week to experiments in his laboratory. According to his wife: “It was for him a day of happiness; some friends who shared his views and some young men proud to be admitted to the honor of collaborating in his experiments assembled in the morning in the laboratory. There they lunched; there they debated. . . . It was there that you could have heard this man with his precise mind, his clear intelligence, his high genius, the loftiness of his philosophical principles illuminating his conversation.”

Ironically, Lavoisier, the ardent and zealous chemical revolutionary, eventually was caught in the web of intrigue of a political revolution. The *Traité* was published in 1789, the same year as the storming of the Bastille. A year later, Lavoisier complained that “the state of public affairs in France . . . has temporarily retarded the progress of science and distracted scientists from the work that is most precious to them.”

Lavoisier, however, could not escape the wrath of Jean-Paul Marat, the adamant revolutionary, who began publicly denouncing him in January 1791. During the Reign of Terror, arrest orders were issued for all of the Ferme Générale, including Lavoisier. On the morning of May 8, 1794, he was tried and convicted by the Revolutionary Tribunal as a principal in the “conspiracy against the people of France.” He was sent to the guillotine that afternoon. The next day, his friend, the French mathematician Joseph-Louis Lagrange, remarked that “it took them only an instant to cut off that head, and a hundred years may not produce another like it.”

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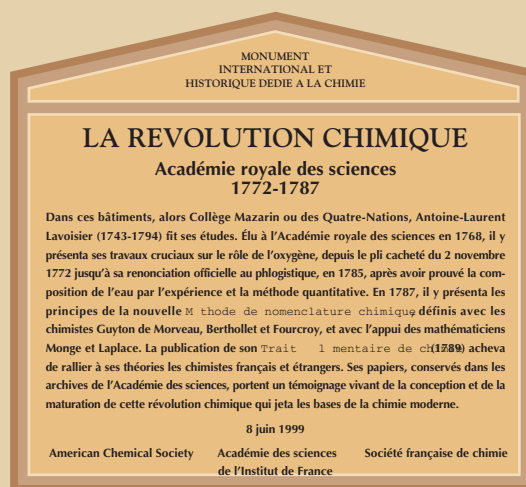
## THE HISTORIC CHEMICAL LANDMARKS PROGRAM

The Historic Chemical Landmarks Program recognizes our scientific and technical heritage and encourages the preservation of historically important achievements and artifacts in chemistry, chemical engineering, and the chemical process industries. It helps to remind chemists, historians, students, and teachers of how chemical discoveries are made and developed, and how they are exploited for the benefit of people.

A historic chemical landmark represents a distinctive step in the evolution of chemical science and technology. Designations of sites and artifacts note events or developments of clear historical importance to chemists and chemical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of chemistry and chemical engineering.

The American Chemical Society started a National Historic Chemical Landmarks Program in 1992. It has been extended internationally as part of the 1999 International Chemistry Celebration. The Société Française de Chimie and the Académie des Sciences de l'Institut de France have joined the American Chemical Society in honoring Antoine-Laurent Lavoisier's revolution of chemistry as an International Historic Chemical Landmark, the fourth to be designated under the international arm of this program.

For further information about the Historic Chemical Landmarks Program, please contact the American Chemical Society, Office of Communications, 1155 Sixteenth Street, NW, Washington, DC 20036, USA; telephone: 800-227-5558, ext. 6274; e-mail: [nhclp@acs.org](mailto:nhclp@acs.org).



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