# Arthur E. Guedel Memorial Anesthesia Center

## Music Illuminates Science

*By Merlin Larson, M.D.*

Our residents enter training somewhere around the age of 28 years. They are in the beginning stages of their careers, just learning the essentials of what will become their life's work. Two hundred years ago, Antoine Lavoisier at the age of 28 started his research that eventually led to his discovery of oxygen. Also, at the age of 28, Ludwig von Beethoven wrote his famous ***Pathetique Sonata***. This essay will use the first movement of the ***Pathetique*** to describe the interplay between Lavoisier and the chemists of the 18th century.

Lavoisier and Beethoven lived during the waning years of the Age of Enlightenment, the time the seeds of our specialty were planted. During the three decades from 1760 to 1790, oxygen and nitrous oxide were isolated, the oxygenation of carbonaceous material to carbon dioxide was described, and the basic laws of chemistry and metabolism were established.

The Age of Enlightenment has also been called the Age of Reason because it was characterized by small groups of curious (usually wealthy) individuals who met in clubs or cafes to "reason" and discuss the pressing political and scientific issues of the day.

The artists of the era also were influenced by this culture. For example, the newly devised musical format called the string quartet was characterized by diverse presentations ("arguments") that could be interpreted as discussions on a basic theme. Beethoven's string quartets present several contrasting arguments in each movement. The German philosopher Goethe said Haydn's string quartets resembled "four civilized persons holding a conversation." The piano sonata also evolved into a series of contrasting arguments and the composers adhered loosely to what became known as the "piano sonata form" that used this design.

The following narrative describes the argument that Lavoisier had with the dominant chemists of the 18th century, who universally supported the phlogiston theory of combustion. The era under discussion falls between the years 1772 and 1790 and encompasses the years of Lavoisier's most significant contributions to our specialty, namely the discovery of oxygen and its role in sustaining life.

A full appreciation of Lavoisier's arguments can be achieved by listening to the first movement of Beethoven's Piano Sonata No. 8 in C minor, Opus 13#

(**Pathetique**). The 28-year-old Beethoven was living in Vienna at the time (1798) and presumably was unaware of the revolution in chemistry that had taken place in France. However, the first movement of this sonata portrays (in nine minutes) the arguments between the phlogistonists and Lavoisier with much more expression than can be achieved with the written word. It is easy to listen to the arguments by typing "**Pathetique Sonata**" into Google and then listen to the YouTube entry by Michael Roosen.

The sonata opens with the "***Grave***" which (in our analogy) is a somber presentation of the phlogiston theory of combustion. The ***Grave*** is only 10 measures and it simply states that all flammable objects contain phlogiston, and phlogiston is released into the air when objects burn.

After the 10th measure, Beethoven concludes the ***Grave*** and introduces the ***Allegro di molto e con brio*** which (in our design) represents Lavoisier's initial misgivings about the phlogiston concept. By May of 1772, Lavoisier had noticed that charcoal (also diamond) heated in a vacuum would not burn, but in common air it was transformed completely into fixed air (carbon dioxide) (Figure 1).

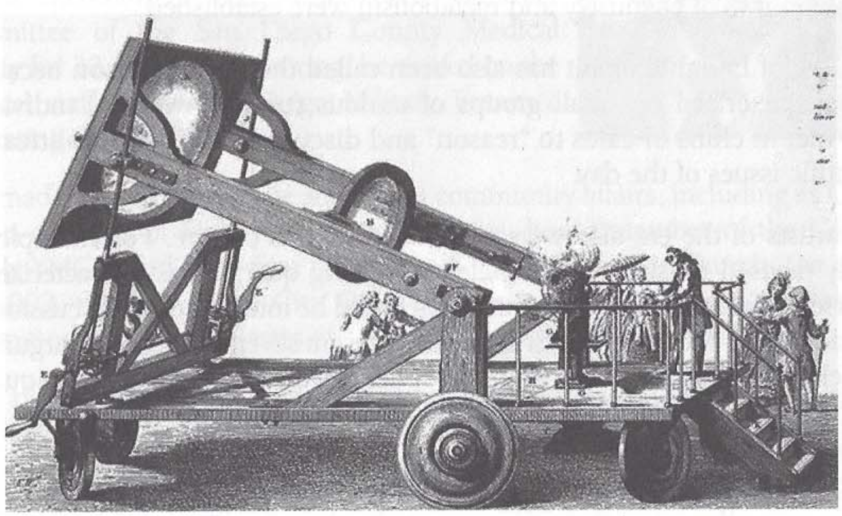

**Figure 1:** Giant lenses were used to heat diamonds and charcoal. Lavoisier participated in these early experiments in 1772 and was puzzled by the fact that diamonds would burn only if they were exposed to the atmosphere. Priestly and Lavoisier used similar giant lenses to heat the calx of mercury (mercuric oxide). Public Domain document; Courtesy of the Chemical Heritage Foundation.

Phosphorus and sulfur, when heated in common air, would burn briefly and in the process would consume about one-fifth of the volume of common air. Furthermore, the process of burning **increased** the weight of these agents, which would not be compatible with a loss of phlogiston into the air during burning. The ***Allegro con brio*** (literally in Italian: happily, with spirit) is a cheerful contrast to the ***Grave*** and represents the elation that Lavoisier felt with his new discoveries and his confidence that he would eventually develop a new theory of combustion.

Lavoisier presented these initial findings in a sealed note that was delivered to the Academy of Sciences (Paris) on November 1st of 1772, and it was read before this august body the following May 5, 1773. To his surprise and dismay, however, his experimental results were received with widespread skepticism and doubt. The weights were probably faulty, and anyway, the results could be explained entirely by the fact that phlogiston, when released from phosphorus, would combine with the air and decrease its volume. Here Beethoven's sonata reveals again the powerful ***Grave*** with its restatement of the phlogiston theory. Lavoisier was dejected and disappointed, but not defeated.

Now the spirited ***Allegro*** returns, and we follow the fascinating subsequent experiments that eventually led to the discovery of oxygen and the formulation of our modern theories of combustion and metabolism. One puzzling fact that Lavoisier was unable to explain was that metallic calx (mercuric oxide) and charcoal (carbon), when both were heated in a vacuum, would be transformed into fixed air (carbon dioxide), but when charcoal was heated by itself in a vacuum it would not burn. The visit by Joseph Priestly to France in 1774 would prove to be the breakthrough that enabled Lavoisier to further his ideas. Priestly had shown that heating the calx of mercury produced a remarkable gas that was hitherto unnamed and characterized. Lavoisier formulated the idea that a new gas was released from heating the calx of mercury, and it was this same gas that was consumed by the heating of phosphorus and sulfur. This gas constituted one-fifth of the atmosphere, and it alone allowed charcoal to burn and to transform phosphorus and sulfur into acids. He named this gas oxygen after the Greek word for acid-producing substance.

Once more Lavoisier presented his results, this time in a communication to the Academy of Science in 1777. The points he made were:

1. About four-fifths of the air that we breathe is incapable of supporting the respiration of animals or the burning of substances.
2. Only the residue, or one-fifth of the volume of atmospheric air, is respirable.

3. By the calcination of mercury, the pure part of the air (oxygen) is absorbed and the mephitic (nitrogen) part remains.
4. By combining the two parts that have been separated, one can again obtain atmospheric air.

The experiment that he described is illustrated in Figure 2. With his analysis there was no need for phlogiston, and that concept began a slow demise.

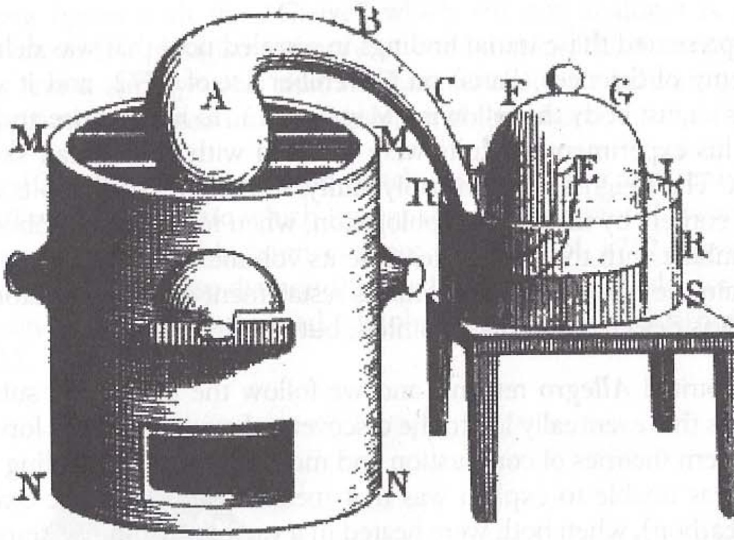


**Figure 2:** Lavoisier's most famous experiment. The canister on the left is a furnace. In the curved flask (A) he placed 4 ounces of pure mercury. This flask opened under bell jar (E) into atmospheric air that was sealed by immersing it in a liquid containing vessel (R). By heating the mercury, it slowly oxidized to mercuric oxide and simultaneously consumed one-fifth of the atmospheric air. Mephitic air (nitrogen) remained in vessel E. He then heated the mercuric oxide by a powerful lens, released its oxygen, and combined it with the residual air in E, again obtaining atmospheric air. Drawn by Lavoisier's wife, Marie-Anne Pierrett Paulze, and published in ***Traité Élémentaire de Chimie, 1789.***

Nevertheless, Lavoisier had his enemies. In Germany he was hung in effigy by the Stahlists (originator of the phlogiston theory), who were unable to accept the oxygen concept. In France, his most vocal enemy was Jean-Paul Marat who openly published slanderous articles about Lavoisier, calling him a man whose chemical theories were rubbish. Beethoven gives us a third ***Grave*** near the end of the first movement, this one weaker than the previous two, and this represents the resistance of the remaining phlogistonists that included Priestly, Marat and the German chemists. Finally, the first movement ends with a flourish, repeating the triumphant theme from the ***allegro con brio***, signifying that the Lavoisier chemical revolution had essentially triumphed by the year 1790, 18 years after his first experiments on combustion and one year after publication of his famous book, ***Traité Élémentaire de Chimie***.

Three years after the French Revolution in 1789, Lavoisier was in political trouble. Chemistry was not his only avocation. He had been a member of several pre-Revolutionary (Royalist) societies, including the Academy of Sciences and the hated ***Ferme Générale***, the primary tax-collecting agency of the Royalist government. Unfortunately, his scientist friends deserted him when he was thrown into prison in November 1793. No one wanted to sympathize with any of the previous members of the ***Ferme Générale***, and this included his scientific associates such as Antoine Fourcroy, who had collaborated with Lavoisier on a new nomenclature in chemistry. Lavoisier spent seven months in prison awaiting trial and was executed after a short mock trial. Lavoisier had spent his time in prison revising his ***Traité Chimie*** and was reportedly a calm voice among the other 23 condemned prisoners who wanted to take toxic doses of opium to avoid execution. Lavoisier convinced the group to face death with dignity because suicide would be an admission of guilt.

Within three years, the Reign of Terror had run its course. Marat was murdered in his bathtub. Georges Danton, Maximilien Robespierre, and the judge presiding over Lavoisier's trial (Pierre-Andre Coffinhal) had all been executed and the affairs of the ***Ferme Générale*** were completely exonerated. At the time of his death, Lavoisier was 51 years old and at the peak of his scientific career. Beethoven would have found it difficult to express the tragic loss to society that took place on the morning of May 8, 1794, when the device promoted by Lavoisier's friend and collaborator, Dr. Joseph-Ignace Guillotin, performed its designated task.