## PERSPECTIVES LECTURE

### History of Chemistry and the Education of Teachers

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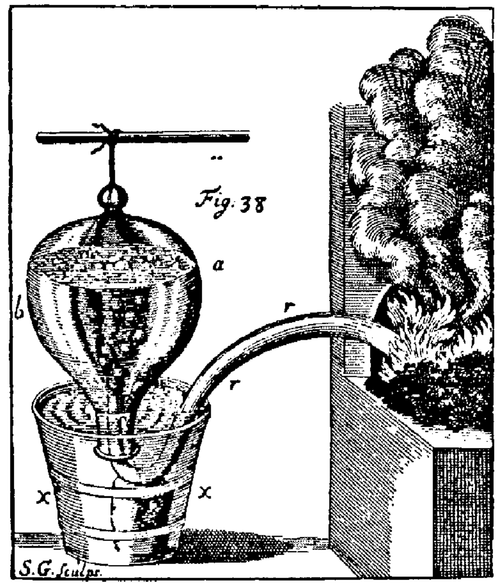
Early in my teaching career I became convinced that history has value in causing the student to look at chemistry in a realistic fashion. But, like classroom demonstrations, history should fulfill a teaching objective and not be used merely as entertainment. Further, history is made by human beings and lends a human interest which is lacking when only the facts of chemistry are expounded (1).

Merely telling students that Priestley discovered oxygen is a historical fact which frequently leads to some yawns and even the query, "Do we have to know that on the exam?" If we introduce Priestley at all, let's make him meaningful. Why did Priestley, a minister, carry out an experiment which produced oxygen? Because he wished to better understand the design of the Creator. Are you aware that many of the names in 17th and 18th century science were theologians and nearly all scientists of the day were deeply devout? That point is worth further discussion.

Why was Priestley carrying out an experiment which produced oxygen? Because he was, like many of his contemporaries, a pneumatic chemist. Why were there so many pneumatic chemists at that moment? Because Stephen Hales, another theologian, had invented the pneumatic trough a half century earlier (2). For the first time in human history it was possible to isolate airs by decomposition of chemical substances and collect the resulting air comparatively free of contaminants. Hales developed the apparatus because he was curious to learn how much air was trapped in various solids in non-aerial form. He measured the volume of air which could be driven out of various chemicals, rocks, seeds, and plants by heating (3).

Hales' objective was wrong. Rather than asking "How much air?" he should have been asking, "What kind of air?" At

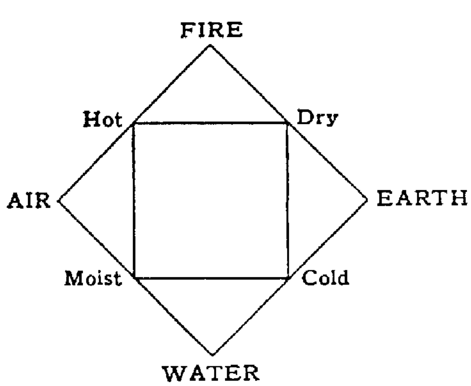



Stephen Hale's pneumatic trough

that date the quantity of air obtained was of little significance but the nature of the air was important. Though at the time he failed to suspect that there are many kinds of airs, or more properly, gases, his efforts were not totally lost. He introduced a new tool into the scientific world which allowed others to avidly pursue the study of new gases. Scientific progress is accompanied by a vast amount of stumbling, some of it fruitful for the wrong reason.

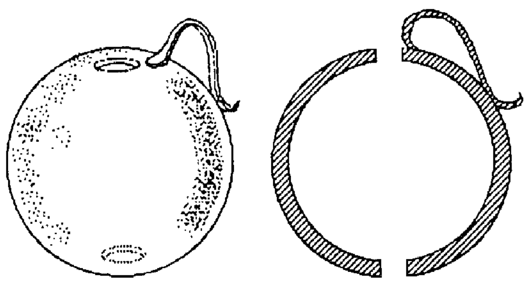
The Priestley-Hales incident illustrates some important points. An experiment should have an objective but the experiment need not achieve that objective. If it uncovers some useful knowledge, it has not been a failure. Hales produced a useful piece of apparatus which soon advanced the chemical study of gases and their sources. Priestley discovered oxygen with a modification of the apparatus. However, he did not call his gas oxygen, but named it dephlogisticated air. Why? Because he was a creature of his time, not because he was stupid. But that is another story.

Stephen Hales was also a philosophical product of his time. A gas was simply air, a substance that had been considered elemental since antiquity. The Greek philosophers believed there were only four elements: earth, air, fire, and water. However, the four elements were not considered truly elementary since they were derived from a more primitive matter which had become elementary following the acquisition of two primary qualities: hot or cold, and wet or dry. The relationship was portrayed for many centuries in the form of a square of qualities within a square of elements.




The four elements of the Greeks

Earth and water were easily identified and fire was a phenomenon easily recognized by its effects. What about air? The Greeks had demonstrated its existence soon after inventing the *clepsydra* as a device for carrying water or measuring



A Greek clepsydra

time. This was a glass or ceramic globe with a handle and two small holes, one at the top, the other at the bottom. When plunged into a pool of water, it filled with water through the bottom hole. If one then placed a thumb over the top hole, the clepsydra could be carried to the kitchen without loss of water through the bottom hole. Then, removal of the thumb over the top hole permitted the water to flow into other vessels. On the other hand, if the thumb were placed over the top hole before plunging the device into the water, no water entered the bottom hole and the globe failed to fill because it was already full of air, a substance which occupied space even though invisible.

Thus, centuries later Hales still looked upon all gases as air and it was his successors, particularly Priestley, who recognized that there are more than a dozen different airs which could be prepared and collected in the pneumatic trough.

The four-element hypothesis remained popular through the Middle Ages and actually stimulated the pursuit of alchemy for more than a millennium in Greece, Egypt, Arabia, China and Europe. The notion that the elements could be transformed into one another by abstracting and introducing qualities led to the notion that base metals, such as lead, tin, or iron, could be transmuted into silver and gold by alteration of certain characteristics such as color. It was only after centuries of failure to transmute or perfect base metals into gold that chemical philosophers began to lose interest in transmutation and sought to examine matter more thoughtfully.

In truth, the 16th and 17th centuries were a rich period for progress in understanding the heavens, the atmosphere, the earth and, more slowly, the nature of living organisms. The age of the great navigations led to knowledge of new flora and fauna while creating problems such as determining one's location on the earth's surface. It was learned that the heavens were not perfect and that the earth revolved about the sun and not vice versa. Ancient beliefs began to be questioned and this challenge was stimulated by the development of new tools and the improvement of old ones, such as the balance, the still, and the compass. All these devices had previously had a vastly greater role in commerce than in natural philosophy. Concern with instruments added, during this period, the mechanical clock, the telescope, the barometer, the air pump, the thermometer, and a primitive microscope.

With this new armament of tools, scientific phenomena could be investigated more effectively. The opportunity to gain understanding of old mysteries attracted new investigators into the field. The universe was a vast system amenable to investigation and even measurement.

Although physics and astronomy responded quickly to investigation during the Enlightenment, chemistry revealed its secrets more slowly. This is not surprising since chemistry is a subtle science not responsive to traditional methods of human observation. In part, the tardiness of chemistry is attributable to seeking understanding of the more complex properties of matter by experimenting with solids and liquids, while ignoring gases.

The emergence of pneumatic studies channeled chemical investigation in a fruitful direction since the properties of gases are more amenable to investigation than those of the other two states of matter. Lavoisier's insight that common air is not an element rich in hotness and wetness but is a mixture of two unique gases, initially labelled dephlogisticated air and noxious air, was an important step in turning chemistry into a direction for viable studies and improved understanding. He soon renamed these gases oxygen (acid former) and azote (without life). It was Chaptal who suggested "nitrogen" for the latter, since it is a component of nitre, and that name has had general acceptance (4).

Lavoisier went on to clarify the nature of combustion and calcination (burning without flame). Recent studies, particularly by Robert Siegfried in America and William Smeaton in England, have shown that Lavoisier, starting from the conventional wisdom of the phlogistonists, argued that, upon heating:

nonmetal → acid + phlogiston

metal → calx + phlogiston

Siegfried further suggests that Lavoisier, having recognized that phlogiston could be thought of as negative oxygen, then reformulated these reactions as:

nonmetal → acid + negative oxygen

metal → calx + negative oxygen

which, upon rearranging algebraically, gave our currently accepted versions:

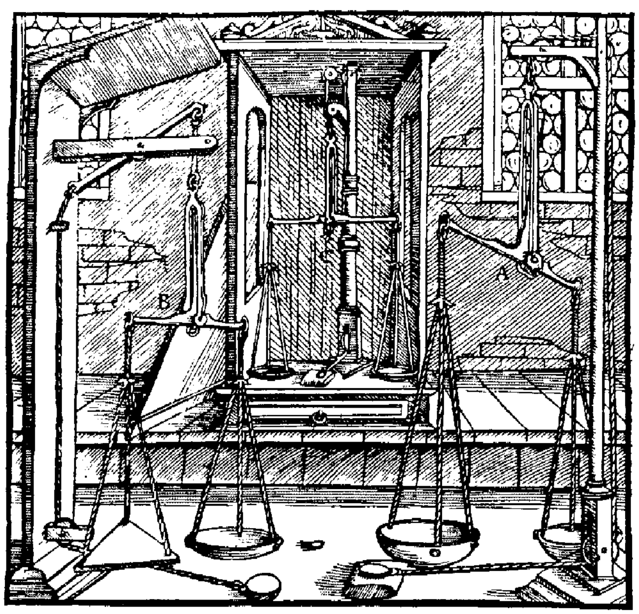
nonmetal + oxygen → acid

metal + oxygen → calx

Thus Lavoisier considered Priestley's dephlogisticated air as the principle of acidity. Actually, he dramatized the phenomenon as a correction of a fallacious concept of combustion and calcination and spoke of his version as the "Anti-Phlogistic Theory". In truth, Siegfried has revealed that, while the phlogiston theory had been around for more than a century, it was used in a multitude of ways but was never highly regarded among leading scientific investigators. Lavoisier dramatized a generally known concept as something his investigations could overthrow (5).

Lavoisier's explanation of combustion began to attract adherents by 1785 and picked up additional disciples after the publication in 1787 of the *Méthode de nomenclature chimique*, which he coauthored in collaboration with Guyton de Morveau, Berthollet, and Fourcroy, and after the publication of his own *Traité élémentaire de chimie* in 1789. Although the phlogiston theory retained a few defenders, such as Priestley, the new chemistry quickly gained a strong following, despite some obvious flaws in Lavoisier's total system.

The book on nomenclature was an impressive treatise which superseded the unsystematic nomenclature of the past which had named chemicals after persons, industrial associations, appearance, color, taste, odor, place of origin, physiological effects, or other historical or chance observations. The four authors argued that names should be based on chemical composition, utilizing as the elemental basis a list of simple substances, soon to be called elements. Lavoisier's input into the nomenclature reform is clearly secondary to that of Guyton de Morveau, who had been publishing such arguments since 1780. Berthollet was apparently included as an author on the basis of his seniority and immense reputation; he appears to have contributed little if anything to the system. Likewise, though Fourcroy, the youngest of the authors, played an important role later in his position as a chemistry teacher, his early contributions were, at best, minimal.




Assaying balances from Agricola's *De re metallica* of 1556

The major success of Lavoisier's work was in revealing that chemical reactions have a quantitative basis. They can be checked by the chemical balance, just as a business transaction can be checked by the balance sheet, and Lavoisier was professionally a businessman. In a chemical reaction the masses of the reactants must be accounted for in the masses of the products.

Lavoisier's concept of oxygen as the acid former was questioned by Berthollet almost from the beginning and was demolished early in the next century by Davy, who established that marine acid (i.e., HCl) lacked oxygen. Other studies soon undermined Lavoisier's contention that oxygen was the sole agent of combustion or oxidation by showing that oxidation processes can be associated with a variety of oxidizing agents, many of which, like the halogens, contain no oxygen. In a similar fashion, Lavoisier's concept of the element caloric as a heat substance would give way to the concept of heat energy a half century later.

Like elements, atoms had been discussed since antiquity. Leucippus and his pupil Democritus philosophized about a particulate world at the time of Socrates in 5th century B.C. Athens. We have no original sources from either Leucippus or Democritus. What we know about ancient atomism is found in the writings of its critics. The theory was expanded somewhat later by the philosopher Epicurus, known primarily for his suggestion that life should be enjoyed. Our best source of what the atomists believed is found in the (1st century B.C.) Roman poet Lucretius' long poem *De rerum natura* (Concerning the Nature of Things) (6).

Ancient atomism never really caught on, in part because Epicurean philosophy became suspect by Christian theologians, but more particularly because it was a speculative philosophy which to many minds was less persuasive than the competing view of matter as a continuous plenum (a full universe). After all, an atomic system required a void in which the atoms could move.

Thus, the atomic philosophy of matter was largely rejected from late antiquity until well into the Renaissance. Following the work of Torricelli, Pascal, and Boyle, which demonstrated the reality of a vacuum, atomism started to make a reappearance, but more in the form of physical molecules, generally called particles or corpuscles, than in the form of indivisible chemical atoms.

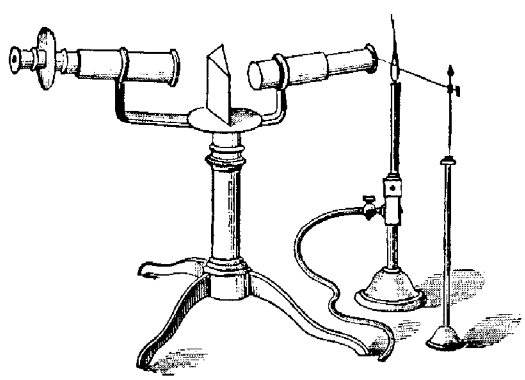
It was primarily John Dalton, after 1800, who recognized that atoms might be useful to chemists in connection with the post-Lavoisierian concept of elemental (simple) substances. While Dalton recognized that atoms had weight and that combining weights might reveal atomic weights, he was unable to produce a reliable table of atomic weights, partly because he was not a good analyst, but primarily because he lacked the insight to deduce correct formulas. His Swedish contemporary, Berzelius, was a superb analyst whose insight into certain chemical relationships led him to satisfactory formulas and hence to satisfactory atomic weights (7).

Through the investigations of Dalton, Berzelius, Avogadro, Dumas, and Cannizzaro there was a general acceptance of atoms of elements, and molecules of compounds and elements by 1870. The introduction of the periodic classification of the elements by Mendeleev was a strong factor leading to acceptance of elements, atomic weights, and family relationships among elements.

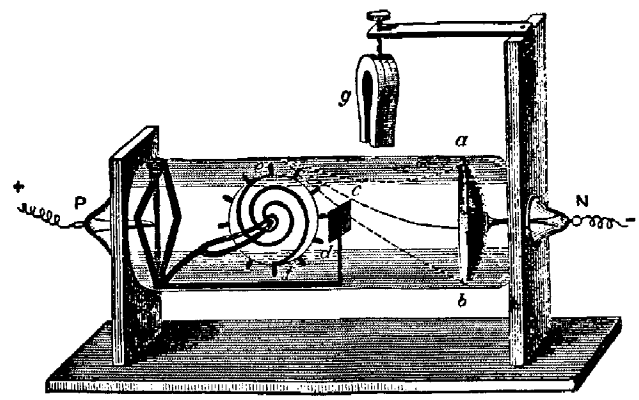
New discoveries, however, created new problems just as elements and atoms were being accepted. The introduction of the spectroscope by Bunsen and Kirchhoff in 1859 revealed that elements emitted and absorbed light under proper circumstances, and that each element emitted and absorbed light of very specific wave lengths. The spectroscope quickly led to the discovery of rubidium and cesium by Bunsen and Kirchhoff. William Crookes, when examining the spectrum of selenium, observed an anomalous green line which proved to be due to an impurity and led to the discovery of thallium. Others quickly uncovered several additional, new elements and, after that time, the spectroscope figured in the discovery or verification of almost all new elements. In astronomy the spectroscope soon provided information about the composition of stars and star systems, and the speed of their radial motion. Thus the creation of the physicist, the spectroscope, profoundly influenced the research of both chemists and astronomers (8).

The spectroscope quickly raised puzzling questions about atoms of elements. Johann Balmer found in 1884 that the wave lengths of the spectral lines of hydrogen formed a convergent series based on a simple mathematical formula. In the next several years he published similar results for the spectra of helium and lithium. The origin of such lines raised questions about whether the atom was truly a small homogeneous particle.

A second physical phenomenon raised further questions about the indivisible atom. About 1850 it was recognized that if two electrodes were placed in the closed ends of a glass tube and the air then evacuated, a current began to flow between the



A 19th century spectroscope




A 19th century Geissler tube designed by Crookes

electrodes and, at a high degree of evacuation, a purple glow appeared. When a different gas was substituted in the evacuated tube, the flow took on a color characteristic of the specific gas. This phenomenon led, during a 40-year period of intensive research with different gases and with tubes of varying design, to a series of discoveries of sub-atomic phenomena which, by 1900, included positive rays, electrons, and X-rays.

In 1896 Antoine Henri Becquerel, while studying the fluorescence of various salts on exposure to X-rays, found that uranium salts sensitize a photographic plate long after they stop fluorescing. He quickly established the fact that uranium-containing materials are constantly undergoing a form of decay in which radiation, presumably X-rays, are emitted. It was soon established that the radiation had no connection with fluorescence and was a property of uranium itself.

At this point Marie Curie undertook a study to learn if radioactivity was present in other elements. She soon established thorium to be radioactive. Upon testing the mineral pitchblende (80% $U_3O_8$), she found the ionizing power to be several times that of pure uranium. She suspected the presence of another radioactive element and, with the help of her husband Pierre, set out to isolate it. By July 1898 they reported the presence of a new element which she named polonium, after Poland, her native homeland.

Since there was still very active radiation in the barium fraction, they also set out to isolate it. By December they had a concentrate which glowed in the dark and enabled them to announce the presence of a second new element, radium. Their material was still very impure and the next four years were spent in preparing a pure sample of radium chloride. From several tons of pitchblende residues from which the uranium had been commercially separated for glassmaking, they obtained 0.1 gram of radium chloride showing no spectroscopic evidence of contamination with barium.

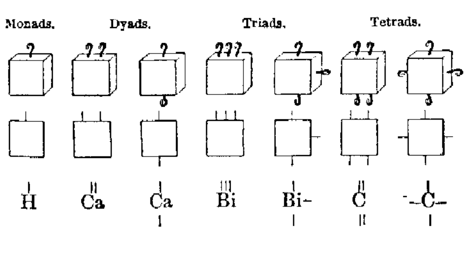
In the meantime, Becquerel discovered that a part of the radiation was deflected by a magnet in the same direction as cathode rays and was composed of electrons. About the same time, Ernest Rutherford learned that the radiation contained a very penetrating fraction, which he named *beta*, and an easily absorbed fraction, which he named *alpha*. He and his associates ultimately established that alpha radiation was made up of doubly positive helium ions, whereas *beta* radiation had already been identified as a beam of electrons. A third form of radiation, even more penetrating than the electrons, was named *gamma*. It was shown to be a form of short wave-length X-ray.

In looking at the state of atomism between 1860 and 1910, one observes the transformation of the atom from a small indivisible particle to an atom of parts. During the same period, chemists had been seeking an explanation of the nature of chemical combination. What was there about atoms that led to their combination to form molecules? Hooks and eyes were even suggested. Why did some compounds conduct electricity while undergoing decomposition while others did not decompose?

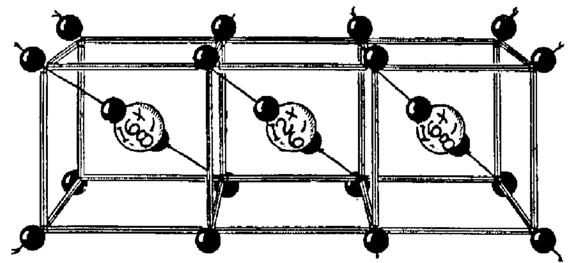
The concept of a complex atom with parts that can be shared with other atoms, or even transferred, began to be postulated before World War I and was expanded upon shortly thereafter. Somewhat naive atomic structures introduced by G. N. Lewis and Irving Langmuir provided an image of ionic and covalent combination which was widely adopted in teaching and research, despite their use of a static atomic model which clearly failed to represent dynamic reality.

In conclusion, I believe that history of chemistry has a place in the armament of chemistry teachers at all levels, but particularly at the introductory level. It humanizes the subject by making it a part of the human enterprise rather than leaving it as an abstract search for the understanding of chemical change. The discipline has had a profound impact on virtually every human enterprise, starting with agriculture and health and passing on to the extraction, processing, and production of raw materials for industry and finished products for the consumer (9).

Ultimately, the use of history reveals to the student that chemical knowledge is never static. New facts are being uncovered continually which must be tested against current theory. Frequently new facts create a strain upon contemporary interpretations of the existing facts and in time there may come a rejection of existing explanations in favor of more persuasive ones. More frequently, new facts cause a modification of existing explanations.




A late 19th century view of atomic combination in terms of hooks and eyes



A 3-D model of a Lewis-Langmuir cubical atom representation of carbon dioxide

As noted above, the word element has evolved from a fundamental something resulting from the presence of a pair of qualities into a set of 100-plus simple substances whose properties are determined by the number of protons and electrons (with a variable number of neutrons associated with each of the elements). However, we are now aware that the three components of atoms, when they collide at high velocities, are shattered into still smaller particles. Should we abandon our elements in favor of these fragments? I think not, at least not until the high energy physicists show us that their mesons and quarks are truly of fundamental relevance to chemists in explaining the nature of chemical change.

Natural philosophers have been learning over a period of more than 2,000 years that the interpretation of experimental observations is subject to change following the acquisition of new knowledge. Our students are entitled to become aware that, while there are no final answers at the level of present knowledge, there are still useful answers which are worth understanding. They should also be aware that even the most persuasive items of knowledge are subject to change in the future. The expansion of chemical knowledge in the past three centuries has been very impressive, particularly in the past century, but we must make students realize that there will continue to be changes in the next century as well. They must be prepared to understand that our present knowledge is still subject to change. By understanding change in the past, one becomes prepared to accept change in the future.

Only history clearly reveals the true nature of science. Students who fail to understand the nature of scientific progress will also fail to understand that:

* Science is an endless frontier.
* Ideas are necessary, but must be continually questioned.
* Scientists are bumblers who make progress only when they recognize their mistakes and adjust for them rather than defending them.
* Instruments are not only essential to scientific research, but an appropriate new tool can contribute to an impressive advance in understanding.
* Important scientific discoveries are frequently made simultaneously, but independently, in different laboratories. Only

rarely is plagiarism involved. When the background knowledge is complete, the subsequent discovery is almost inevitable (10).

**References and Notes**


Presented as a Perspectives Lecture to the Division of Chemical Education at the 198th National Meeting of the American Chemical Society in Miami Beach, FL, 10-15 September 1989.

1. The most readily available reference sources on the general history of chemistry are E. Farber, *The Evolution of Chemistry*, Ronald, New York, 1952; H. M. Leicester, *The Historical Background of Chemistry* , Wiley, New York, 1956; and A. J. Ihde, *The Development of Modern Chemistry*, Harper, New York, 1964. Both the Leicester and Ihde volumes are currently available as Dover reprints. J. R. Partington, *A History of Chemistry* , 4 Vols., Macmillan, London and New York, 1961-1970 is much more comprehensive than the others and has very complete references to the original literature. However, it fails to give much attention to the 20th century and says almost nothing about developments after World War I. Ihde's volume has the best coverage of the first half of the 20th century and includes 75 pages of bibliographic notes and appendices on discovery of the elements, radioactive isotopes, and Nobel Prizes in the sciences.

2. J. Parascandola and A. J. Ihde, "History of the Pneumatic Trough", *Isis*, **1969**, *62*, 351-361.

3. S. Hales, *Vegetable Staticks* , Innys, London, 1727.

4. A. J. Ihde, *Development of Modern Chemistry*, Harper, New York, 1964, Chapters 2 and 3.

5. R. Siegfried, "Lavoisier and the Phlogistic Connection", *Ambix*, **1989**, *36*, 31-40 and "The Chemical Revolution in the History of Chemistry", *Osiris*, **1988**, *4*, 34-50.

6. Lucretius (Titus Lucretius Carus), *De rerum natura. (Of the Nature of Things)*. A good English translation is the one by William Ellery Leonard published by E. P. Dutton, NY, 1916.

7. J. Dalton, *New System of Chemical Philosophy*, 2 Vols., Bickerstoff, Manchester and London,, 1808, 1810. Also reference 4, Chapters. 4, 5, and 6.

8. Ihde, reference 4, Chapters 9 and 18.

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# JEAN-BAPTISTE DUMAS (1800-1884): THE VICTOR HUGO OF CHEMISTRY


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Romanticism is the term used to gather together a whole series of literary and artistic movements of the late 18th to late 19th centuries. These various movements, which spread throughout Europe and even to America, had one common element - the rejection of the traditions and rules of classicism, of the "Establishment", as it were. Romanticism produced Wordsworth, Keats, and Shelley; Goethe and Heine; Hugo and Dumas (Alexandre, that is); Pushkin; and Poe. It produced Delacroix, Constable, and Turner; Schumann, Chopin and Liszt; and, of course, Wagner, who tried to put it all together in his musical dramas. The Romantics' emphasis on emotion over reason, and on subjectivity and imagination over objectivity and intellect, would seem to rule out any inclusion of the sciences in these movements. But we know better. We know that science is not just a collection of facts and techniques; that it is a human endeavor, carried out in the context of a specific society or culture. We know that scientists are not (or at least not always) one-dimensional, narrowly trained and focused, and cooly objective; but are three-dimensional human beings with interests in, and with attitudes affected by, the arts, literature, religion, and politics.

In that wonderful volume of biographical essays, *Great Chemists*, edited by Eduard Farber, there is a short piece on Jean-Baptiste Dumas and Charles-Adolphe Wurtz, written by Georges Urbain and first presented to the Société Chimique de France in May of 1934. Urbain gave an unusual and provocative summary of his two subjects when he wrote (1):

> Living in the brilliant period of romanticism, they did not escape its influence. Dumas was the Victor Hugo of chemistry and Wurtz its Sainte-Beuve.

Because I knew a bit about Hugo, my first reaction to this statement was perhaps a little odd: I wondered whether Wurtz had tried to steal Dumas' wife (as Sainte-Beuve did to Hugo). I have seen no evidence that this was the case; apparently all that was implied was that Wurtz was a pupil and a friend of Dumas. The parallels between Wurtz and Sainte-Beuve will have to await another paper. But the statement intrigued me. In what sense was Dumas the Victor Hugo of chemistry? This essay is my attempt to answer that question.

There are, in fact, a number of parallels in the lives of these two men (2,3). First of all, they were almost exact contemporaries; Dumas was born in July 1800, 19 months before Hugo, and died in April 1884, 13 months before Hugo. Their childhood and adolescence spanned the rise and fall of Napoleon I. Hugo's father was an officer in Napoleon's army; Dumas at the age of 14 was determined to join the navy, but was