Lavoisier and the Chemical Revolution

Precision Instruments and Chemical Equations
Antoine-Laurent Lavoisier (1743-94)

- Born to a prosperous legal family.
- Graduated from the College des Quatre Nations, and obtained his law license.
- He made his living as a tax collector.
- 1771 - Married Marie-Anne Pierette Paulze, who became his collaborator and English translator.
- 1775 - National Gunpowder Commission. Worked in the labs at the Arsenal, using his own equipment.
Lavoisier’s Life (con’t)

• He was commissioned by the AS to study chemical nomenclature.

• This led to a new theory of chemical processes built on a new theory of combustion; did away with phlogiston.

• He was a liberal reformer, and developed progressive economic policy during the early years of the revolution.

• During the Terror, he was guillotined. [Lagrange: “It took only an instant to cut off that head, and a hundred years may not produce another like it.”]
Lavoisier’s Work

- Was a capable chemist but had few profound discoveries. Nevertheless, he is thought by many to have founded the modern field of chemistry. Wurtz (1868): “Chemistry is a French science. It was constituted by Lavoisier of immortal memory.”
- Introduced extreme precision to chemical experiment.
- Worked on respiration.
- Worked with Laplace on the theory of heat (caloric).
TRAITÉ
ÉLÉMENTAIRE
DE CHIMIE.

PREMIERE PARTIE.
De la formation des fluides aéiformes &
de leur décomposition; de la combustion
des corps simples & de la formation des
acides.

CHAPITRE PREMIER.
Des combinaisons du calorique & de la formation
des fluides élastiques aéiformes.

C'EST un phénomène constant dans la nature,
& dont la généralité a été bien établie par
Boerhaave, que lorsqu'on échauffe un corps
Tome I.  A
Lavoisier’s Legacy

• On the basis of a number of bold hypotheses, Lavoisier was able to reorganize chemical knowledge with little or no new ‘discoveries.’

• He quite consciously conceived of himself as a chemical revolutionary.

• He introduced a new conception of the chemical process, which lead to a new research program.

• He stressed and secured the importance of quantitative analysis.
Fundamental Ideas

- The different kinds of air found by Black, Priestley and Cavendish are, in fact, fundamentally different chemical *substances*. Common air is a mixture not a compound.
- *Mixtures* are simply different *substances* jumbled together.
- *Compounds* are *new substances* composed of more fundamental substances. They are characterized by constant composition (ratios), by weight, of the fundamental substances.
- Fundamental substances (simple substances, elements) are found by chemical analysis.
Fundamental Ideas (con’t)

• In every chemical reaction, no matter is created or destroyed. (Conservation of mass.)
• The measure of matter is its weight.
• Hence in every reaction, the weight of all reactants before and after will always be equal.
• Every chemical reaction is like an equation involving matter and the balance establishes its validity. (Chemical equation.)
• Substances should be named for their constituent parts. (Nomenclature.)
New Language

- He instituted a new *nomenclature* in which chemical names indicates (1) the substances involved in their compositions and (2) the ratios in which they occur.
- He was influenced by Linnaeus’ binomial classification of plants and Condillac’s theory of a universal algebra.
- Condillac: “We think only with words -- languages are true analytical methods -- algebra, the means of expression which is the simplest, most exact and best adapted to its object, is both a language and an analytical method. In short, the art of reasoning can be reduced to a well constructed language.”
Elements of Chemistry, 1790: “The impossibility of separating the nomenclature of a science from the science itself, is owing to this, that every branch of physical science must consist of three things; the series of facts which are the objects of the science, the ideas which represent these facts, and the words by which these ideas are expressed… And, as ideas are preserved and communicated by means of words, it necessarily follows that we cannot improve the language of any science without at the same time improving the science itself; neither can we, on the other hand, improve a science, without improving the language or nomenclature which belongs to it.”
Nomenclature

• The results of this work were codified in his report to the AS and in his *Elements of Chemistry*.

• Because his theory of chemical processes was built into the new naming system, the nomenclature served to reinforce the theory.

• Thus, oxygen was given that name because it was conceived as the root of all acids. (Hydrogen.)

• Examples of the new nomenclature are calcium nitrite and calcium nitrate, nitric oxide and nitrous oxide, carbon monoxide and carbon dioxide, etc. Iron oxide, magnesium carbonate (magnesia alba).
• *Elements of Chemistry*, 1790: “To those bodies which are formed by the union of several simple substances we gave new names, compounded in such a manner as the nature of the substances directed; but, as the number of double combinations is already very considerable, the only method by which we could avoid confusion, was to divide them into classes. In the natural order of ideas, the name of the class or genus is that which expresses a quality common to a great number of individuals: The name of the species, on the contrary, expresses a quality peculiar to certain individuals only.”
Lavoisier’s Simple Substances

• This theory puts great weight on the building blocks, the elements.

• Lavoisier stated that the elements are identified by analysis, laboratory experience. They are not theoretical.

• They may be further broken down at a later point. (He considered chlorine (Cl) to be an oxide.)

• L: “Chemistry advances toward perfection by dividing and subdividing...these things we at present suppose simple may soon be found quite otherwise. All that we dare venture to affirm of any substance is that it must be considered simple in the present state of our knowledge, and so far as chemical analysis has hitherto been able to show.”
Lavoisier on elements

• *The Elements* (1790): “It will be a matter of surprise, that in a treatise upon the elements of chemistry, there should be no chapter on the constituent and elementary parts of matter; but I shall take occasion, in this place, to remark that the fondness for reducing all the bodies in nature to three or four elements, proceeds from a prejudice which has descended to us from the Greek philosophers. The notion of four elements … is a mere hypothesis, assumed long before the first principles of experimental philosophy or of chemistry had any existence…”
• All that can be said upon the number and nature of elements is, in my opinion, confined to discussions entirely of a metaphysical nature... I shall, therefore, only add upon this subject, that if, by the term *elements*, we mean to express those simple and indivisible atoms of which matter is composed, it is extremely probable we know nothing at all about them; but if we apply the term *elements*, or *principles of bodies*, to express our idea of the last point to which analysis is capable of reaching, we must admit, as elements, all the substances into which we are capable, by any means, to reduce bodies by decomposition.”
TABLE OF SIMPLE SUBSTANCES.

Simple substances belonging to all the kingdoms of Nature, which may be considered as the chemical elements of bodies.

<table>
<thead>
<tr>
<th>English</th>
<th>Latin</th>
<th>Correspondent old Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Light</td>
<td></td>
</tr>
<tr>
<td>Caloric</td>
<td>Caloricum</td>
<td>Light, Principle or element of heat, Fire, igneous fluid, Matter of fire and of heat, Dephlogisticated air, Empyrean air, Vital air, or Base of vital air.</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Oxygenum</td>
<td></td>
</tr>
<tr>
<td>Azot</td>
<td>Azotum</td>
<td>Phlogisticated air or gas, Mephitis, or its base. Inflammable air or gas, or the base of inflammable air.</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Hydrogenum</td>
<td></td>
</tr>
</tbody>
</table>

Oxydable and Acidifiable simple Substances not Metallics.

<table>
<thead>
<tr>
<th>Name</th>
<th>Latin</th>
<th>Correspondent old Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur</td>
<td>Sulphurum</td>
<td></td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Phosphorum</td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>Carbonum</td>
<td></td>
</tr>
<tr>
<td>Muriatic radical</td>
<td>Murium</td>
<td>The same names.</td>
</tr>
<tr>
<td>Fluoric radical</td>
<td>Fluorum</td>
<td>The simple element of charcoal.</td>
</tr>
<tr>
<td>Boracic radical</td>
<td>Boracum</td>
<td>Still unknown.</td>
</tr>
</tbody>
</table>

Oxydable and Acidifiable simple Metallic Bodies.

<table>
<thead>
<tr>
<th>Name</th>
<th>Latin</th>
<th>Correspondent old Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
<td>Antimonium</td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>Arsenicum</td>
<td></td>
</tr>
<tr>
<td>Bismuth</td>
<td>Bismuthum</td>
<td></td>
</tr>
<tr>
<td>Cobalt</td>
<td>Cobaltum</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>Cuprum</td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>Aurum</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>Ferrum</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>Plumbum</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>Manganum</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>Mercurium</td>
<td></td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Molybdenum</td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>Nickelum</td>
<td></td>
</tr>
<tr>
<td>Platinum</td>
<td>Platinum</td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td>Argentum</td>
<td></td>
</tr>
<tr>
<td>Tin</td>
<td>Stanum</td>
<td></td>
</tr>
<tr>
<td>Tungsten</td>
<td>Tungstenum</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>Zincum</td>
<td></td>
</tr>
</tbody>
</table>
# TABLE OF SIMPLE SUBSTANCES.

<table>
<thead>
<tr>
<th>New Names</th>
<th>Correspondent old Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Light</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Dephlogisticated air. Vital air.</td>
</tr>
<tr>
<td>Azote [Nitrogen]</td>
<td>Phlogisticated air or gas.</td>
</tr>
<tr>
<td>Mephitis</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Inflammable air or gas.</td>
</tr>
</tbody>
</table>
Oxydable and Acidifiable simple Substances not Metallic.

New Names. Correspondent old names.

Sulphur The same names.

Phosphorus

Charcoal

Muriatic radical Still unknown. [HCl]

Fluoric radical

Boracic radical

…
Lavoisier’s Laboratory
Lavoisier’s Balance

- Lavoisier’s balance (background) was very expensive and precise.
- It was made for him by the best instrument makers in Paris.
- In the foreground, we see a machine for generating and storing static electricity.
Lavoisier’s Gasometer

- Lavoisier’s gasometer allowed him to measure the volume and the weight of gases with high precision.
- It was so much better than any other balance, that he could carry out experiments that others could not verify.
Lavoisier’s Theory of Combustion

• “Memoir On Combustion,” 1777.

• Phenomena of combustion always
  – Involves fire or light (caloric).
  – Takes place in the presence of pure air \( (O_2) \).
  – Pure air is decomposed and the weight of the burning body increases in the amount of the pure air taken in.
  – The burning body becomes an acid by the addition of pure air. (sulfur->vitriolic acid, carbon based->fixed air \( (CO_2) \).)

• He argued that all these phenomena can be explained without using phlogiston. (*There is no need for phlogiston.*)

• He proposed that the key lay in the role of \( O_2 \).
Theory of combustion

• “Memoir On Combustion,” (1777) : “I venture to propose to the Academy today a new theory of combustion. Materials may not burn except in a very few kinds of air, or rather, combustion may take place in only a single variety of air: that which Mr. Priestley has named dephlogisticated air and which I name here pure air. In all combustion, pure air in which the combustion takes place is destroyed or decomposed and the burning body increases in weight exactly in proportion to the quantity of air destroyed or decomposed.
Pure air, the dephlogisticated air of Mr. Priestley, is then, from this point of view, the true combustible body and perhaps the only one in nature, and we see that there is no longer need, in explaining the phenomena of combustion, of supposing that there exists an immense quantity of fixed fire in all bodies which we call combustible, that on the contrary it is very probable that little of this fire exists in metals, sulfur, and phosphorus and in the majority of very solid, heavy, and compact bodies; and perhaps even that only the matter of free fire exists in these substances by virtue of the property which this matter has of coming into equilibrium with neighboring bodies.”
Theory of Combustion

- He argued that all of these phenomena could be explained without using phlogiston.
  - mercury + oxygen $\leftrightarrow$ mercuric oxide
  - wood + common air $\rightarrow$ ash + carbon dioxide
  - ore (metallic oxide + charcoal) $\rightarrow$ metal + carbon dioxide
  - metal (pure base) + water $\leftrightarrow$ metallic oxide + hydrogen
  - water $\leftrightarrow$ hydrogen + oxygen

- In arguing against the phlogiston theory “my object is not to substitute a rigorously demonstrated theory but solely a hypothesis which appears to me more probable, more conformable to the laws of nature, and which appears to me to contain fewer forced explanations and fewer contradictions.”
Lavoisier’s Study of Respiration
Lavoisier’s theory of respiration

- *Experiments on Respiration*, 1777: “…one may conclude that one of two things occurs as a result of respiration: either the respirable air contained in the air of the atmosphere is converted into gaseous acid of chalk (CO$_2$) during its passage through the lung; or there is an exchange in this organ, respirable air being absorbed and an almost equal volume of gaseous acid of chalk (CO$_2$) being given up by the lung…..”
Theoretical substances

- Lavoisier’s theory got rid of the theoretical substance of *phlogiston*, claiming that it was no longer needed as an explanatory category but it introduced the idea of *caloric*.
- Caloric, like phlogiston, was colorless, odorless and weightless.
- It was a theoretical fluid that accounted for “heat flow.”
Priestley’s reaction I

- He never accepted the new chemistry.
- *The Doctrine of Phlogiston*, 1796: “There have been few, if any, revolutions in science so great, so sudden, and so general, as the prevalence of what is now usually termed the new system of chemistry, or that of the Antiphlogistians, over the doctrine of Stahl [the phlogiston theory], which was at one time thought to have been the greatest discovery that had ever been made in the science.”
Priestley’s reaction II

- He went on to state his doubts about the theory.
- He claimed that the new theory gave no better account of rusting than the old.
- That there was no grounds for believing that water is composed of hydrogen and oxygen.
- And that the new theory added as many complications as it resolved (relation between hydrogen and water and the substance of carbon).
Priestley on water

- *The Doctrine of Phlogiston*, 1796: “A pretended proof that water is composed of dephlogisticated and inflammable air, is that when the latter is burned slowly in the former, they both disappear, and a quantity of water is produced, equal to their weight. I do not, however, find that it was in more than a single experiment that water so produced is said to have been entirely free from acidity... But the apparatus employed does not appear to me to admit of so much accuracy as the conclusion requires; and there is too much of correction, allowance, and computation, in deducing the result.”
Priestly on Hydrogen

• *The Doctrine of Phlogiston*, 1796: “If inflammable air, or hydrogen, be nothing more than a component part of water, it could never be produced but in circumstances in which either water itself, or something into which water is known to enter, is present. But in my experiments on heating finery cinder together with charcoal, inflammable air is produced, though, according to the new theory, no water is concerned.”
Priestley on new substances

- The Doctrine of Phlogiston, 1796: “Though the new theory discards phlogiston, and in this respect is more simple than the old, it admits another new principle, to which its advocates give the name of carbon, which they define to be the same thing with charcoal, free from earth, salts, and all other extraneous substances; and whereas we say that fixed air consists of inflammable air and dephlogisticated air or oxygen, they say that it consists of this carbone dissolved in dephlogisticated air.”
The Chemical Revolution

• Produced a new nomenclature based on a theory of simple substances.
• Provided a definition of elements based on laboratory practice.
• Established the principle of constant combination.
• Cemented the methodology of analysis by weight.
• Elucidated the role of oxygen in combustion and respiration.
• Developed a new theory of acids, bases and salts.
• Overthrew the phlogiston theory.
• Established the importance of quantitative precision.