The Chemical Revolution

Gasometer (synthesis of gases)
Mercury tube
Hales device
Glass flask (synthesis of water)
Brass hydrometer (density of fluids)
Manuscript – Traité Élémentaire de Chimie
Artists portfolio

Jakques-Louis David,
“Portrait of M. Lavoisier and his Wife”
1788

Antoine-Laurent Lavoisier

- 1743 – 1794
- Began publishing chemical studies in 1764
- Member of the French Academy of Sciences (1768)
- Member of the Ferme Générale (1768 – ’91)
- Worked on first geological map of France (1769, w/ Jean-Ettiene Guettard)
- Director of the Gunpowder Administration (1775)
- Director of the Discount Bank (1788)
- Appointed to the Royal Treasury (1790 – ’91)
Jean-Paul Marat

- 1743 – 1793
- Physician shown to be a scientific charlatan by Lavoisier in 1779.
- Developed an animosity towards the Academy in general and Lavoisier in particular.
- “Man has the right to deal with his oppressors by devouring their palpitating hearts.”

Mesmerism

- Anton Mesmer (supported by Marat)
- Report of the Commission Charged by the King to Examine Animal Magnetism, 1784

On Probability and Charlatans

“The art of drawing conclusions from experiments and observations consists in evaluating probabilities and estimating if they are large and numerous enough to constitute proofs. This type of calculation is more complicated and more difficult that we think: it demands a great sagacity, and is in general beyond the powers of ordinary men.

It’s on their errors in this sort of calculation that the success of charlatans, sorcerers and alchemists is founded: likewise, in other times, that of magicians, enchanters, and in general, all those who have deluded themselves or who seek to abuse public credulity.”

“The Father of Modern Chemistry”

- Demise of phlogiston theory of combustion
- Modern concepts of element, compound & mixture
- Production of a table of elements
- Naming of oxygen and hydrogen
- Nomenclature
- Modern methods of chemical analysis
- Stoichiometry
- Principle of “conservation of mass”
Chemistry suffered from the lack of an organizing theory.

Chemistry needs someone who could bring about a “revolution” in the science.
Phlogiston Theory

Johan Becher introduced the idea that there was an element (terra pinguis) contained within combustible matter that was released upon combustion (1667)

- Water
- Terra lapidea (fusibility)
- Terra fluida (fluidity, volatility, metallicity)
- Terra pinguis (oily, sulphurous, combustibility)

Georg Stahl

- 1697: Introduces the term “phlogiston” for the (nearly) weightless “inflammable principle” and studies its role in combustion and calcination (oxidation)
  - Charcoal & oil were rich in phlogiston.
  - Metal = calyx (oxide) + phlogiston
- Chemical reactions occur by phlogiston transferring from one substance to another.
- A theory that unified combustion, metabolism, rusting and other phenomena.

Phlogiston explained ...

- Weight loss when combustibles are burned because they lose phlogiston
- Fire burns out in an enclosed space because it saturates the air with phlogiston
- Charcoal leaves very little residue when burned because it is made mostly of phlogiston
- Animals die in an airtight space because the air becomes saturated with phlogiston
- Some metal calxes turn to metals when heated with charcoal because the phlogiston from the charcoal restores the phlogiston in the metal
1772: Lavoisier becomes interesting in “airs”

- Discovered that phosphorous and sulfur gain weight when they are burned.
- They must be absorbing something, most likely from the air.
- In a private note to the secretary of the Academy, he extends this to all bodies undergoing combustion or calcination.

1772: Crisis!

- Louis Bernard Guyton de Morveau shows that all metals gain weight when calcinated (oxidized).
- But if calcination was explained by the loss of phlogiston from the metal, how could this be?

Joseph Priestly

- 1733 – 1804
- Directions for Impregnating Water with Fixed Air (1772)
- Experiments and Observations on Different Kinds of Airs (1774 – ’86)
- Member of the Lunar Society (1780 – ’91)
- Defended phlogiston to the end

Priestley’s Study of Airs

- Nitrous air
- Marine acid air
- Alkaline air
- Dephlogisticated nitrous air
- Dephlogisticated air
- Nitric oxide
- Hydrochloric acid
- Ammonia
- Nitrous oxide
- Oxygen

Modern
1773

“The importance of this subject has prompted me once more to undertake all this work, which seemed to me destined to bring about a revolution in physics and chemistry.”

Lavoisier burning diamonds, 1773

Discovery of a new “air”

- 1771 - Carl Scheele isolates “fire air”
- 1774 - Joseph Priestley isolates a new air and subsequently (1775) calls it “dephlogisticated air” in his “An Account of Further Discoveries in Air”
- 1774 - Priestley visits Lavoisier in Paris and describes his experiments
- 1776 - Lavoisier repeats Priestley’s experiments
- 1777 - Scheele’s Treatise on Air & Fire published.
Producing Oxygen

1777: Lavoisier coins “oxygen”

“I shall henceforth designate dephlogisticated air or eminently respirable air in its state of fixity by the name of the acidifying principle, or, if one prefers the same significations in a Greek word, by that of oxygen principle.”

Becomes oxygène in 1787

Death of Phlogiston

- Lavoisier publishes his “Memoir on Combustion in General” (1777). He uses Priestley’s original experiments on oxygen, combustion and water against the theory of phlogiston, and shows that combustion required the presence of oxygen.

- Priestly responds in “Experiments relating to Phlogiston” (1783) and “Considerations on the Doctrine of Phlogiston” (1796).

Erasmus Darwin

The Botanic Garden, 1791

Popularized oxygen(e) to English

“When Morn, escorted by the dancing Hours, O’er the bright plains her dewy lustre showers; Till from her sable chariot Eve serene Drops the dark curtain o’er the brilliant scene; You form with chemic hands the airy surge, Mix with broad fans, with shadowy tridents urge.
SYLPHS! from each sun-brilliant leaf, that trembling shakes O’er Earth’s green lap, or shoots amid her lakes, Your playful bands with simpering lips invite, And wed the enamour’d OXYGENE to LIGHT...”
**Richard Kirwan**

- 1733 – 1812
- Fellow of the Royal Society / Awarded Copley Medal / President of the Royal Irish Academy.
- One of the last supporters of phlogiston
  - Essay on Phlogiston and the Constitution of Acids (1787)
- Eventually abandoned phlogiston in 1791
- Also opposed Hutton’s theory of the Earth

**Hydrogen**

- First produced by the alchemist Paracelsus (1493 – 1541)
- 1671: Re–discovered by Robert Boyle
- 1766: Called “inflammable air” by Henry Cavendish
- 1783: Called “hydrogen” by Lavoisier after he and Simon LaPlace replicate Cavendish’s experiments.

**Henry Cavendish**

- 1731 – 1810
- Made “inflammable air” by combining metals and strong acids.
- Discovered that when it was mixed with “dephlogisticated air,” water resulted.
- Discovered that 79.167% of the atmosphere is “phlogisticated” and 20.833% “dephlogisticated”

**Henry Cavendish**

- Independently discovered (but never published):
  - Ohm’s Law
  - Dalton’s Law of Partial Pressures
  - Coulomb’s Law
  - Charles’ Law of Gases
Lavoisier took seriously Étienne Bonnot de Condillac’s claim that “the art of reasoning depends on a well-made language.”

He also had learned Linnaean nomenclature.

1787: *Méthode de nomenclature chimique* (Method of Chemical Nomenclature) with three others.

- Lists 55 elements
  - Nitric acid \( \text{HNO}_3 \) / Nitrurous acid \( \text{HNO}_2 \)
  - Nitrato \( \text{NO}_3^- \) / Nitrite \( \text{NO}_2^- \)

Tied to Lavoisier’s theory

1789

- Emphatically rejected phlogiston and outlined the oxygen theory of combustion.
- Defined an element as a substance that cannot be broken down further by any known method.
- Defined compounds as combinations of two or more elements - example of water.
- Outline theory of radicals (combinations of elements that work together)
- Clearly stated the Law of Conservation of Mass

---

Conservation of Matter

- “Wrongly do the Greeks suppose that aught begins or ceases to be; for nothing comes into being or is destroyed: but all is an aggregation or secretion of pre-existing things; so that all becoming might more correctly be called becoming mixed, and all corruption, becoming separate.” (Anaxagoras, c450 BCE)

- “The sum total of things was always such as it is now, and such it will ever remain” (Epicurus, 341–270 BCE)

- “A body of matter cannot disappear completely. It only changes its form, condition, composition, color and other properties and turns into a different complex or elementary matter.” (Tusi, 1201 – 1274 CE)

---

Lavoisier, 1785

“Nothing is created, either in the operations of art or in those of nature, and it may be considered as a general principle that in every operation there exists an equal quantity of matter before and after the operation; that the quality and quantity of the constituents is the same, and that what happens is only changes, modifications. It is on this principle that is founded all the art of performing chemical experiments; in all such must be assumed a true equality or equation between constituents of the substances examined, and those resulting from their analysis.”
Other Sciences

- Introduction of the metric system
- Drawing of vertical cross-sections to represent stratigraphic order.
- Studies of transpiration and respiration

Human Respiration

Marie-Anne Pierette Paulze

- 1758 – 1836
- Father was member of Ferme Générale
- Married Lavoisier in 1771
- Served as Lavoisier’s assistant, illustrator, and translator (English & Latin)
- Translated Kirwan’s Essay on Phlogiston for publication and the works of Cavendish & Priestley (for Lavoisier’s own use).
### TABLE 1. Description of Plates engraved by Marie Anne Paulze Lavoisier for Elementary Treatise on Chemistry

<table>
<thead>
<tr>
<th>PLATE NUMBER</th>
<th>PLATE DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Petri dishes, flasks, and grinders</td>
</tr>
<tr>
<td>II</td>
<td>Funnels, flasks, and other filtration apparatus</td>
</tr>
<tr>
<td>III</td>
<td>Heating apparatus and vessels for crystallization</td>
</tr>
<tr>
<td>IV</td>
<td>Distillation equipment and mercury apparatus</td>
</tr>
<tr>
<td>V</td>
<td>Water apparatus</td>
</tr>
<tr>
<td>VI</td>
<td>Ice calorimeter</td>
</tr>
<tr>
<td>VII</td>
<td>Apparatus used in recombination and decomposition of water</td>
</tr>
<tr>
<td>VIII</td>
<td>Balance for weighing reactants and products of reactions</td>
</tr>
<tr>
<td>IX</td>
<td>Open combustion apparatus</td>
</tr>
<tr>
<td>X</td>
<td>Fermentation reaction apparatus</td>
</tr>
<tr>
<td>XI</td>
<td>Oil apparatus</td>
</tr>
<tr>
<td>XII</td>
<td>Combustion apparatus, glass siphons, jars and pitchers</td>
</tr>
<tr>
<td>XIII</td>
<td>Furnace</td>
</tr>
</tbody>
</table>

Chemistry, banished until now to a small circle of adepts whose language and ideas were equally obscure, has become the inseparable aide and companion to Physics: these sciences, united and guided by experiment alone, have proceeded at a rapid pace; Chemistry itself has undergone a great revolution, a frightful scaffolding has given way to a simple and illuminating theory, based upon immediate consequences of experiment ... Everything indicates that we are on the right path, and that it will lead daily to discoveries in the natural sciences.

“This then is the revolution which has occurred in an important branch of human knowledge since your departure from Europe; I look upon this revolution as well advanced and it will be complete if you will stand with us”
“All the young scientists adopt the new theory and I thence conclude that the revolution is accomplished in chemistry”

The Spread of the New Chemistry
- 1787 – Cavendish abandons phlogiston (but never accepts oxygen)
- 1789 – Universal acceptance in France
- Early 1790’s – Edinburgh & Glasgow
- 1791 – Kirwan abandons phlogiston
- 1800 – Spread throughout Europe and on to America

I.B. Cohen (1985)
“Lavosier’s Chemical Revolution passes all the tests for a revolution in science. It has been recognized as a revolution by all historians and scientists, just as it was seen to be a revolution in its own time. Additionally, the whole science of chemistry and its language have followed the lines set forth in the Chemical Revolution. The Chemical Revolution is thus a paradigmatic example of a revolution in science.”
Revolution in Science, 236.

Carleton E. Perrin (1990)
“The Chemical Revolution is a classic instance of conceptual change in science – one of the first to be foretold. Venel had called for a breakthrough that would exploit the distinctive methods and concepts of chemistry to establish it as the independent peer of physics. … [Lavoisier’s] innovations transformed the structure and language of chemistry, generating a crisis that split the community. Chemistry emerged from the conflict as a more mature discipline with the public recognition Venel had desired.”
Companion to the History of Modern Science, 276.
“Now that you have been informed as to what has transpired in chemistry, it might be well to speak of our political revolution. We look upon this as accomplished and accomplished irretrievably.”

“I denounce to you the Corypheus of the charlatans, Master Lavoisier, son of a land-grabber, apprentice-chemist, pupil of the Genevan stock-jobber Necker, a Farmer General, Commissioner for Gunpowder and Saltpeter, director of the Discount Bank, secretary to the King, member of the Academy of Science, intimate of Vauvilliers, unfaithful administrator of the Paris Food Commission, and the greatest schemer of our times.”
“To ensure public tranquility, two hundred and seventy thousand heads more should fall.” (Marat)

―Let them be closed forever, these schools of flattery and servility ... to speak of one Academy is to speak of them all; there is the same spirit in all of them and in all are found the same men ... In the name of humanity, in the name of justice, and above all for your love of youth, let us destroy - let us annihilate - these deadly academies, which can no longer survive under a free regime.”

The Reign of Terror, 1793-'95

Jacques-Louis David

1794: Arrest of the Ferme Générale
“Like Jesus, Marat loved ardently the people, and only them. Like Jesus, Marat hated kings, nobles, priests, rogues and, like Jesus, he never stopped fighting against these plagues of the people.”

Charlotte Corday, Paul-Jacques-Aimé Baudry, 1860
Lavoisier after the Revolution