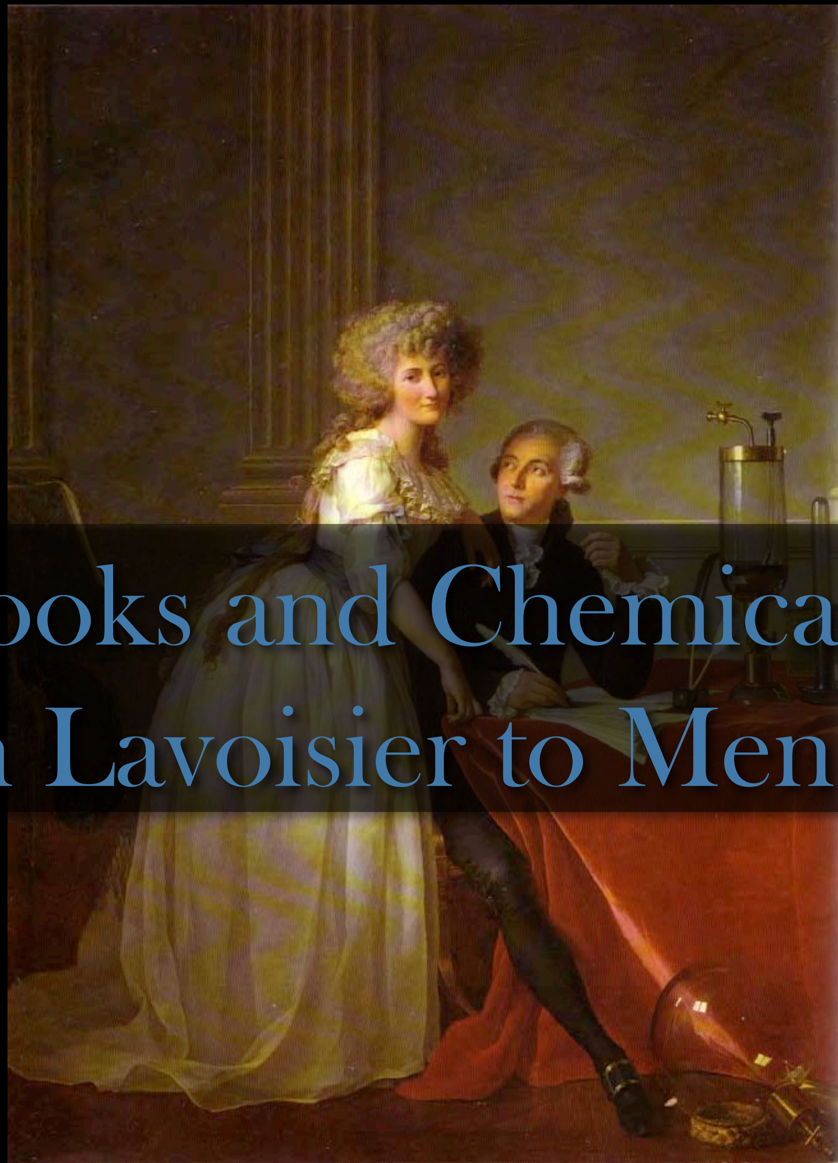
Textbooks and Chemical Order
From Lavoisier to Mendeleev



Prof. David Kaiser

Monday, September 20, 2010, STS.003

Matter unit

Overarching questions:

Is the stuff of the world unchanging or transmutable?
How have the institutions of science evolved?

I. Enlightenment and Revolution

II. Priestley, Lavoisier, and Airs

III. Atoms, Elements, and Order

Readings: Lavoisier, *Elements of Chemistry*, preface;
Dear, *Intelligibility of Nature*, 67-89.

The Age of Enlightenment

Urbanization

N. Guérard, "Les Embarras pour la circulation, au Pont Neuf à Paris," ca. 1700

Public Sphere

W. Hogarth, *An Election Entertainment*, 1755

Middle Class

J. Zoffany, British middle-class men, 1796

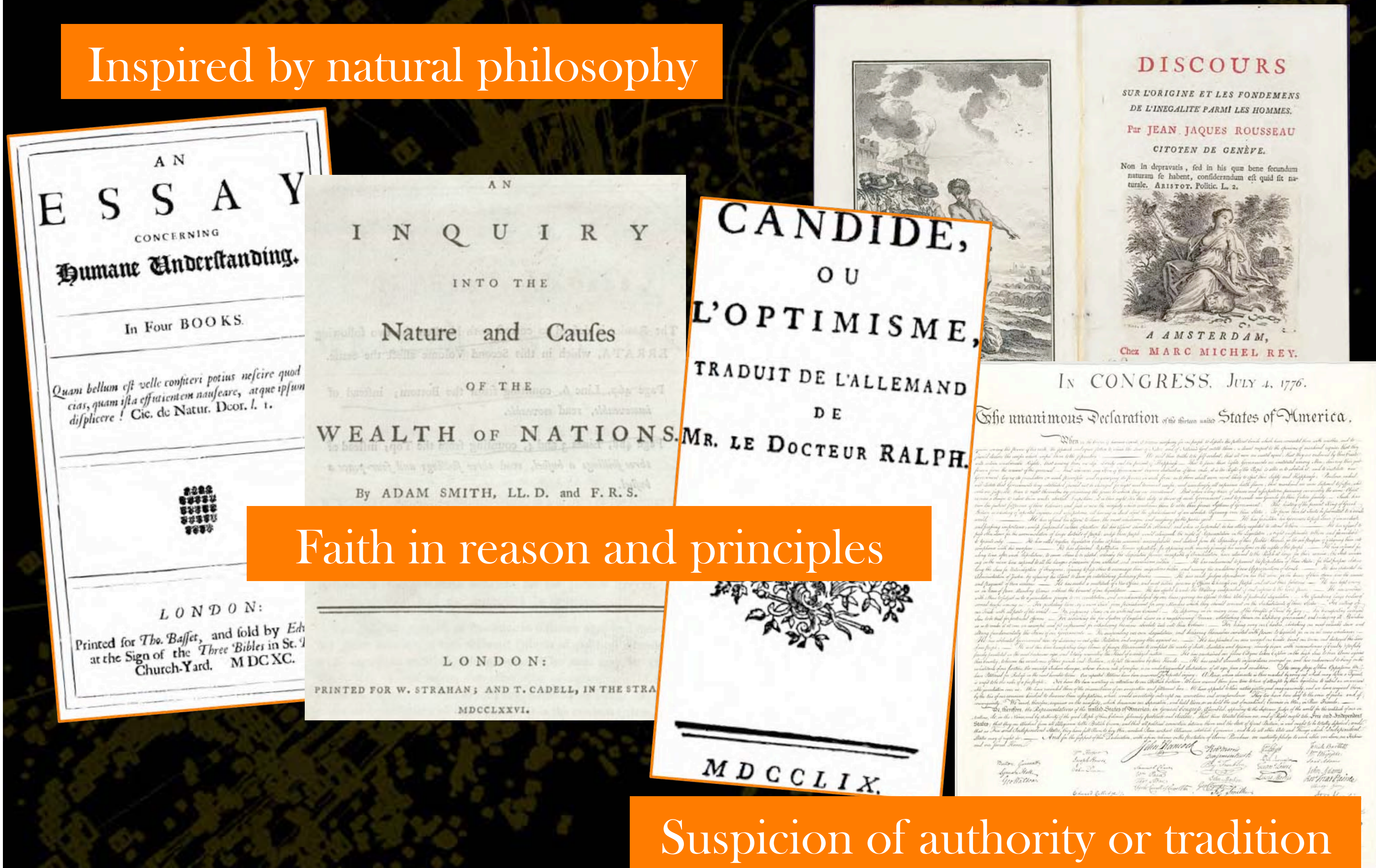
Print Culture

Enlightenment Characteristics

Inspired by natural philosophy

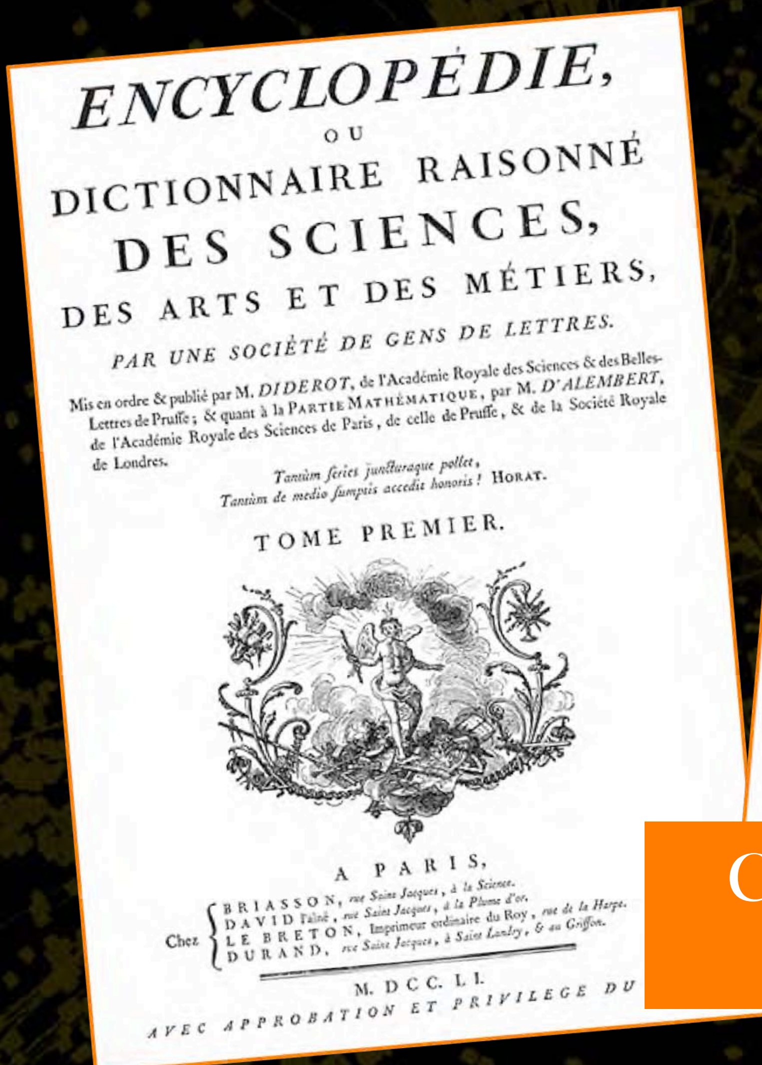
Faith in reason and principles

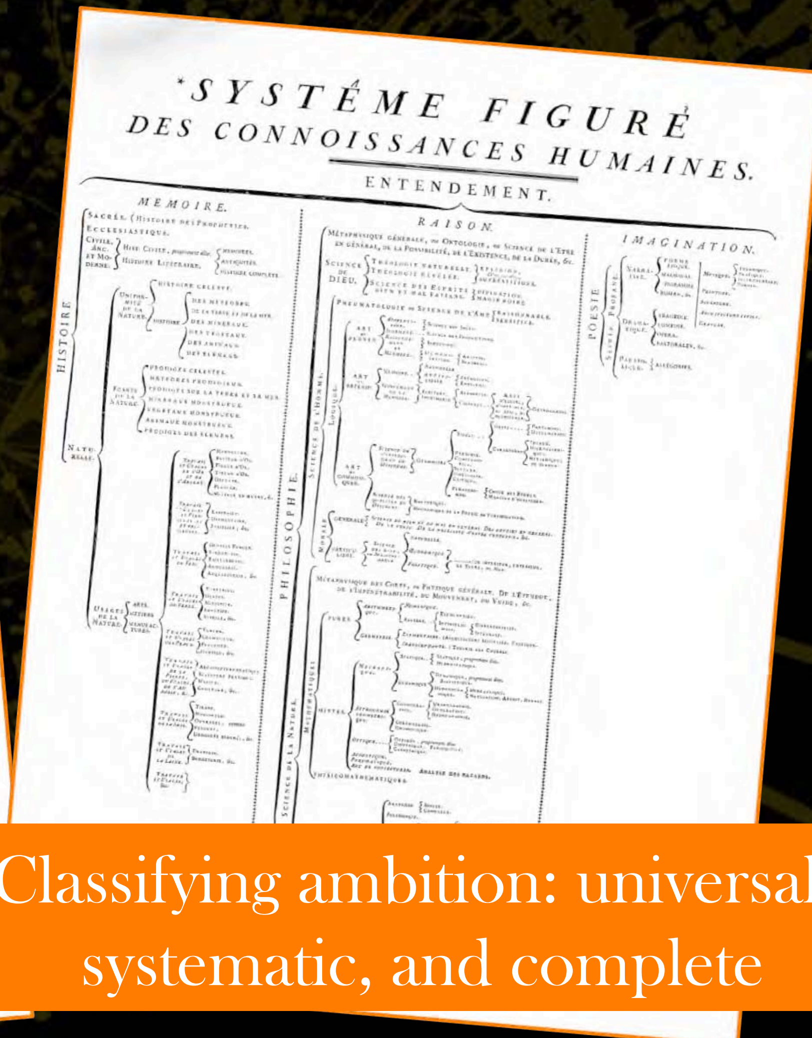
Suspicion of authority or tradition



Encyclopedic Aspirations

Knowledge as an end in itself; expand education

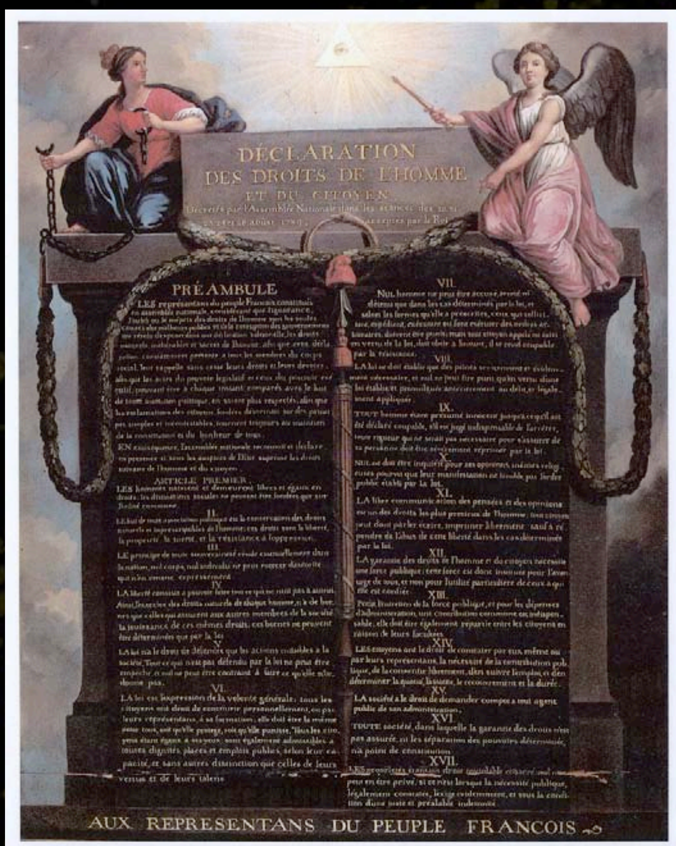




Classifying ambition: universal, systematic, and complete

French Revolution

"Ancien Régime": steep and rigid social structure. Three "orders"—nobles, clergy, and commoners. Privileges by birthright (or purchase); little social mobility.



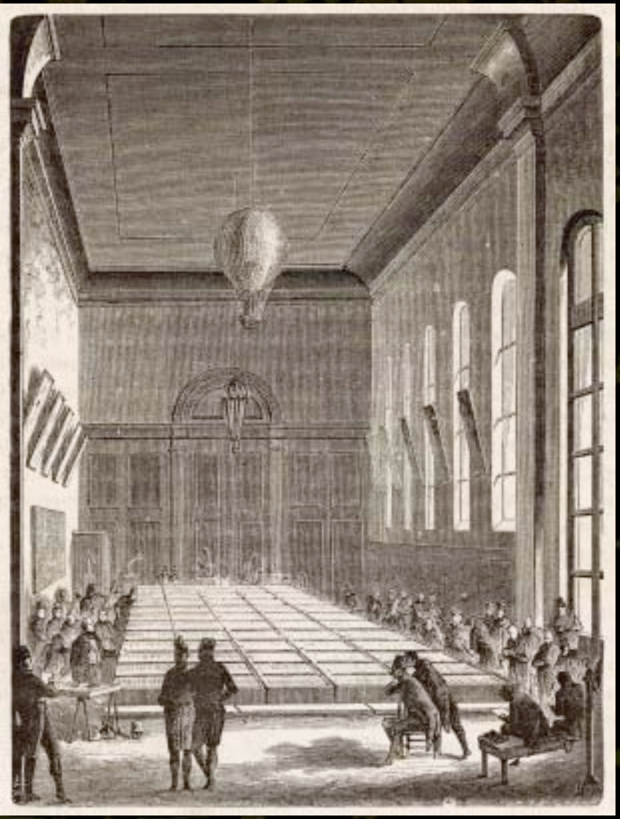
Jean-Pierre Houël, *The Storming of the Bastille*, 1789

Summer 1789: commoners in Paris stormed the Bastille; peasants in the countryside attacked feudal manors. That August, the National Assembley adopted the "Declaration of the Rights of Man and Citizen."

Revolutionary Institutions

During the early years of the Revolution, the new government established several new educational institutions, including the *École Polytechnique* and the *École Normale Superieure.*

Image of Decret de la Convention 9 Brumaire An 111, Ecole Normale Superieure removed due to copyright restrictions.



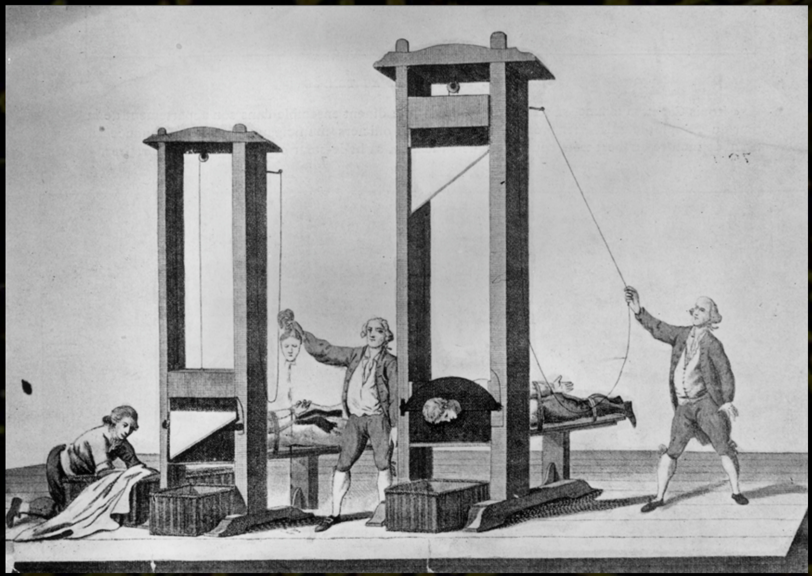
Louis Figuier, *Voltaic Battery Constructed at the École Polytechnique*, ca. 1860

These elite institutions focused on science and engineering, as properly "enlightened" topics around which to train new generations.

"The Terror"

By 1793, chaos reigned. France was fighting wars against Prussia and Austria, and internal factions divided the country. The Legislature appointed a 12-person "Committee on Public Safety," which quickly imposed martial law.

Execution of Louis XVI, January 1793



Between September 1793 and July 1794, tens of thousands of people were charged with "treason" and sent to the guillotine.

Priestley: Dissenting Chemist

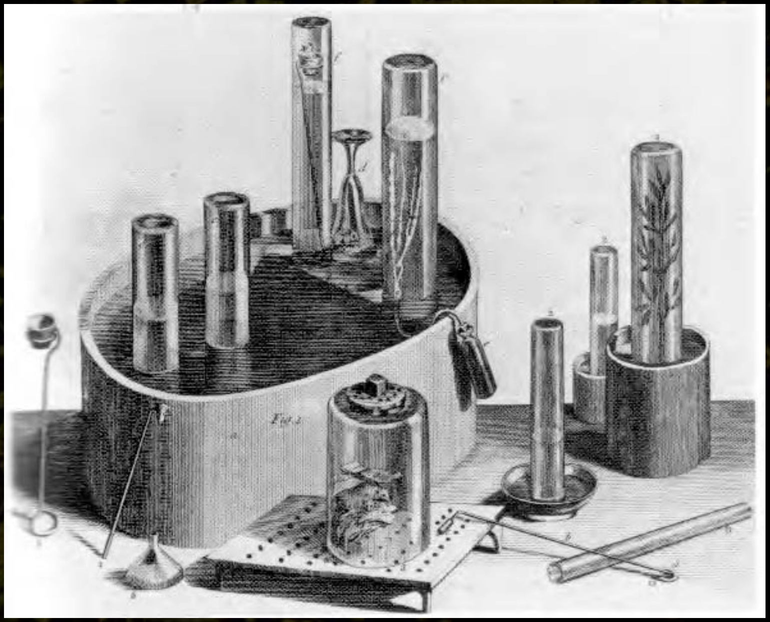
Joseph Priestley (1733 – 1804) was barred from Oxbridge because of his religious beliefs. He was educated in Dissenting Academies outside London, with their mix of abstract theory and practical application. His work was principally supported by new institutions like the Lunar Society of Birmingham, rather than the Royal Society.

Ellen Sharples, *Joseph Priestley*, 1794

A master experimentalist and writer, Priestley discovered more new gases than any of his contemporaries.

Phlogiston

wood + common air → ash + phlogisticated air



J. Priestley, *Experiments and Observations on Different Kinds of Air*, 1774

Common air can only absorb so much phlogiston before it becomes saturated. Thus the flame of a burning candle placed in a sealed jar will go out. The air that remains inside the container ("phlogisticated air") will support neither combusion nor respiration (poor mouse).

Immediate public health applications: test the "goodness" of air in prisons, mines, hospitals, and schools.

Dephlogisticated Air

Priestley found that when he heated mercury in ordinary air, it formed a red precipitate. Upon heating the precipitate, a new kind of air was released that could revive asphyxiated mice. Flames burned brigher in the new air as well. Priestley called it “vital air” or “dephlogisticated air”: the new air was able to absorb even more phlogiston than common air.

In 1774, Priestley traveled to Paris and told the Lavoisiers about his experiments.

Lavoisier: Aristocratic Chemist

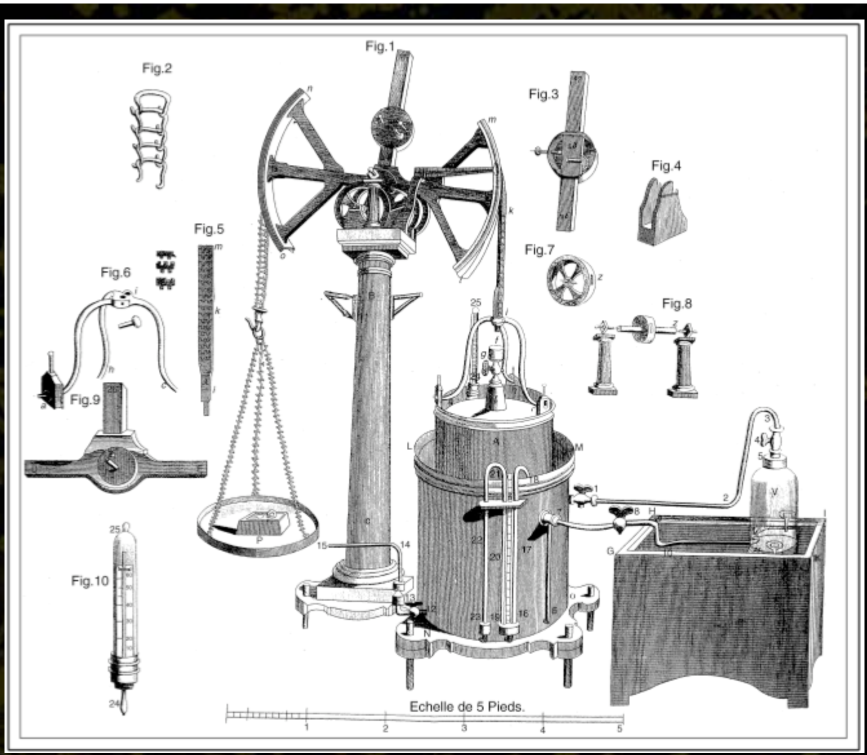
Antoine-Laurent Lavoisier (1743 – 1794) was born into an aristocratic family. He was elected at an early age to the Académie Royale des Sciences, and also served as a royal tax collector.

Jacques-Louis David, *Monsieur de Lavoisier and his wife, Marie-Anne Paulze*, 1788

His wife trained herself to assist in the laboratory. She also learned English to be able to read and correspond with English chemists like Priestley. And she drew detailed illustrations to accompany Lavoisier's publications.

Mass Balance

Inspired by advances in physics, Lavoisier sought precision and quantification. He carefully weighed reactants before and after combustion to ensure that total mass was conserved. When he re-did Priestley's experiment with mercury, he found that the precipitate weighed *more* than the original sample. How could that be, if combustion involved the *release* of phlogiston?



Lavoisier, *Traité élémentaire de chimie*, 1789

Priestley was skeptical in part because Lavoisier's apparatus was *too* elaborate. Few others could afford comparable equipment or replicate the results.

Priority Dispute

Lavoisier contined to experiment with the special air. By the late 1770s, he found that the acids of sulfur, carbon, nitrogen, and phosphorus all contained "eminently respirable air." He concluded that *all* acids must come from that air, so he named it "oxygen" (acid-generating).

Image of "Oxygen," Carl Djerassi and Roald Hoffmann, removed due to copyright restrictions.

To Lavoisier, combustion arose when a burning substance combined with oxygen from the air—hence the weight gain. But why was heat released? "Caloric": a fluid of pure heat, with no weight of its own.

Reform Nomenclature

Chemical nomenclature was a mess: substances were named for their composition, or the site they were found, or their discoverer, … No order, no system.

Inspired by Condillac and the *Encyclopédie*, Lavoisier introduced a “rational order” based on *analysis*: start with the simplest substances that cannot be further broken down, and build up from there.

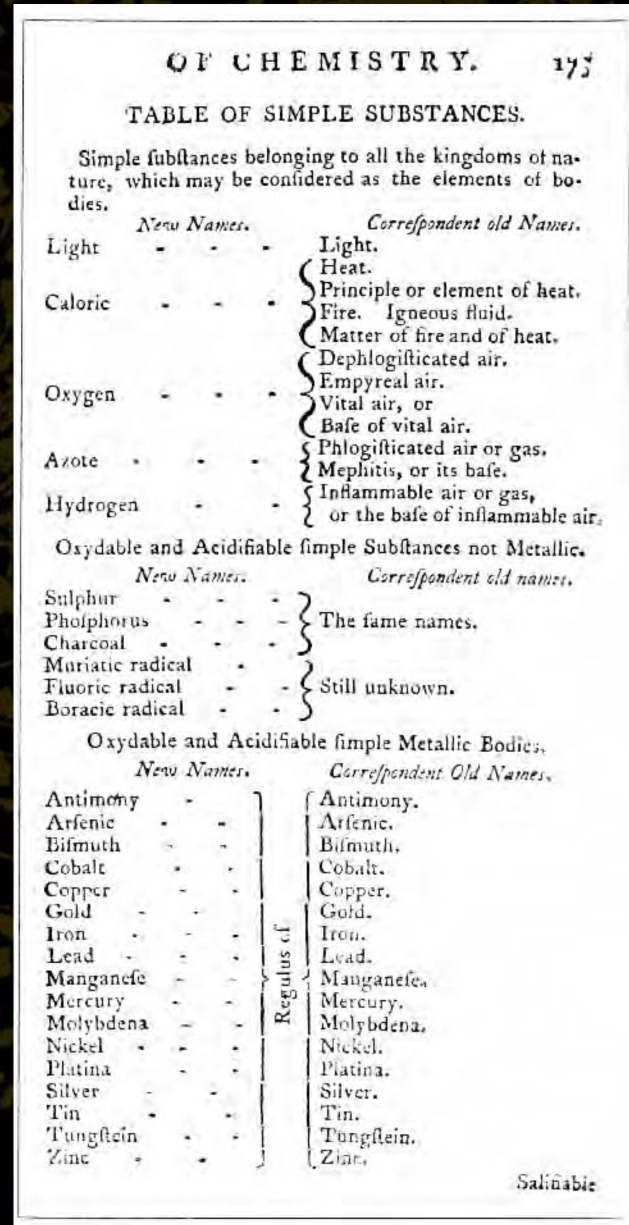

OF CHEMISTRY. 175

TABLE OF SIMPLE SUBSTANCES.

Simple fubftances belonging to all the kingdoms of nature, which may be confidered as the elements of bodies.

New Names.	*Correfpondent old Names.*
Light	Light.
Caloric	Heat. Principle or element of heat. Fire. Igneous fluid. Matter of fire and of heat.
Oxygen	Dephlogifticated air. Empyreal air. Vital air, or Bafe of vital air.
Azote	Phlogifticated air or gas. Mephitis, or its bafe.
Hydrogen	Inflammable air or gas, or the bafe of inflammable air.

Oxydable and Acidifiable fimple Subftances not Metallic.

New Names.	*Correfpondent old names.*
Sulphur	The fame names.
Phofphorus	The fame names.
Charcoal	The fame names.
Muriatic radical	Still unknown.
Fluoric radical	Still unknown.
Boracic radical	Still unknown.

Oxydable and Acidifiable fimple Metallic Bodies.

New Names.	*Correfpondent Old Names.*
Antimony	Regulus of Antimony.
Arfenic	Regulus of Arfenic.
Bifmuth	Regulus of Bifmuth.
Cobalt	Regulus of Cobalt.
Copper	Regulus of Copper.
Gold	Regulus of Gold.
Iron	Regulus of Iron.
Lead	Regulus of Lead.
Manganefe	Regulus of Manganefe.
Mercury	Regulus of Mercury.
Molybdena	Regulus of Molybdena.
Nickel	Regulus of Nickel.
Platina	Regulus of Platina.
Silver	Regulus of Silver.
Tin	Regulus of Tin.
Tungftein	Regulus of Tungftein.
Zinc	Regulus of Zinc.

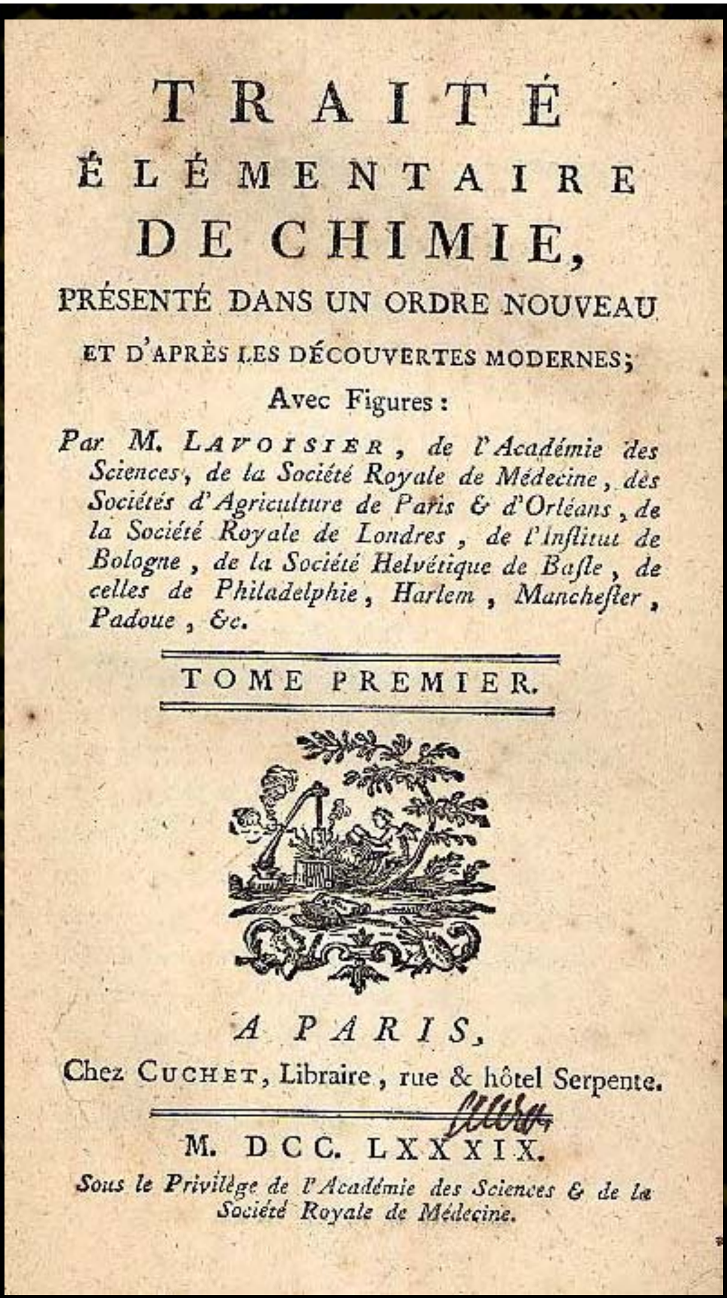
Salifiable

Lavoisier, *Elements of Chemistry*, 1790

Reform Teaching

Lavoisier aimed to reform chemical training in the same way: students should begin with the simplest substances and proceed to complex ones. The new names meant that students no longer needed to re-do every experiment along the way.

The goal was to make it possible to train chemists in a year or two rather than via lifetime apprenticeships.



TRAITÉ
ÉLÉMENTAIRE
DE CHIMIE,
PRÉSENTÉ DANS UN ORDRE NOUVEAU
ET D'APRÈS LES DÉCOUVERTES MODERNES;
Avec Figures :
Par M. LAVOISIER, de l'Académie des Sciences, de la Société Royale de Médecine, des Sociétés d'Agriculture de Paris & d'Orléans, de la Société Royale de Londres, de l'Inſtitut de Bologne, de la Société Helvétique de Baſle, de celles de Philadelphie, Harlem, Mancheſter, Padoue, &c.

TOME PREMIER.

A PARIS,
Chez CUCHET, Libraire, rue & hôtel Serpente.

M. DCC. LXXXIX.

Sous le Privilège de l'Académie des Sciences & de la Société Royale de Médecine.

Ignoble Ends

Priestley's home laboratory was attacked by an angry mob in 1791 because of his outspoken support of the French Revolution. He fled to the US in 1794.

C. J. Hullmandel, *Destruction of Joseph Priestley's Home and Laboratory*, 1791

Lavoisier arrested in his laboratory, 1793

Lavoisier was arrested because of his work as a royal tax collector. He was tried, convicted, and executed by guillotine on the same day: 8 May 1794.

Dalton and Vapors

John Dalton (1766 – 1844) was a Quaker. Like Priestley, he was educated in Dissenting Academies; he was largely self-taught in natural philosophy.

Dalton was fascinated by the soggy climate of England's Lake District. He studied vapor pressure.

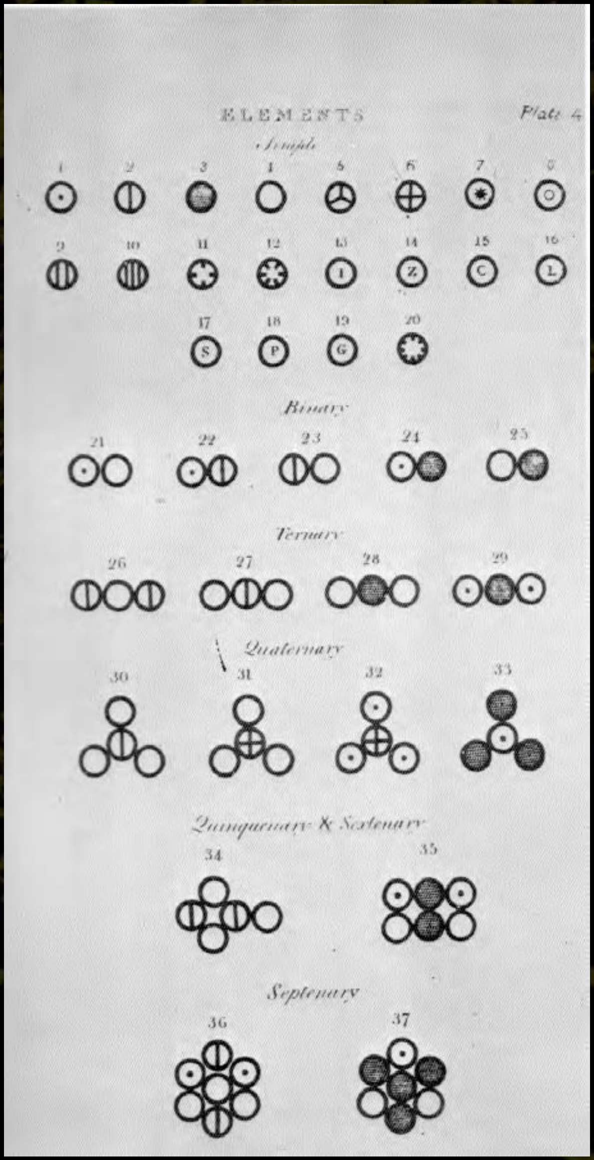
W. H. Worthington, *John Dalton*, 1895

Law of Partial Pressures, 1801: in a mixture of gases, each gas contributes pressure as if it were alone. The total vapor pressure is the sum of each partial pressure.

Chemical and Physical Atoms

Dalton explained his result by assuming that every substance consists of *atoms*. The atoms of a given substance are identical to each other, but different from those of other substances.

Dalton believed that atoms of different elements had different *weights*. The ratios by weight of constituents in chemical compounds arose from the different relative weights of the underlying atoms.

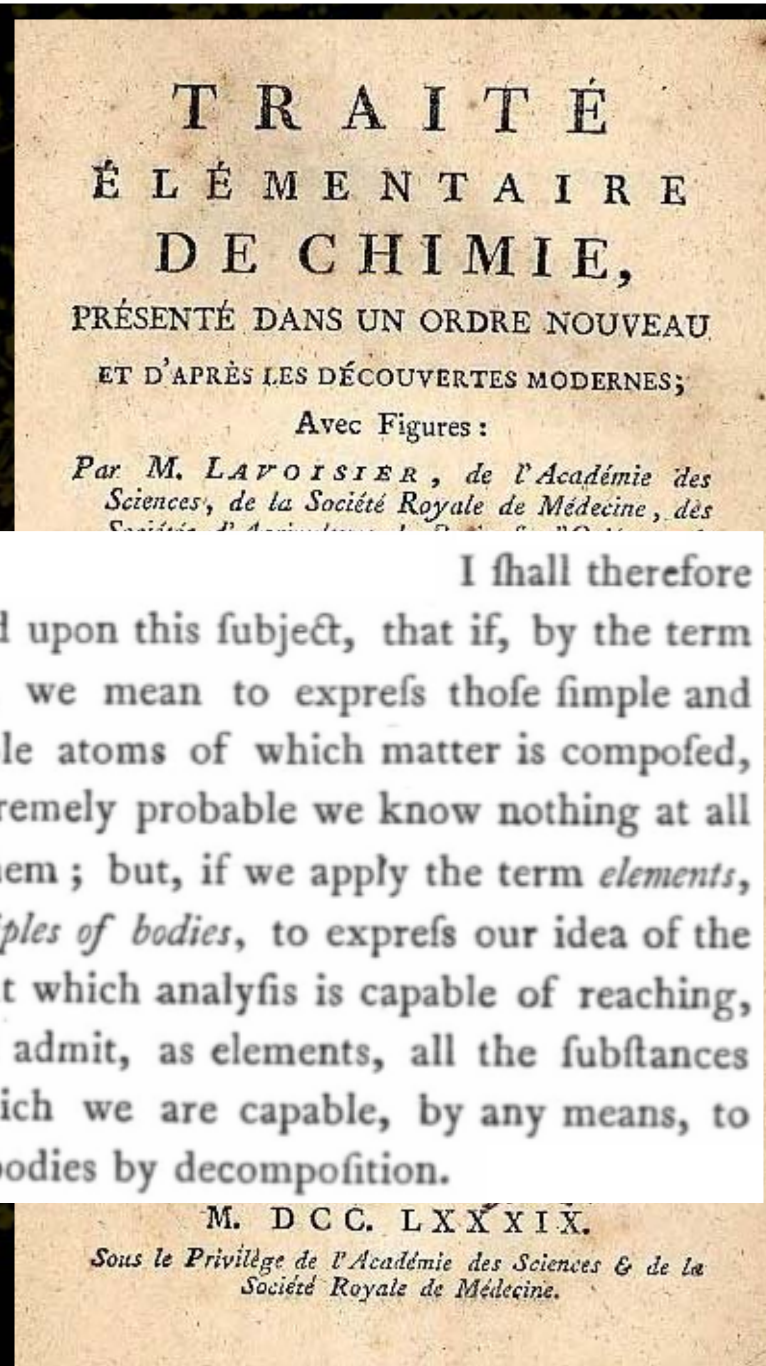


Dalton, *A New System of Chemical Philosophy*, 1808

Atoms or Elements?

Lavoisier had assumed that any list of elements was *temporary*. An "element," to him, meant a substance that chemists had *not yet* further reduced to simpler substances.

Dalton thought otherwise: the world is made of "solid, massy, hard, impenetrable, moveable Particles" or atoms. They were eternal and unchanging, and they corresponded uniquely to chemical elements.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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 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.

Serfs and Substances

In 1861, the Russian Tsar emancipated the serfs throughout the Russian empire. The universities were flooded with new students. Dmitri Mendeleev (1834 – 1907), a young chemistry professor in St. Petersburg, began writing a new textbook.

S. Ivanov, *A Peasant Leaving his Landlord on Yuriev Day*, ca. 1890

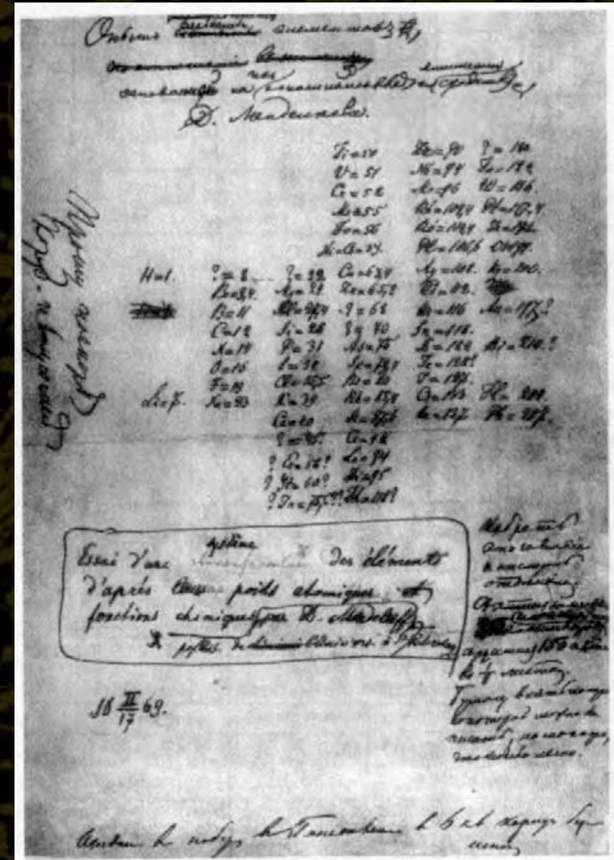
Lavoisier had identified 33 elements. By Mendeleev's day, 63 were known. He eschewed chemical theory and focused on laboratory techniques: how do chemists learn about simple substances?

Classify!

By late January 1869, Mendeleev had finished volume 1 of his textbook, having only treated 8 elements – that left 55 to go!

			Ti = 50	Zr = 90	? = 180.
			V = 51	Nb = 94	Ta = 182.
			Cr = 52	Mo = 96	W = 186.
			Mn = 55	Rh = 104,4	Pt = 197,4
			Fe = 56	Ru = 104,4	Ir = 198.
			Ni = Co = 59	Pl = 106,6	Os = 199.
H = 1			Cu = 63,4	Ag = 108	Hg = 200.
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,5	Br = 80	J = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204.
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207.
		? = 45	Ce = 92		
		? Er = 56	La = 94		
		? Yt = 60	Di = 95		
		? In = 75,6	Th = 118?		

Mendeleev's first published periodic table, 1869



Mendeleev's first draft of the table, Feb. 1869

He latched on to *atomic weight*: it was numerical, not random, and it offered some *system* for plowing through the rest of the material.

From Classroom to Nature

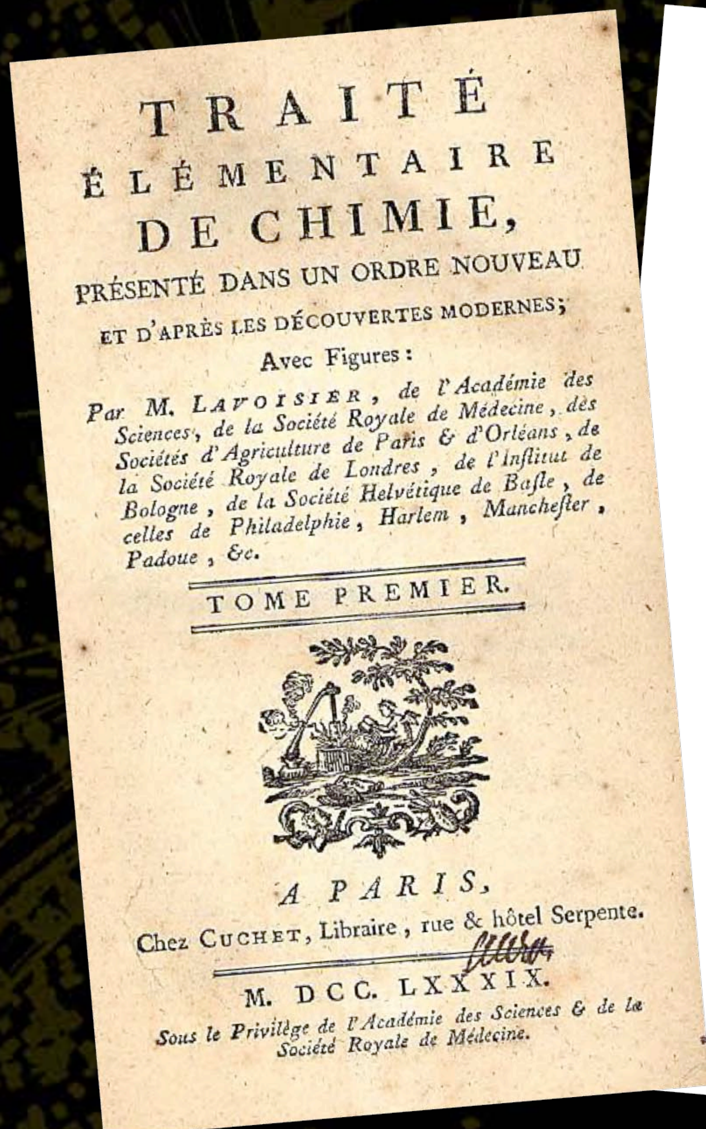
Mendeleev left gaps in his table to be filled in: he *predicted* the weights and chemical properties of three new elements.

Image of "A Well Ordered Thing: Dimitrii Mendeleev and the Shadow of the Periodic Table," Michael D. Gordin, removed due to copyright restrictions.

The discovery of those "missing" elements in the 1870s helped to establish Mendeleev's reputation and that of his periodic table.

The discoveries also helped to solidify the association between *chemical elements* and *physical atoms*.

Politics, Pedagogy, and the Stuff of Matter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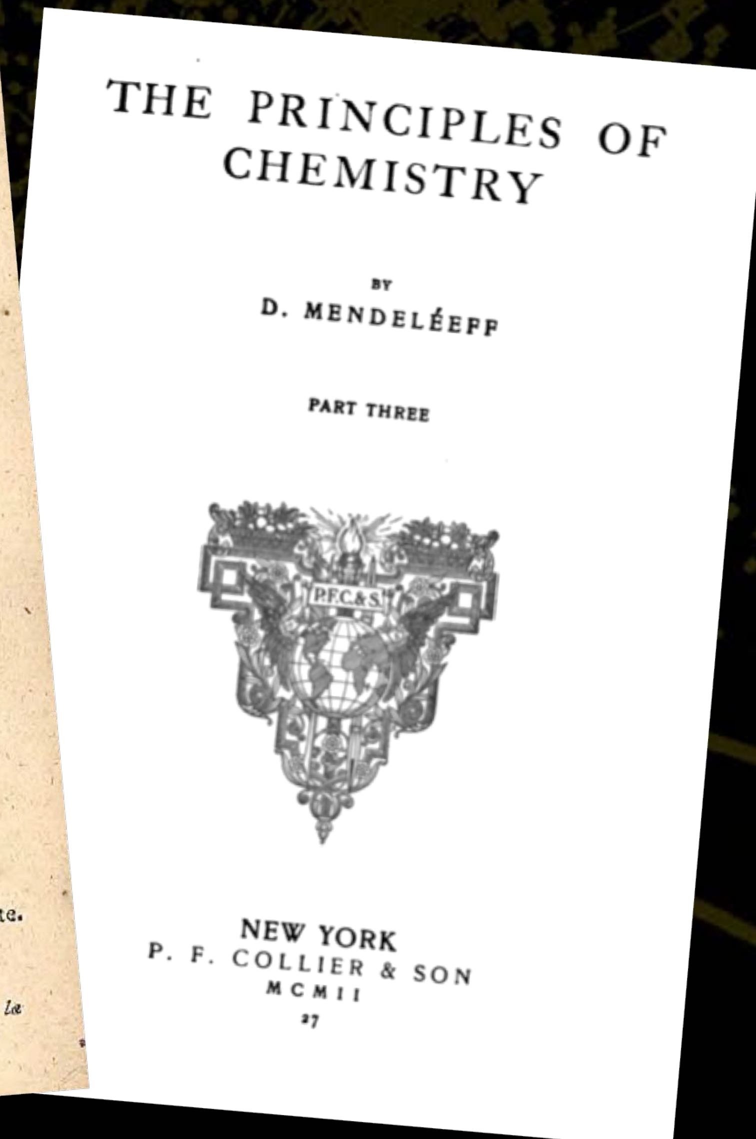
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D. MENDELÉEFF

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