The New Chemistry: Crash Course History of Science #18

Crash Course: History of Science
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One of the problems with the whole idea of a single Scientific Revolution is that some disciplines decided not to join any revolution.

And others just took a long time to get there. In the case of chemistry—the study of what stuff is—a real scientific revolution, like in the Thomas Kuhn sense, didn't really get going until the 1770s.

Until then, mainstream chemistry in Europe was based on phlogiston theory, which may be difficult to wrap your head around because it is the opposite of how we understand chemical reactions today. To shake loose that particular scientific status quo, it took the power of the Enlightenment, and one of its most emblematic natural philosophers, Lavoisier. [Intro Music Plays] If the 1600s was the century of science in Europe, centered on London, then the 1700s was the century of philosophy, centered on Paris. This new philosophy largely consisted of a movement called the Enlightenment—dated by some from 1715, when France's powerful "Sun King," Louis the Fourteenth, died, to 1789, when the French Revolution started.

The Enlightenment was a shift in ideas about knowledge, away from traditional sources of authority, like the Church, and toward the kind of scientific rationality described by Bacon. This aspect of the Enlightenment is summed up by the catchphrase sapere aude, or "dare to know." This suggested that knowing is something you should do—a moral good. This was an "Age of Reason." The Enlightenment was also about social values, such as individual liberty, the progress of civilization, and religious tolerance, including the separation of church and state.

The Enlightenment at times even fed into anti-religious, specifically anti-Catholic, feelings, setting the stage for a later perceived break between science and religion. The term "Enlightenment" was coined by German writer Johann Wolfgang von Goethe, and it was used by Voltaire, and later by Kant. Thinkers like them—called les philosophes, or "the philosophers"—met in scientific societies, literary salons, and coffeehouses.

The philosophes saw it as their job to discover the laws of nature—the natural law that helped guide human behavior. They dreamed of a "republic of letters," a world ruled by rational thought and guided by reasoned debate. So, yes, if you remember episode two: the philosophes were kinda like the Presocratics.

The ideas of the Enlightenment undermined the authority of kings and churches and helped set the intellectual stage for the soon-to-come revolutions in the United States, France, and Haiti. But the Enlightenment was also about increasingly centralized state power and colonization of non-Europeans, which we talked about two episodes ago. Statistics, for example, was developed at this time to serve the interests of nation-states and early corporations.

So we can also call this the Age of Empire… Perhaps no object better represents the Enlightenment than the ambitious book named the Encyclopédie. Edited by Jean d'Alembert and Denis Diderot from 1751 to 1777, the twenty-two volume Encyclopédie attempted to organize literally all of the knowledge available to humanity. Basically...

Wikipedia! The Encyclopédie physically demonstrated three big ideas: First, knowledge is cumulative. Humans add new knowledge to our collective pool all the time.

Second, knowledge is record-able. We can transmit knowledge through things like books. And third, knowledge is political.

Diderot, like Bacon, believed that knowledge should be used to alleviate human misery. Diderot hoped to "change the general way of thinking" by popularizing recent achievements in science and technology and combating superstition. He wanted to use knowledge to help people out.

He also thought that all traditional beliefs should be reexamined "without sparing anyone's sensibilities." But strict censorship by the state made any explicitly anti-religious articles impossible, so Diderot had to cleverly slip in critiques of the church. For example, in the cross-reference for the entry on the Eucharist: "see cannibalism." Now, the Encyclopédie systemized knowledge in a neat way, but it was largely qualitative, describing things according to values—for example, what a good ship looks like. But Enlightenment thinkers increasingly dreamed of quantification, or describing things in numbers—like units of length, mass, heat, and so on.

But for quantification to work, you have to have an agreement about how to measure things. In other words, you have to have standards. The meter, for example, was defined by a commission of scientists in France in the 1790s as one ten-millionth of the earth's meridian through Paris.

The commission included Pierre-Simon Laplace, who wrote the five-volume Celestial Mechanics, starting in 1799. This greatly expanded Newton's work on classical mechanics, opening up a range of topics to the problem-solving power of calculus. Celestial Mechanics became a sort of Principia - volume two.

And in order to actually measure the meter, the commission sent out two guys, Pierre Méchain and Jean-Baptiste Delambre, to make measurements. ... I'm not good at French. This was a time of widespread war in Europe.

Méchain and Delambre struggled against skirmishes, yellow fever, and imprisonment—but they got the job done. And along with standards, measurement required new instruments, like the barometer and electrometer, as well as new ways of interpreting data, AKA statistics, which were also pioneered by Laplace. By the end of the eighteenth century, physics was already well on its way to rationalization, quantification, and even standard measurement.

But what about chemistry? In the late 1700s, natural philosophers believed that chemical reactions occurred thanks to an ether—a colorless, odorless, "self-repulsive," extremely fine, and therefore hard-to-measure fluid—called phlogiston. According to phlogiston theory, this ether was released during combustion.

For example, a burning candle was thought to release phlogiston. If you covered that candle with a jar, the flame would go out, because the air would become saturated with phlogiston and couldn't absorb any more. This is exactly the opposite of how we now understand it: that the flame goes out because it's used up all of the oxygen, which is necessary for a chemical reaction.

Likewise, it was thought at the time that, when plants grew, they absorbed phlogiston from the air. When their wood was burned, it released phlogiston back into the air. Or when we ate them, our bodies released phlogiston through respiration and body heat.

In this system, "phlogisticated air" or "fixed air" was what we would now call carbon dioxide. Joseph Black isolated fixed air in 1756. "Dephlogisticated air," on the other hand, was oxygen. This system worked pretty well to explain chemical reactions qualitatively—why they seemed to appear a certain way—but no one could quantify phlogiston.

And minor anomalies in phlogiston theory kept adding up. For example, mercury gained weight during combustion, even though, by releasing phlogiston, it should have lost weight. The person who

changed chemistry from a qualitative discipline to a quantitative one was Antoine-Laurent de Lavoisier.

A good example of an Enlightenment natural philosopher, Lavoisier was born to a noble family in Paris in 1743. He studied law but was obsessed with geology and chemistry. Lavoisier also worked on the metric system.

Lavoisier first presented research on chemistry, in a paper about gypsum, to the French Academy of Sciences in 1764. In 1768, the Academy made Lavoisier a provisional member. Two decades later, he would become the founder of the “new chemistry,” revolutionizing the entire discipline.

Thought Bubble, show us what this means: Lavoisier knew phlogiston theory well. But he began his chemical research with the hypothesis that, during combustion, something is taken out of air rather than put into it. That hypothesis turned out to be correct, and that something turned out to be oxygen.

Lavoisier’s tested his hypothesis by accounting for inputs and outputs in chemical reactions—a perfect example of the eighteenth-century quantification of science. And Lavoisier also discovered that the mass of matter remains the same even when it changes form or shape. Which is very important!

Working carefully over years, he generated the first modern list of elements. He named oxygen in 1778, hydrogen in 1783, and silicon—merely a prediction at that point—in 1787. In fact, Lavoisier and his allies developed a whole new nomenclature for chemistry, in 1787. “Inflammable air” became hydrogen. “Sugar of Saturn” became lead acetate. “Vitriol of Venus”—which had also been called blue vitriol, bluestone, and Roman vitriol—became copper sulfate.

Yeah, the new naming system was less fun than the old one. But it was more rational: the terms better described the underlying stuff they pointed to. “Copper sulfate” meant a compound of sulfur and copper. Lavoisier published the textbook Elementary Treatise of Chemistry in 1789, which taught only the new chemistry.

In the introduction to his book, Lavoisier also separated heat and chemical composition. So water is water whether it’s heated up to steam or cooled down to ice. He understood that heating something up doesn’t always change what it is, fundamentally.

To explain these state changes, Lavoisier made up a new ether, which he called the caloric. Caloric could penetrate a block of ice, melting it into water by pushing the ice particles apart. Thanks Thought Bubble.

Spoiler: caloric is not thought to be a real thing today. (Many people wish calories weren’t real, but, here we are.) Led by the prominent English chemist Joseph Priestley, these old-timers kept modifying phlogiston theory so that it could rationally account for chemical reactions without falling apart, due to the whole phlogiston-in versus oxygen-out thing. Well into the 1780s, many chemists still believed in phlogiston—which no one had actually seen or measured—simply because it was familiar. What changed their minds?

Well, Lavoisier and his allies published results that favored their system. But more importantly, the students who learned from them could only speak the language of the new chemistry. The phlogiston believers were increasingly isolated.

Thus in a couple of decades, phlogiston moved from the center of chemistry into exile. With the new chemistry, Lavoisier brought the discipline into the system of rational, experimental science dreamed up by methodologists such as Bacon and fleshed out by Newton. Outside of chemistry, Lavoisier was a noble with a powerful state job: he worked at the hated tax collection agency of the French kingdom, known for being both secretive and violent.

He profited from his job there, helping fund his chemical research. But the French Revolution broke out in 1789, and being an aristocratic tax collector was not a good look. Lavoisier was tried for defrauding the people of France.

And the judge denied the appeal to save his life, despite his immense contributions to knowledge, declaring that: “The Republic needs neither scientists nor chemists; the course of justice can not be delayed.” Lavoisier died by guillotine in 1794. His friend, mathematician Joseph-Louis Lagrange, said of Lavoisier’s death: “It took them only an instant to cut off his head, but France may not produce another such head in a century.” Now, how was Lavoisier so successful at setting up the new chemistry as a paradigm? Well, he had a lot of support!

Marie-Anne Pierrette Paulze, AKA “Madame Lavoisier,” was born into a noble family in south-central France in 1858. And she contributed significantly to Antoine’s work. She translated his texts into English, and after Antoine’s death, she published his complete papers, securing his legacy in the field.

Madame Lavoisier eventually remarried another scientist, Count Rumford, a physicist who had a role in shaping thermodynamics. But she insisted on keeping Lavoisier’s name to show her allegiance to the man she loved. Also, Madame Rumford is way less cool.

After the Lavoisiers, a new generation of thinkers continued to develop their ideas, in France and beyond. Notably, John Dalton observed that the ratio of elements in reactions were often made up of small numbers, meaning that chemical elements are in fact discrete particles, not fluids. He called these particles chemical atoms—true indivisible units.

And Joseph Fourier published the Analytical Theory of Heat in 1822, using calculus to describe how heat flows. Fourier also discovered the greenhouse effect, or the capture of the sun’s radiation in the earth’s atmosphere. Next time—we’ll classify plants’ sexy parts, disintegrate a willow tree, and debate whether whole species can … go extinct.

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