The Creation of Chemistry - The Fundamental Laws: Crash Course Chemistry #3

Crash Course: Chemistry
https://youtube.com/watch?v=QiiyvzZBKT8
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You got a pretty good idea of what chemistry is, right? It's atoms and molecules doing stuff and making cars and food and life and everything. And of course it's the study of those things. But like how did we get here?

There's certainly no everyday evidence for much of what we have discovered through the science of chemistry. Discoveries that were not derived or made up, but just laws of the Universe that exist simply because the Universe is the way the Universe is.

So in today's episode of Crash Course Chemistry we're going to taking a bit of a historical perspective on the creation of the science of chemistry. A science that didn't really even exist until a super-smart, super-wealthy French guy put the puzzle pieces together into a coherent theory for, quite literally, how everything works.

And if you've ever found yourself sitting at your desk reading the same line in your chemistry book for the 22nd time, and you think to yourself "Gah, the guy who invented chemistry should be put to death!" Well you should feel bad, because he was.

[intro music]

=====Alchemists to Chemists (1:07)=====

Antoine Lavoisier, was pretty fantastic. He was a geologist, a botanist, a biologist, and a physicist. He helped define the metric system, creating an international language of chemistry, named hydrogen and oxygen, predicted the existence of silicon, outlined what elements were, figured out how animals extracted energy from food, determined that an element can take different forms on discovering that both ash and diamond contained pure carbon, published the very first chemistry textbook ever, and there's a reason why the Law of Conservation of Mass used to be called Lavoisier's Law.

Born into a wealthy family, Lavoisier inherited a massive amount of money when his mom died when he was five years old. And though he did get licensed to practice law as his father expected him to follow in his lawyer-ly footsteps, young Antoine chose science instead.

When the opportunity arose to marry a wealthy girl whose father's massive income came from collecting taxes for the French government, he did it, even though she 13. A questionable decision, though not uncommon at the time, it turned out that the family connections would be his undoing, though, not the age of the bride at her marriage.

Marie-Anne, as she grew older, would become a colleague as well as a wife, assisting Antoine in his experiments and his analysis of the work of others. Indeed it was Marie-Anne who translated *Essay on Phlogiston* for Antoine, which he ripped to pieces, changing everything forever.

Until Antoine Lavoisier started inspecting everybody's work, the prevailing theory of chemical change was that some substances contained an elusive element called "phlogiston." By burning these phlogiston-containing elements, they would lose their phlogiston, and become new things.

Lavoisier took those theories and their research, combined it with research being done elsewhere, and added in his own genius experiments and then tore the chemical world to pieces, with a little thing called "combustion." He determined that hydrogen wasn't "inflammable air," it was an element. Indeed he named it hydrogen because it was generated from water, or hydro-generated.

And he determined that oxygen was a vital ingredient for combustion and also what would later be known as oxidation, something that we'll discuss quite a lot in this course.

By hooking people up to his bizarre contraptions, he determined that burning wood consumed the same amount of oxygen, and produced the same amount of carbon dioxide, as people consuming food and breathing. Thus determining that people, and all animals, are powered by some form of internal combustion.

=====Law of Conservation of Mass (3:25)=====

Now experimenters of the day (I hesitate to call them chemists), noticed that when you burned something, its massed decreased. Like here's a fuse, and I put it on a scale and I burn it, and its mass decreases.

But Lavoisier determined that if all the particles in gas are collected, like if I burn the fuse inside a closed bottle, the mass stays the same.

Stuff remained stuff. You can't lose any, you couldn't make more. This realization, though it seems obvious to us now and its acceptance by the general scientific community, as far as I'm concerned, was the precise moment at which alchemy ended and chemistry began.

Lavoisier's chief contributions and ultimately his discovery of the Law of Conservation of Mass relied on careful measurement and careful thinking. And as you'll see, both of those things are key to success in chemistry to this day.

=====Decapitated Aristocrat (4:11)=====

Lavoisier the man was a bit of a dichotomy, having worked as a tax collector and helping to create a literal wall around Paris to assist in the collection of taxes, but also a supporter of the French Revolution as it began. But the enemies he had made with his wall, and by denying certain powerful politicians entry into the French Academy of Sciences, eventually caught up with him as the revolution's lunacy increased, he was beheaded on May 8th, 1794.

Lavoisier was pardoned a year and a half after his execution. That's good. Marie-Anne was delivered all of his confiscated belongings, and a note of apology, like "Sorry we killed your husband, here's all his stuff back."

The mathematician Joseph Lagrange said of the event: "It took them only an instant to cut off that head, but France may not produce another like it in a century."

It's worth noting, though this isn't really science talk, that Lavoisier couldn't have done any of his magnificently careful measurements had it not been for his enormous wealth. He commissioned the creation of hundreds of pieces of equipment, large and small. Only the system of economic inequality that the French were revolting against made it possible for Lavoisier to do his work. I'll leave you to think on the implications of that, on your own.

Lavoisier's work was, for a full century, the basis of all chemistry. Proving that you don't have to be rich to get a law (at least temporarilly) named after you, French pharmacist Joseph Proust built on Lavoisier's ideas of extremely careful measurement showing that a chemical compound always contains the same proportions of elements. For a while we called this Proust's Law, but to make it easier to remember for the world we just call it the Law of Definite Proportions now.

=====Chemical Compounds (5:44)=====

And then an English schoolteacher, John Dalton, followed Proust by examining what at first appeared to be a problem with Proust's work. Carbon and oxygen, when reacted together, would form two different proportions, not just one.

Of course what was happening is obvious to us, carbon and oxygen were reacting to form two different compounds: carbon dioxide and carbon monoxide. As Dalton's work continued, he found something truly mind-bendingly fascinating.
=====Atoms and Molecules (6:07)=====

If you limited the amount of carbon reacting to exactly 1 g, the mass of oxygen consumed to produce one compound was 1.33 g, while the mass consumed to produce the other compound was 2.66 g, exactly double what was required for the other compound.

This shook out for other reactions, too. When reacting nitrogen and oxygen, and limiting to exactly one gram of nitrogen, three compounds formed. One compound consumed 1.750 g of oxygen, another consumed 0.8750 g of oxygen, and another consumed 0.4374 g. All of those numbers are relatable by small whole number ratios.

Oxygen wasn't reacting with some ephemeral cloud of the idea of nitrogen, it was reacting with individual, discrete bits of nitrogen, that couldn't be divided. It could react in a number of ways, but it was always the same oxygen and the same nitrogen with the same properties.

And so while in our first episode we showed you how Einstein actually proved that atoms exist with super fancy math, Dalton had used multiplication to become the first person to actually have real data supporting the idea of atoms.

Dalton still, though, had it kind of wrong. He thought that the products of his reactions were elements as well. Basically, he believed that atoms and molecules were the same thing. We often simplify this and don't note Dalton's confusion on this particular point, but that leaves a couple of other fantastic chemists out of the story.

For example, Joseph-Louis Gay-Lussac, who in 1804 became the highest scientist ever in history, by taking a hot-air balloon to the dangerous height of 7,000 m to take air samples. But in addition to maybe being a little bit crazy, Gay-Lussac published a paper showing that a volume of oxygen gas is two times smaller than the volume of water vapor it creates, indicating that somehow, oxygen was splitting into two pieces.

Dalton, would not accept this, because it meant that oxygen was not one, but two atoms, and apparently that just messed with his whole conception of the Universe, and he never did accept it, even unto his death.
=====Avogadro and his Number (8:05)=====

It took an Italian house-elf--I mean genius, Lorenzo Romano Amadeo Carlo Avogadro di Quaregna e di Cerreto. (I did it the first time.) We'll just call him Amadeo Avogadro, but he was a count, so he had to have a super-fancy name, and I'm mean, so I had to try and say it.

Much like Lavoisier, Avogadro's political alliances would get him into trouble. After Napoleon's downfall in 1815, Avogadro was active in the Italian Anti-Monarchy Revolution, possibly even sponsoring some revolutionaries with his personal fortune. For this he lost his chair at the University of Turin, but thankfully he did not lose his head.

Avogadro proposed, correctly, that any gas in a container of the same size, with the same temperature and pressure, would have roughly the same number of molecules in it, no matter what the gas was. So any difference in mass between two flasks of the same size full of two different gases would be because of a difference in the actual physical mass of the molecules. And thus, Avogadro basically figured out how to weigh atoms and molecules, as long as they were gaseous.

To support his hypothesis, which was certainly good enough to support, he suggested that, in forming water, oxygen gas would actually split into two oxygen atoms, what he called "elementary molecules" that could not be broken down any further. For some fifty years, Avogadro's idea of fundamental molecules were ignored.

Maybe because of incorrect ideas of how atoms stuck together, maybe because Italy was a bit of a backwater of science and Avogadro wasn't considered an important thinker at the time. But the scientific community, as it usually does, came back around to Avogadro's ideas eventually. Not only naming his proposal that equal volumes at the same temperature and pressure contained the same number of molecules Avogadro's Law, but also giving him his own number, maybe the most important number in chemistry, certainly one of my very favorite numbers, but we'll get to that later.
=====Credits (9:57)=====

Thank you for watching this episode of Crash Course Chemistry. If you were paying attention you now know the story of how we went from alchemists, who thought that the element of fire hid inside of substances just clamoring to get out, to chemists, who understood the Law of Conservation of Mass, as proposed by a decapitated aristocrat. Greater understanding of how chemical compounds work, thanks to a pharmacist and a schoolteacher. And eventually a complete understanding of what atoms and molecules are, thanks to a neglected Italian house-elf--nobleman.

This episode of Crash Course Chemistry, it was written by myself, filmed and directed by Michael Aranda, and edited by Nick Jenkins. The script was edited by Blake de Pastino and Dr. Heiko Langner. Michael Aranda is also our sound designer. Caitlin Hofmeister is our script supervisor and our graphics team is Though Café.

If you have any questions, please ask them in the comments below. Thank you for learning with here at Crash Course Chemistry.