The Nucleus: Crash Course Chemistry #1

Crash Course: Chemistry
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Hello, I'm Hank Green and I want to teach you chemistry. But please, do not run away screaming. If you give me five minutes to try to convince you that chemistry is not torture, but instead the amazing and beautiful science of stuff. And if you give it a chance it will not only blow your mind but also give you a deeper understanding of your world.

This is just my opinion here, but I think that understanding the world leads to greater ability to enjoy the world and there's nothing that helps you understand the world better than chemistry. Chemistry holds the secrets to how life first formed, how cancers are cured, how iPhones have bigger hard drives than 5 year old laptops and how life on this planet might just be able to continue thriving, even ours, if we play our cards right.

Chemistry is the science of how three tiny particles, the proton, the neutron and the electron came together in trillions of combinations to form, get this, everything.

Now chemistry is a peculiar science, sometimes talked about as a bridge between the ultra abstract world of particle physics and the more visible sciences like biology. But calling chemistry a bridge is like calling Eurasia an island. Chemistry has it all, mad scientists, world changing revelations, the practical, the impractical, medicine, bombs, food, beauty, destruction, life and death, answers to questions you never knew you had. I love chemistry, and I hope I can give you a glimpse into why. So today, let's start out with maybe the biggest idea of all time, and move on from there, stuff is made from atoms.

(Intro)

=====Atomic Theory and Einstein (1:44)=====

I know, you aren't shocked, you aren't awed, you might not even be paying attention any more, but when atomic theory was first proposed, it sounded pretty crazy. And yes, we call it 'Atomic Theory', using the scientific definition of theory, which is "a well-tested set of ideas that explains many disparate observations", not the colloquial definition of theory, which is "a guess." But luckily there's no-one running around any more saying "atoms are just a theory."

But it wasn't that long ago that people were running around saying that. You wanna know who settled it for good? Einstein! Atoms had been postulated for a long time by the 20th century, but it wasn't until Einstein mathematically proved the existence of atoms and molecules in 1905 that the matter was truly settled. And you thought Einstein was all about relativity and $E=mc^2$, he also proved atoms exist!

Here's how it happened. In 1827, a botanist named Robert Brown was looking at pollen grains in water through a microscope and he noticed that they jiggled randomly even when there was no movement to cause the jiggling. It was a mystery for a long time, until 1905 when Einstein theorized that this phenomenon was caused by as-yet-unproven atomic particles actually smacking into the grains of pollen.

He wrote up some fancy math, showing that his theory predicted this motion almost perfectly, and everyone had to concede that yes, tiny discrete bits of matter were indeed smacking into the pollen, and thus molecules, and by extension atoms, must exist. Today, we remember this botanist and his discovery by calling the motion he observed Brownian motion.

=====Composition of Atoms (3:18)=====

It's kinda crazy that every physical thing you've ever interacted with is made up of little ball thingies. It started with people wondering what would happen if you just kept slicing something in half forever. Eventually, and of course it turns out that there's no knife sharp enough to do this, you end up with one, pure, unbreakable bit of that substance. The word "atom", indeed, is from the Greek for "indivisible", though, of course, as we learned in World War II, atoms can be broken as well.

So all the stuff that we think of as stuff is made of atoms, tiny discrete particles that have specific properties depending on the arrangement of three simple subatomic particles. There's the proton, heavy and positively charged, the neutron, about the same size as the proton but neutral, and the electron, which has the same amount of charge as the proton, just opposite, and very nearly has no mass at all, about 1800 times less massive than the proton or neutron.

Protons and neutrons hang out in the nucleus, and thus are the nuclear components or nucleons; electrons hang out around the nucleus and are the parts of the atom that do all the interesting chemical stuff. But before we get to the chemistry of the electrons, we first have got to understand the properties of the nucleus.

=====Protons and Atomic Number (4:27)=====

Okay, this is pretty important, so pay attention here. The number of protons in an atom determines what element it is. 79 protons: always gold. 59 protons: always praseodymium. The number of protons in an element is its atomic number, it sits right on top of the box in the periodic table because that is the element's defining trait. So an atom of silver with 47 protons in its nucleus is always an atom of silver.

Depending on what its electrons are doing and what it's bonded to it might be part of a chemical that's silver-colored or black or blue or shiny or poisonous or a cure for disease, but whatever it is, that atom is still silver and will remain an atom of silver probably forever, because that core number is very, very difficult to change.

Now you might have noticed something weird about silver here, it's chemical symbol, the one- or two-letter short code that tells you what it is, is Ag, not Si, which is silicon, or Sv which is perfectly available, but Ag. Why? To torture you? No.

Silver, of course, because we've known about it for a long time, was one of the first elements added to the periodic table, and back then it was called "argentum", Latin for "shiny gray stuff", also, the root of the word "Argentina", where Spanish explorers heard rumors of mountains made of silver, which of course did not exist. The name "Argentina", just like the chemical symbol "Ag", stuck, despite neither of them being particularly representative of reality. Now, back to science.

=====Neutrons (5:51)=====

Nuclei, which is the plural of nucleus, are boring. They're thousands of times smaller than the atom as a whole and they mostly just sit around being exactly the same as they were when they were first created billions of years ago, held together by the strongest of the four fundamental forces of physics, the strong nuclear force.

The fact that nuclei are so boring is the very reason they are the defining characteristic of elements. While electrons can jump from atom to atom whenever it's convenient, the number of protons is almost always extremely stable. So that core of the atom, the nucleus, always comes out of chemical reactions unscathed. It's the bit that we can bump around from reaction to reaction but always remains pure and behaves the same way as any other atom with that number of protons. The atomic number is the soul of the atom. It's what makes it it.

Neutrons are important too, of course, in their own way, but they don't change what element an atom is. One of the two keys to all things chemical is charge, we'll discuss that in another episode, and since neutrons don't have any charge, they mostly don't change the properties of an atom. But they are, nonetheless, vital.

We all know that like charges repel each other. Neutrons serve as a kind of buffer between the protons. You couldn't pack silver's 47 protons together in the nucleus by themselves. They couldn't handle it; they'd rip themselves apart. So nuclei only clump together permanently when the right number of protons and neutrons get together. Silver needs about 60 neutrons to space out the 47 protons correctly. But it doesn't have to be 60. In fact, silver nuclei are also very stable with 62 neutrons. 61 though, that doesn't work, and the reasons for that, I don't know, you would have to talk to a nuclear physicist.

=====Relative Atomic Mass (7:28)=====

The atomic number of silver doesn't change as the number of neutrons changes because the number of protons stays the same. But the relative atomic mass does change. Relative atomic mass, which used to be called atomic weight back when I was in school, is basically the number of protons plus the number of neutrons averaged across all the silver on Earth.

Because silver has two different stable isotopes, each with a different number of neutrons, its relative atomic mass ends up not being a whole number. About 52% of silver has 60 neutrons and about 48% has 62. The relative atomic mass, then, ends up being about halfway between 107 and 109, 107.8682.

=====Isotopes (8:04)=====

You'll note that I said these two different sorts of silver are called isotopes, they have different masses but the same chemical properties, and are the same element and so belong in the same place on the periodic table. In fact, the word "isotope" means "same place". And different isotopes have different mass numbers. The mass number is just the total number of nucleons in the nucleus, which is different from atomic mass, it's simple addition for a single atom, rather than an average of all the relative atomic masses of all the silver atoms on Earth.

So silver has two stable isotopes, one with a mass number of 107, which we'd call silver-107, and one with a mass number of 109, silver-109. There's an easy way to write all this out, of course, to keep your information straight. The chemical symbol, with the atomic number or number of protons here, the mass number, or number of protons and neutrons here, and the charge out here, which tells you by simple addition or subtraction how many electrons there are.

Finally, before we conclude this first episode of Crash Course Chemistry, and thus, our discussion of the atomic nucleus, a note on the pronunciation of "nucleus". You are welcome to say "nuculus", it is an accepted pronunciation of that word, but if you can find it in you, it's probably best to switch over to "nucleus", which is, after all, how it's spelled.

=====Credits (9:17)=====

And that is all for today's episode of Crash Course Chemistry, if you were paying attention, you now know:

More about atoms than anyone did in 1900, like that they were finally confirmed when Einstein mathematically defined Brownian motion;
That elements are chemically pure substances, and the type of element an atom is is defined by how many protons it has in its nucleus, or its atomic number;
That neutrons stabilize nuclei for their proton friends;
That different isotopes of the same element are the reason relative atomic masses are never whole numbers; and you know
That nuclei are the uninteresting, boring bits of the atom, and the electrons are where all the interesting chemical-ly stuff happens.

Crash Course Chemistry is filmed, edited, and directed by Nick Jenkins, Dr. Heiko Langner is our Chemistry consultant, sound design is done by Michael Aranda, and our graphics team is Thought Bubble. If you have any questions, comments, or ideas on any of this stuff we will endeavor to answer them in the comments below. Thank you for watching Crash Course Chemistry.