=====Intro/Ancient History===== (00:00)
How do you picture an atom in your mind- like this, or like this, or maybe one of these? If you understand enough about atoms to visualize any of those things, then you know more about atomic theory than scientists did just a hundred years ago, and, like, WAY more than they thought they knew twenty-five hundred years ago. That's when Greek philosopher Leucippus and his pupil Democritus first came up with the idea that matter is composed of tiny particles. No one knows how they developed this concept, but they didn't think the particles were particularly special- they just thought that if you cut something in half enough times, eventually you'll reach a particle that can't be cut anymore. They gave these particles the name "**atomos**," which means uncuttable or indivisible. So basically, they thought that iron was made up of iron particles and clay was made up of clay particles and cheese was made up of cheese particles. And they attributed properties of each substance to the forms of the atoms. So, they thought that iron atoms were hard and stuck together with hooks, clay atoms were softer and attached by ball and socket joints that made them flexible, and cheese atoms were squishy and delicious.

Now this makes a certain amount of sense if you don't happen to have access to electron microscopes or cathode-ray tubes or the work of generations of previous scientists, cause the fact is atomic theory as we know it today is the product of hundreds, if not thousands, of different insights. Some models, like that of Leucippus, were just blind guesses. As time went on, many more were the result of rigorous experimentation. But, as has been the case in all science, each scientist built on what had been learned before.

We've been talking a lot about the fine details of chemistry in recent weeks, and we're gonna keep doing that as we move on to nuclear chemistry and then to the basics of organic chemistry, but we do, I wanted to set aside some time to explain how we know what we know about the atom today, and how we know that we're not quite done figuring it out.

(Intro)

=====Enlightenment History=====

(01:51)
Now you might think that once Leucippus and Democritus came up with the general idea of atoms, it'd be pretty easy for someone else to take that little, indivisible ball and run with it. But you'd be wrong. The next major developments in atomic theory didn't come along for nearly twenty-three hundred YEARS. I've already told you, for instance, about the French chemist Antoine Lavoisier, who proposed the law of conservation of mass, which states that even if matter changes shape or form, its mass stays the same. And you should remember the English teacher James Dalton who determined that elements exist as discreet packets of matter.

=====Thompson's Discovery of the Electron===== (02:20)
Thanks to these, and other great minds, by the eighteen hundreds we had a better grip on the general behavior of atoms. The next logical question was "Why? Why do they behave the way they do?" This led to the investigation of atomic structure. In the 1870s, scientists began probing what stuff was made of using discharge tubes, basically gas-filled tubes with electrodes in each end, which emit light when an electrical current passes through them- basically, what a neon light is. Because this light was originally produced by a negative electrode, or cathode, it was called a cathode ray, and it had a negative charge.

But in 1886, German physicist Eugen Goldstein found that the tubes also emitted light from the positive electrode- basically, a ray headed in the opposite direction, which meant that there must also be a positive charge in matter. Goldstein didn't fully understand what he'd discovered here- I mean, scientists still hadn't figured out what was responsible for the negative charge in the rays either.

Then, English physicist J.J. Thompson took the discharge tube research further: by measuring how much heat the cathode rays generated and how much they could be bent by magnets and other things, he was able to estimate the mass of the rays. And the mass was about a thousand times lighter than a hydrogen, which was the smallest bit of matter known at the time. He concluded that the cathode "rays" weren't rays or waves at all, but were, in fact, very light, very small negatively-charged particles. He called them "corpuscles;" we call them "electrons."

So even though we didn't understand what shapes they took, we knew that there were both negative and positive components to matter. The next question was "How were they arranged in the atom?" Thompson knew that the atom overall had a neutral charge, so he imagined that the negatively charged electrons must be distributed randomly in a positively charged matrix. And the very English Thompson visualized this model as a familiar English dessert: plum pudding, the positive matrix being the cake, and the electrons the random, floating bits of fruit within it. Even today, Thompson's model of the atom continues to be called the "plum pudding model." And while a single electron's motion is random, the overall distribution of them is not.

=====Rutherford and the Nucleus=====

(04:22)
The next big step was taken by New Zealander Ernest Rutherford in 1909. He designed an experiment using an extremely thin sheet of gold foil and a screen coated with zinc sulfide. He bombarded the sheet with alpha particles, which he didn't really know what they were, just that they were produced by the decay of radium, they were positive charged, and they were really, really small. He expected them to just fly right through the foil, with no deflection, and many of them did just that. But as it turned out, some of the particles were deflected at large angles and sometimes almost straight backward.

The only explanation for this was that the entire positive charge of an atom, the charge that would repel an alpha particle, must be concentrated in a very small area, an area that he called "the nucleus." Because most of the alpha particles passed right through the atoms undeterred, Rutherford concluded that most of the atom is empty space, and he was correct. Rutherford would later discover that if he bombarded nitrogen with alpha particles, it created a bunch of hydrogen ions. Now he correctly surmised that these tiny positively charged ions were themselves fundamental particles: protons.

=====Bohr and the Planetary Model=====

(05:24)
Now we're getting close to reality. So these chemists had a fairly good idea of the structure of the atom, they just needed to figure out what exactly the electrons were doing. Enter Niels Bohr. In 1911, the same year the results of Rutherford's gold foil experiment were published, Bohr traveled to England to study with Rutherford. And as a physicist, he was also interested in the mathematical model set forth by German physicists Max Planck and Albert Einstein to explain the behavior of electromagnetic energy. Over time, Bohr

came to realize these mathematical principles could be applied to Rutherford's atomic model. His analysis of the gold foil experiment and calculations based on the proportion of the alpha particles that went straight through, those that were slightly deflected, and those that bounced almost completely backward allowed him to predict the most likely positions of electrons within the atom. Bohr's resulting model, sometimes called the planetary model, is still familiar to most people, probably including you. It represents the electrons in orbits around a small central nucleus. Each orbit can have a specific number of electrons, which correlates to the energy levels and orbitals in the modern model of an atom.

=====Uncertainty Arises for Heisenberg=====

(06:24)
And while it's definitely flawed, Bohr's model is very close to reality in some important ways. But like everyone I've mentioned in the past couple of minutes, Bohr was at once fantastically right and way off. The problem was those pesky electrons. It was the German theoretical physicist Werner Heisenberg who got everyone to understand just how huge and mind-blowing this electron problem was. But he was also the one who helped tie the whole mess up into a neat little bundle. Using his wicked math chops, Heisenberg discovered that it is impossible to know with certainty both the momentum of an electron or any subatomic particle and its exact position; and the more you know about one of those two variables, the harder it gets to measure the other one. So if you can't measure the position or momentum of an electron, you obviously can't say with certainty that the electron's in an atom are all neatly aligned in circular orbits, so he and a new wave of physicists and chemists proposed a new theory: a quantum theory, which proposes that electrons weren't particles or waves- instead, they had properties of both and neither.

By this thinking, the arrangement of electrons around a nucleus could only be described in terms of probability. In other words, there are certain regions where an electron is much more likely to be found. We call these regions "orbitals"- you know, the very same orbital that you and I have been talking about- the ones that go by the names "s and d and p and f" and that form sigma and pi bonds- those are the things that Heisenberg's theory predicts. And that's the modern understanding of atoms.
Because it's based on probability, quantum atoms are often drawn as clouds with the intensity of color representing not individual electrons but the probability of finding an electron in any particular position. For this reason, the quantum model is often called the [electron] cloud model of the atom. And now ya know!

=====Conclusion=====

(08:02)
All the people I've mentioned and many others put their heads together over time to build this current and- I might say- quite elegant understanding of atomic theory. Now, after twenty-five hundred years, even though we can't see them, we can know what they're like and how they work, because a long succession of scientists contributed bits and pieces to the whole fantastic picture. But it's also important to recognize that we still may not be quite all the way right. Thompson's contemporaries were sure that the plum pudding model was right; scientists in Bohr's day fully believed that the planetary model was right, and today we're extremely confident that the quantum model is correct. But it may not be all the way correct, and that's where you come in: the only way we can go on being sure is to keep asking questions and conducting experiments. And that's why you're taking chemistry and physics. Pay attention!

=====Sections=====

(08:50)
Thank you for watching this episode of Crash Course Chemistry. If you paid attention, you learned that Leucippus and Democritus originated the idea of atoms nearly twenty-five hundred years ago, but that the real work didn't really begin until both protons and electrons were discovered by experimenting with discharge tubes, and how Ernest Rutherford figured out what and where the nucleus is. You also learned that chemistry can sometimes be done with just math, like how Bohr figured out his model or the way that Heisenberg used math to usher in the quantum theory of the atom.

=====Credits=====

(09:18)
This episode written by Edi Gonzales and edited by Blake de Pastino. Our chemistry consultant is Dr. Heiko Langner, and it was filmed, edited and directed by Nicholas Jenkins. The script supervisor was Katherine Green, Michael Aranda is our sound designer, and Thought Cafe is our graphics team.