Atoms, Molecules, and Ions

Early Atomic Theory

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It was actually the Greek philosopher, Democratis, that originally coined the term atom, meaning indivisible. But it wasn't until 22 centuries later, when John Dalton laid out a series of postulates that formalized this idea and really forever changed the way we thought about the modern world. This was going to be the first of two significant scientific revolutions that we'll be touching on.

Dalton said specifically four things. He said that all matter was indeed composed of indivisible atoms; that the element, or that elements rather were a type of matter composed of only one type of atom; that a compound, on the other hand, was something composed of two or more types of atoms; and finally, that chemical reactions involve the rearrangement of the atoms of the reactants to give products. So again, the notion that, although there are millions and millions of chemical substances known, that they all could be described by various combinations of a small collection of different types of atoms. Now, this actually is tremendously important, because, although these ideas turn out not to be 100% correct, in particular, as we'll learn in just a moment, that atoms, in fact, are divisible and, in fact, those particles even can be divisible. No one knows where the end of this is going to be, in fact. And also, that an atom of a particular element comes in only one characteristic mass. That also, we'll see in a moment, turns out not to be completely true. But, nonetheless, this basic idea that substances were just combinations of different atoms and, in particular, a very small set of different kinds of atoms, was fundamentally important in changing the way that we approached scientific problems and how we thought of our world. So what I want to do now is look at those first experiments that started to probe the details of what the particles are that made up the atom.

Now, first of all, what are we going to deal with? Let's just cut to the chase and I'm going to tell you that in an atom, in a neutral atom, which is again overall neutral, we have three types of particles. We have the electron. The electron has a fundamental unit of charge, which is going to be the opposite of a proton, which we'll get to in a moment, and it has a very, very light mass compared to a proton, 9.11×10^{-31} kilograms. Much, much lighter, about almost 2000 times lighter than a proton, which is going to have a complementary charge to the electron exactly the same, but opposite, and a mass again considerably larger, actually, closer to 1800 times larger than the mass of an electron. And then there is the neutron. A neutron has a mass very similar to a proton. You'll notice it's just a tiny bit bigger, but it has no charge to it, as the name would imply.

Now, how do these numbers come into being? Where did we actually get these numbers from? What were the experiments that gave rise to this information? Let's focus first on the electron and how we ultimately found out what its mass and what its charge actually was. Now, for a number of years before J. J. Thompson here, there were people playing with charged particle beams. People had a lot of fun taking tubes, putting an incredibly high voltage across the tube and generating a beam of charged particles, and then watching that beam bend in magnetic fields or electronic fields. Well, it was eventually realized that the beam that was being generated by doing this very often was just an electron beam. Electrons again are the things that would accumulate to buildup charge on something, for instance. And so one could generate a beam of these electrons and have it very narrowly defined, and Thompson took just a glorified version of what was originally called a crook's tube, which I'll show you here, to try to figure out what the mass and charge of the electron was. Now, let me describe very specifically what this experiment is.

Again, we start out with a pair of plates that we apply a voltage across, very high voltage, such that electrons actually start to travel across the plate. They leave the cathode, they accelerate through this potential difference and most of them just collide on the anode. But a few of them manage to make it through a small pinhole in the middle of the anode, and so they continue to travel then. What we've done at this stage is simply form a uniform beam of electrons and, in fact, the speed of those electrons could be adjusted by varying the potential across that pair of accelerator plates. So that's the first step.

Now, we've got our beam generated. Now, we want to probe this beam of particles, of electrons. So there are two things that Thompson did; he exposed those electrons to another electric field. Now, this is not an accelerating, well, it is; let met just backup a step. We move that beam of electrons through a pair of plates that we apply another potential across, and this causes that beam to deflect. If, for instance, we apply a potential such that we have a buildup of positive charge on the bottom plate and negative charge on the top plate, then this beam of electrons is found to deflect towards the positive plate, indicating again the charge of this beam would be negative in this case, qualitatively. Now, there also is a magnetic field that is applied and a charged beam of particles, when it passes through a magnetic field, as long as it's traveling with velocity, is deflected from that magnetic field, as well. And so what Thompson did was he took the beam, he, first of all, applied an electric field to deflect that beam, and then he applied a magnetic field that caused the beam to deflect in the opposite direction. And, in fact, then he adjusted those

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two fields, the magnetic field and electronic field, until they exactly canceled each other out, so that the beam traveled straight through. Then, by going through some physics calculations, and you have to take a different Thinkwell course to do the physics, he could determine what the speed of that electron beam was. So he knew the speed of the electrons. By knowing the speed of the electrons, he ultimately could determine the ratio of the charge of the electrons to the mass of the electrons, but he couldn't determine the charge or the mass only the ratio of charge to mass. In other words, think about two different particles that you want to look at, and you look at how fast they accelerate by putting them in an electric field. You can't tell the difference between, let's say, the slower moving particle. Is it moving slower because it's more massive, or is it moving slower because it doesn't have as high of a charge? He could not differentiate between those two factors. And so, as a result, the charge to mass ratio that he determined, or rather all he could determine was the charge to mass ratio. And it has a value of 1.75×10^{-11} coulombs, that's the unit of charge, per kilogram. So again, what he really wants out of this is charge and mass, not that ratio. But this was an important first step to getting it.

Now, before we go on, let me just show you specifically what he did. I'll try to show you a demonstration here. This is a device called an acciloscope. It consists indeed of an electron beam traveling toward you, and the beam then hits a phosphorescent screen. And so what happens in this case is where the electron beam strikes the screen, light is emitted, and so you can see where the electron beam is ending. And, in fact, the electronics in this device are scanning that beam, so you see a line rather than a dot. That's purely to make it a little bit easier for you to see. So we have an electron beam traveling directly towards you. And now, if I move this knob, if I do this adjustment, I can push that beam up or I can push that beam down. And all I'm doing inside this box here is changing the potential, the voltage, across these plates, these electric plates. So that again is causing the beam to move up or down. So I can take that beam and I can move it down, let's say, then I can take my magnetic field, in this case, I just have a strong magnet, and bring it in and try to adjust that beam back up again. Now, I'm not going to be able to do that exactly, but let's see if I can move this guy back up here. So you can see what happens when I bring the magnetic field in. I can push that beam down, I can turn the magnet around and push the beam the other direction. You don't want to do this to your television, or you'll really wreck it. By the way, this is exactly how a television works. It's just an electron beam with a screen. The exact same idea and the electronics scan the electron beam all over the place to create a picture for you.

But, anyway, again the idea of the Thompson experiment was to use a magnetic field to deflect the beam, to use an electric field to compensate for that deflection, and do a little bit of calculating to figure out the speed of the electron beam, and from there you can determine the charge to mass ratio. But remember, the most important point, we couldn't determine the charge or mass alone. It wasn't until the Millikan Oil Drop Experiment, where we're going to be able to determine that, and once we find out one of these guys, we're going to know the other. So that's coming up next.