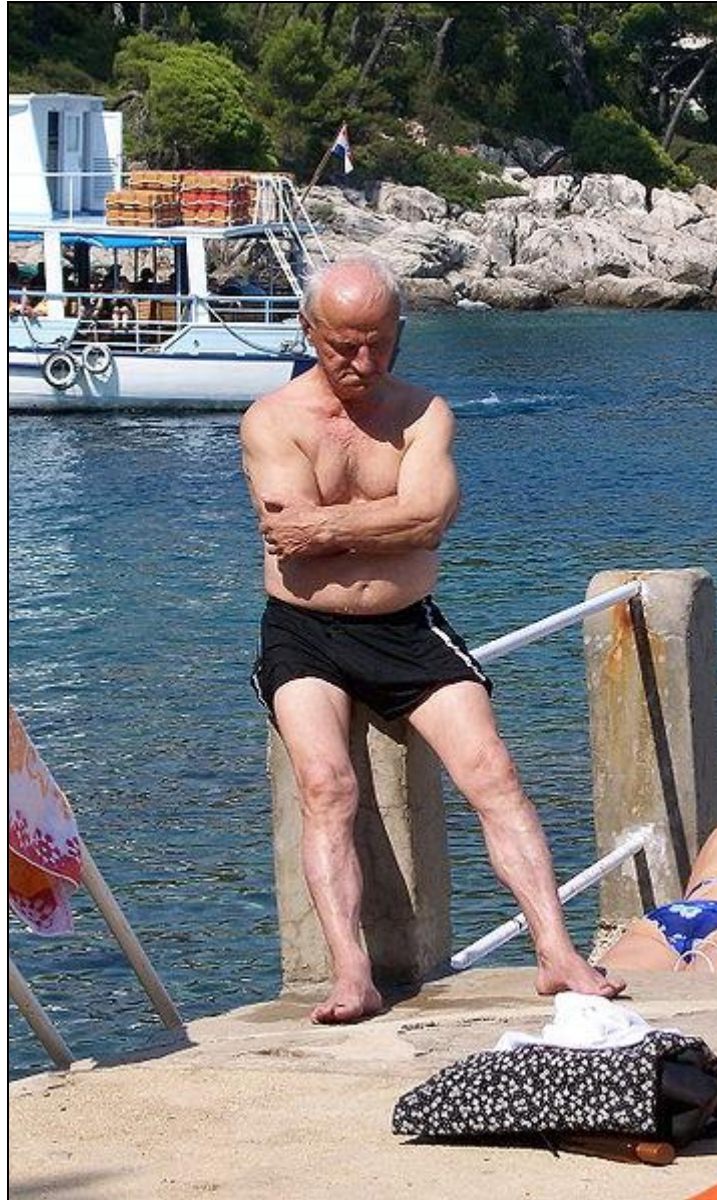


Chapter 4: Old Models of the Atom



Like this man, many discredited models of the atom are old.

Credit: Beyond Silence, http://commons.wikimedia.org/wiki/File:Old_man-1.jpg

Chapter 4: Old Models of the Atom

From the beginning of time, people have wondered what the most fundamental form of matter is. Well, maybe not since the beginning of time, but for a while, anyway. And when I say “people”, I don’t mean “all people” but rather the few people who weren’t busy with jobs or fending off attacks from barbarian invaders and such. Anyway, let’s take a look at what these people came up with.

Section 4.1: Ancient Greeks

Way back in the time of the ancient Greeks, some people thought about the nature of matter. These people were called philosophers, and it’s not entirely clear why people didn’t just tell them to get real jobs. It was a different time.

Anyway, after a lot of philosophizing, these philosophers came up with two competing models of the makeup of matter:

- The **atomic theory** of matter was devised by Leucippus and recorded by Democritus.¹ This theory assumed that matter was made of atoms that were infinitely small and indestructible, and that they traveled through empty space. Atoms could also combine in various ways, and changes in these combinations led to changes in the type of matter they made.²
- The **essence** theory of matter was devised by Aristotle. Unlike the atomic theory, which assumed that different elements gave matter different properties, Aristotle’s model theorized that all matter had a fundamental essence that gave it its properties. By this thinking, gold wasn’t made of gold atoms, but was instead a material that had the gold essence. Because this model didn’t require belief in something that was basically invisible, this is the one that people actually believed.

Because people thought the ancient Greeks pretty much knew everything, nobody really questioned what Aristotle had to say until the Enlightenment period, where the dawn of experimental science started causing scientists to question long-held beliefs.

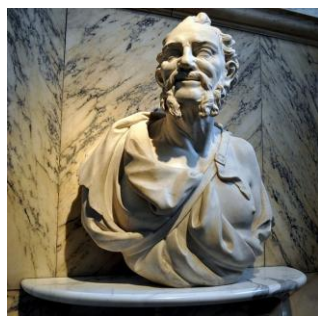


Figure 4.1: Democritus usually gets credit for the atomic theory of matter, even though Leucippus came up with it. I’d show Leucippus’ statue, but nobody ever made one.

http://commons.wikimedia.org/wiki/File:Bust_of_Democritus_-_Victoria_and_Albert_Museum.jpg

¹ Democritus usually gets credit for this idea, but he was really just a student of Leucippus who recorded Leucippus’ ideas. Still, he wrote it down, so he got credit. This is a good example of how you should always show your work.

² This is a pretty good description of a chemical reaction.

Section 4.2: Dalton: The Man, The Model

John Dalton was a guy who lived in the 19th century. Because he totally loved the atomic theory and did some experiments to back it up, he came up with his own theory of the atom. To describe this theory, he came up with a bunch of rules called **Dalton's Laws**:

- Atoms are small and indestructible.³
- Atoms of the same element have the same properties.⁴
- Atoms of different elements have different properties.
- Atoms obey the law of conservation of mass.⁵
- Atoms obey the law of multiple proportions.⁶

Great Men of Science: John Dalton

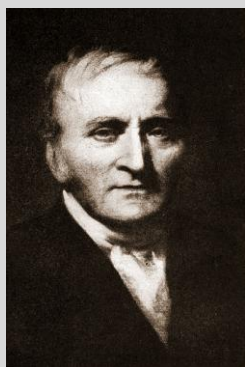


Figure 4.2: John Dalton (1766-1844) was a man who had a wide variety of scientific interests. In addition to his own atomic theory, he studied his own color blindness, which is now known as “Daltonism.” Less successful experiments were held in which he “tried to investigate the humours that move inside of my cranium” by poking sharp sticks in his ear. It’s thought that these experiments led to his 1837 stroke.

<http://commons.wikimedia.org/wiki/File:SS-dalton.jpg>

We’ve been talking a lot about atoms, but haven’t yet defined what they are. An **atom** is the smallest piece of an element that still has the properties of that element. For example, if I break up a bar of gold over and over again, eventually I’ll end up with a single atom of gold – this atom will have the same properties of gold. If I bust this atom up, though, I’ll get a bunch of subatomic particles that don’t have the same properties as the gold it came from.

Section 4.3: Thomson and His Cathode Ray Tube

In 1897, J.J. Thomson decided to run an experiment using something called a cathode ray tube. Basically, a cathode ray tube consists of a big empty glass tube with an electrode on each end. Each electrode is hooked up to one side of a battery; the cathode is the negative electrode and the anode is the positive

³ He swiped this idea from Leucippus. It happens to be false, though, because nuclear reactions can bust apart atoms.

⁴ This isn’t true, because isotopes have different masses (and thus, have some different properties).

⁵ See the last chapter for more about this.

⁶ See the last chapter for more about this.

electrode. When you fire this whole thing up, you can see a beam of particles moving from the cathode to the anode. This beam is called a cathode ray.⁷

When a magnetic field was applied to the tube, the cathode ray bent toward the positive area of the field. As a result, people were able to figure out that these cathode rays consisted of negative particles.

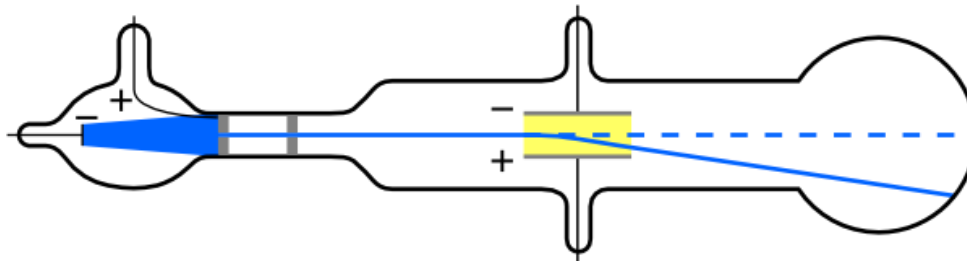


Figure 4.3: The cathode rays bent toward the positive electrode (shown in the middle of the tube), demonstrating that cathode rays have negative charge.

(http://commons.wikimedia.org/w/index.php?title=File:JJ_Thomson_Cathode_Ray_2_explained.svg&page=1)

Thomson put this together to come up with a new model of the atom. Basically, he figured out using his own experiments⁸ that the particles were really really small, and also deduced that they had to come from atoms. To explain this, he came up with the **plum pudding** model of the atom, which theorizes that the atom consists of a big blob of positive charge into which negatively charged electrons are embedded.⁹

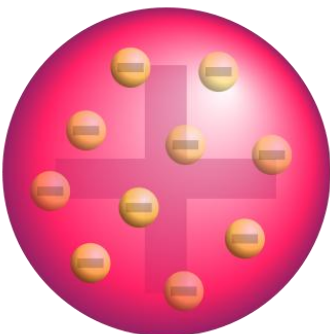


Figure 4.4: In the plum pudding model, the atom consists of a great big blob of positive charge into which electrons are embedded. Thomson's plum pudding model was the first, but unfortunately not the last, of his dessert-related scientific theories.

(http://commons.wikimedia.org/wiki/File:Plum_pudding_atom.svg)

A Lab You Can Do At Home!

Make and enjoy some plum pudding with your family. If possible, place it into a cathode ray tube and knock all of the electrons off of it.

⁷ Creatively named because the ray comes from the cathode.

⁸ They're hard to explain, and not really all that important for our purposes.

⁹ Since nobody knows what plum pudding looks like anymore, imagine a blob of chocolate chip cookie dough, where the dough is the positive charge and the embedded chips are the negatively charged electrons.

Section 4.4: Rutherford's Nukes

Ernest Rutherford was a badass. By 1908 he'd won the Nobel Prize in Chemistry for messing with radioactive stuff, and once you've got the Prize, you can pretty much just loaf around and look awesome for the rest of your life. However, Ernest Rutherford was such an incredible badass that he kept researching stuff.



Figure 4.5: Ernest Rutherford was a total badass.

http://commons.wikimedia.org/wiki/File:Ernest_Rutherford.jpg

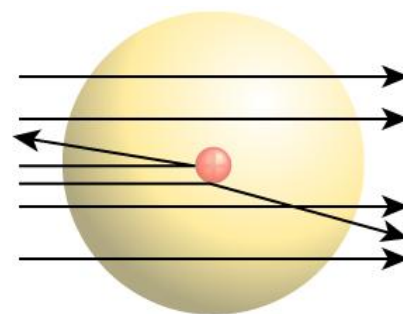
In 1911, Rutherford took time out of his usual schedule of wrestling tigers and making out with hot chicks to do some more experimenting with nuclear stuff. In this experiment, he shot a beam of positively-charged alpha particles¹⁰ at a really thin piece of gold foil to see what would happen. He surrounded the whole thing with a phosphorescent detector screen so he could see where his alpha particles ended up.

When he had run this experiment, he was totally like “WTF.” Though most of the particles travelled right through the foil, others went bouncing off at crazy angles. This didn't make a lot of sense to him, but being the badass he was, he tried to come up with a good explanation for this phenomenon.

The way he explained the deflection of these particles was that the atom has all of its positive charge stuck in a central nucleus. When the positively charged alpha particles didn't go near the nucleus, they passed straight through the gold foil. However, when the particles came near the positively charged nucleus, they were deflected away at odd angles.

Figure 4.6: Because only some of the particles were deflected, Rutherford concluded that most of the atom was empty space and that the positively-charged nucleus had only a very small relative volume.

http://commons.wikimedia.org/wiki/File:Rutherford_gold_foil_experiment_results.svg



So, to conclude, Rutherford was a total badass.¹¹

¹⁰ Alpha particles are helium-4 nuclei and have a charge of +2.

¹¹ He was such a badass that one time this guy totally dissed him in front of his lady and Rutherford totally flying kicked him in the head and when the police came they just let him go because he was so awesome.

Section 4.5: Protons, Neutrons¹², and Electrons

Nowadays, we know about the existence of protons, neutrons, and electrons. Because it's fun to make charts, let's make one that shows what we know about them:

Particle	Symbol	Location	Charge	Mass (amu) ¹³
Proton	p ⁺	Nucleus	+1	~ 1 amu
Neutron	n ⁰	Nucleus	0	~ 1 amu
Electron	e ⁻	Orbitals surrounding the nucleus	-1	~ 0 amu

The atoms of every element have the same number of protons as each other. For example, all atoms of carbon have six protons. This number is called the **atomic number** and can be found on the periodic table.

However, there are different flavors of each element known as **isotopes**. These isotopes have the same number of protons as every other atom of that element, but a different number of neutrons¹⁴. These isotopes are described by their **atomic mass**, which is equal to the number of protons plus the number of neutrons. For example, calcium-41 has 20 protons (just like all atoms of calcium) and 21 neutrons (because 20 protons + 21 neutrons equal a mass of 41). For neutral atoms, the number of protons is equal to the number of electrons, so neutral calcium-41 has 21 electrons.

Section 4.6: Average Atomic Mass

As mentioned above, there are a bunch of different isotopes for each element. Each isotope has its own individual atomic mass, and the average of these atomic masses is equal to the **average atomic mass** of the element. The average atomic mass of an element is described by the following equation:

$$\text{average atomic mass} = \left(\begin{array}{c} \text{abundance of} \\ \text{isotope 1} \end{array} \right) \left(\begin{array}{c} \text{mass of} \\ \text{isotope 1} \end{array} \right) + \left(\begin{array}{c} \text{abundance of} \\ \text{isotope 2} \end{array} \right) \left(\begin{array}{c} \text{mass of} \\ \text{isotope 2} \end{array} \right) + \dots$$

So, if element E¹⁵ has two isotopes, E-22 which has a mass of 22.004 amu and an abundance of 34.09% and E-23 which has a mass of 24.003 amu and an abundance of 65.91%, we'd find that the average atomic mass of element E is:

$$\text{Average atomic mass} = (0.3409)(22.004 \text{ amu}) + (0.6591)(24.003 \text{ amu}) = 23.32 \text{ amu}$$

¹² Neutrons were discovered by James Chadwick in 1932. However, this experiment is really hard to understand, so I'm not going to talk about it.

¹³ An "amu" refers to an "atomic mass unit", which is about 1.67×10^{-24} kg.

¹⁴ Some people think that all isotopes are radioactive, or that they're different from the "normal" type of the element. Nope. All atoms of an element are isotopes of that element, defined by their mass.

¹⁵ The reason I'm using an imaginary "element E" is that most elements have like a zillion isotopes and solving these problems would take forever. Still, you get the idea.

Mini Lab

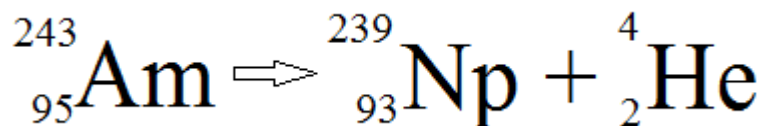
Collect a sample of pure uranium and determine its average atomic mass.

Section 4.7: Radioactivity

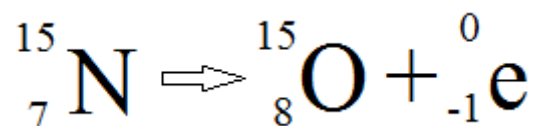
Some nuclei aren't very stable for one reason or another.¹⁶ As a result, they tend to spit off particles to make themselves more stable. The emission of these particles is called **radiation**.

There are several different types of radiation that we normally worry about:

- **Alpha radiation** occurs when a nucleus gives off a helium-4 nucleus (known as an **alpha particle**). The alpha decay of americium-243 is shown below:



- **Beta radiation** occurs when a nucleus emits an electron (known as a **beta particle**). The beta decay of nitrogen-15 is shown below:



- **Gamma radiation** occurs when a nucleus gives off gamma rays, which are basically just really energetic light. They are often given off during other types of radioactive decay to dump off the energy that's associated with these processes.

¹⁶ Like this ex-girlfriend I've got.

Chapter Summary

- Leucippus totally got his atomic theory stolen by Democritus.
- Dalton was the first guy to come up with an atomic theory based on experimental stuff.
- J.J. Thomson liked plum pudding.
- Ernest Rutherford was a total badass. This one time he went for a walk and it started raining, and the rain just parted around him because it didn't want to leave a hair on his awesome head damp.
- Radioactivity and average atomic mass are things you should probably study.

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