

Protons, neutrons, and electrons

Atoms are made of zillions of little tiny particles called quarks and stuff. Fortunately, as chemists, we don't have to worry about these really annoying particles – we just have to keep track of protons, neutrons, and electrons. We'll let the physicists keep the weirdos.¹



Figure 1: An early particle physicist

Though the story behind this picture isn't completely clear, it is believed that it represents one of the many trials early physicists had to complete before they could secure funding.

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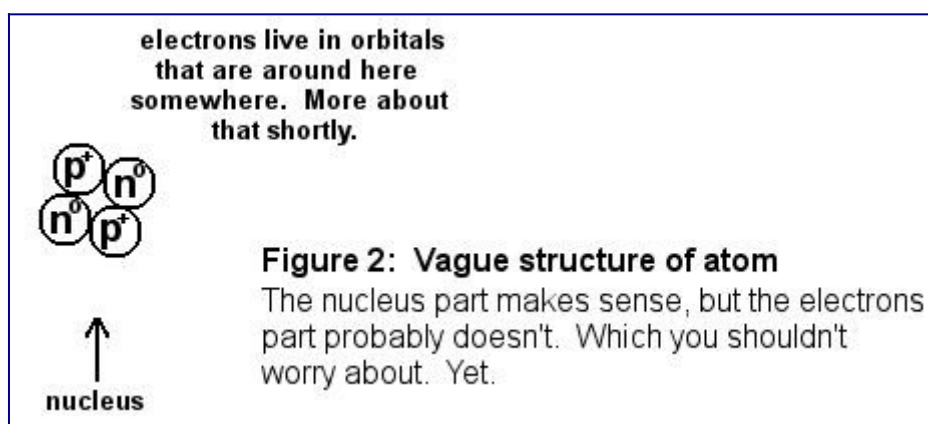
Let's get to work!

Protons, neutrons, and electrons

Unless you've slept your way through every single science class you ever took, you probably know that atoms contain three basic particles: protons, neutrons, and electrons.²

Here's the scoop on these guys:

- **Protons** have a charge of +1 and live in the nucleus of atoms. They have a mass of about 1 atomic mass unit (amu).³ The shorthand symbol for a proton is p^0 , and is equivalent to the atomic number of an element, which is denoted with the letter Z .
- **Neutrons** have no charge and live in the nucleus of atoms. They also have a mass of about 1 amu. Their purpose is to separate the protons so that the repulsion between them doesn't blow the nucleus apart. The shorthand symbol for a neutron is n^0 .
- **Electrons** have a charge of -1 and live in the orbitals of the atom, outside of the nucleus. The mass of an electron is so small (about 1/1836 that of a proton) that it's generally just ignored and treated as zero. It is the transfer and sharing of electrons between atoms that is responsible for chemical interactions.

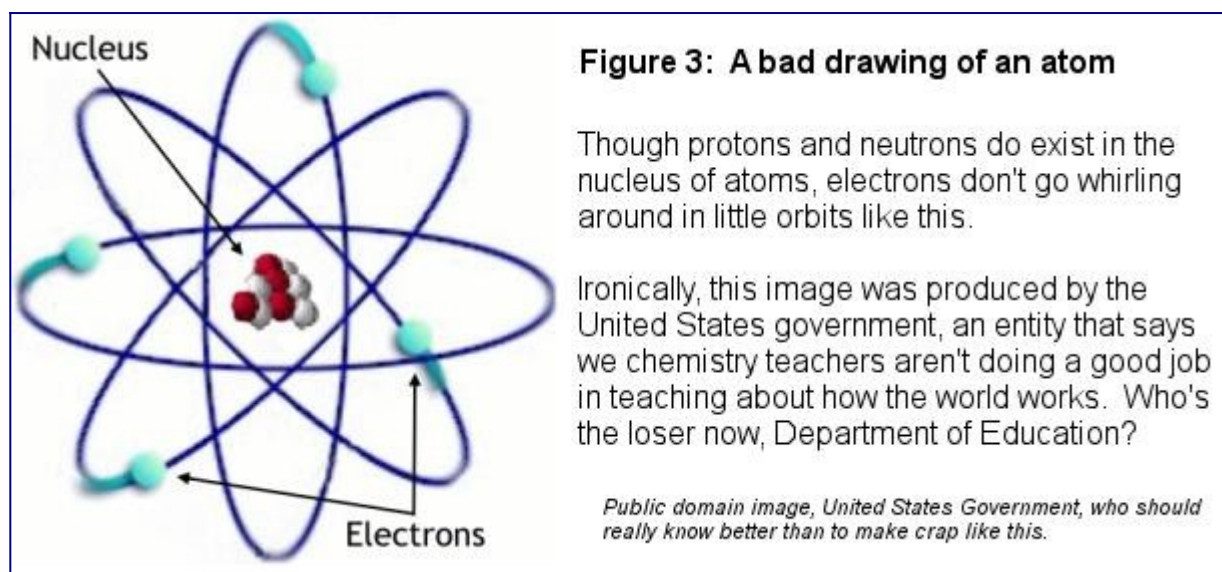


The deal with electrons and orbitals:

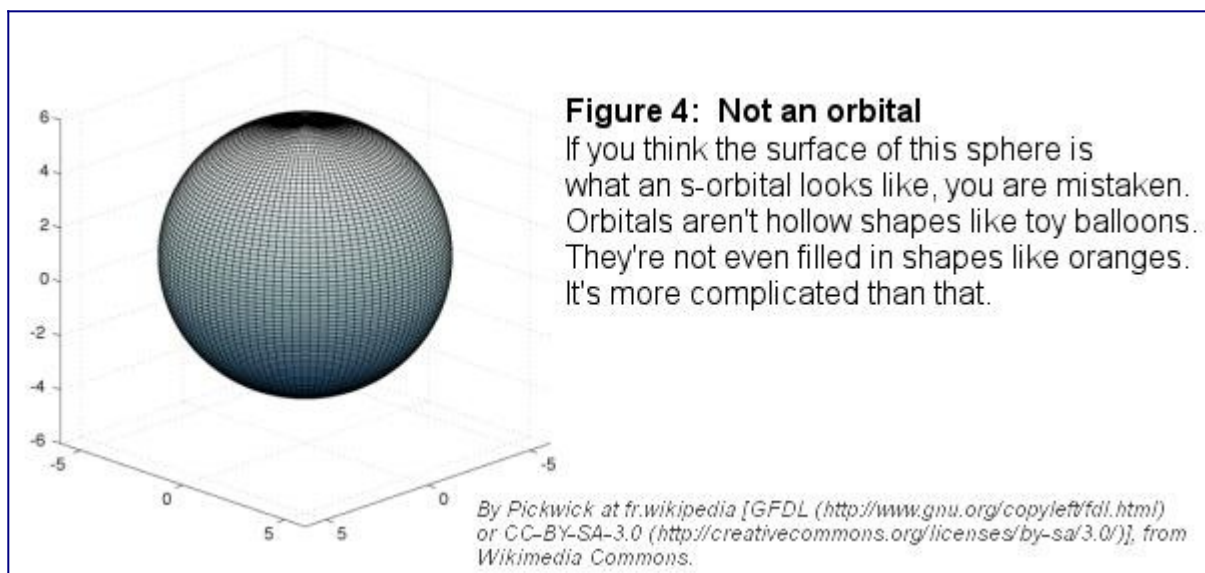
As promised, let's deal with what's going on with electrons and orbitals. Before we do that, however, let's talk about what electrons and orbitals *don't* look like:

What electrons and orbitals aren't:

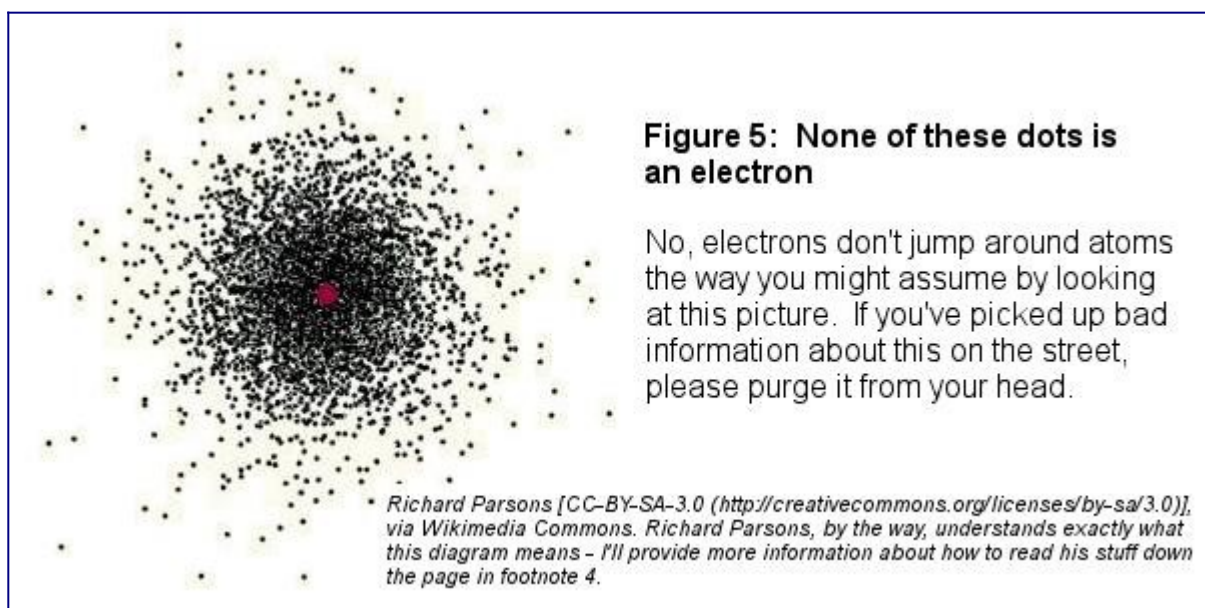
- Electrons are not little particles that move around the atom. Yes, I know that they're said to exist in orbitals, but they don't actually orbit anything. So quit pretending that they circle the nucleus in some fashion!



- Electrons and orbitals don't look anything like a basketball. Though you may see pictures in which orbitals look like these cool 3-D shapes, they're just shorthand ways of showing you what orbitals look like. For this reason, please don't think that a 1s orbital looks like the surface of a basketball.



- Electrons are not little particles that jump around the atom. Teachers often see pictures like the one below and assume that each dot represents a location where the electron briefly makes an appearance before moving someplace new. This is absolutely, positively, not the case.

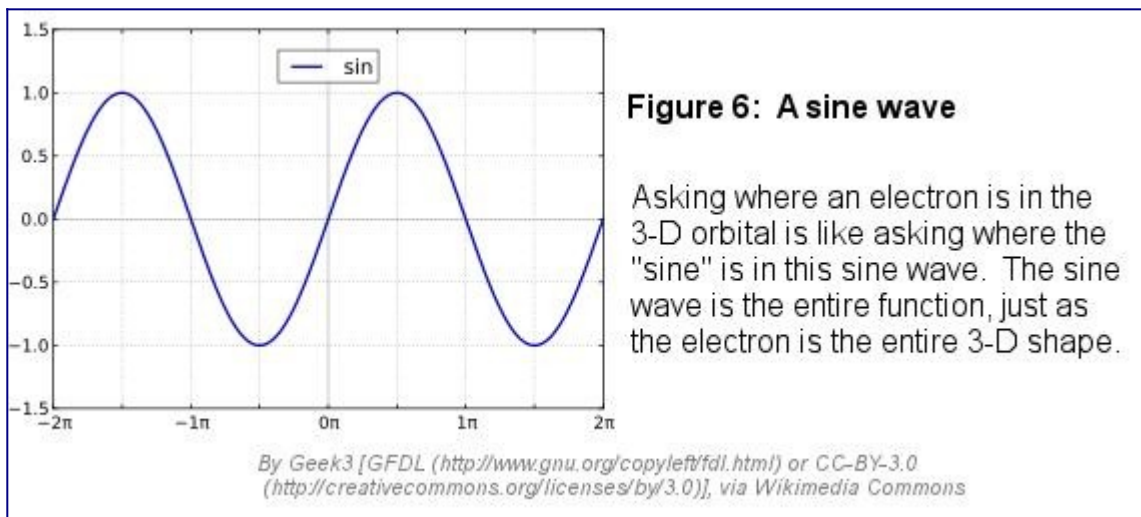


What electrons are:

Electrons are three-dimensional standing waves.

Because by now you know I like making bulleted lists for practically everything, let's take a look at a bulleted list that describes what the heck this means:

- **In an atom, electrons are not particles of negative charge, but 3-dimensional waves with negative charge.** Think back to your math classes: They make a big deal about making you draw a bunch of mathematical functions. Well, electrons can be described by mathematical functions, too – when you draw them out, they turn out to be 3-D shapes.



- **Electrons are usually referred to as “electron clouds” as a way of helping people understand what they are, but they’re not clouds at all.** The term “cloud” makes it sound like an electron is just loafing around occupying space. In real life, an electron is a stable, three dimensional standing wave. If you’ve ever played guitar, you’ve probably seen that the guitar string appears to be stationary when a note is played, with moving areas and areas that are standing still. This is a 2-D standing wave – a 3-D standing wave is the same idea in three dimensions.⁵ To give you the best idea of what this might look like that I’ve been able to find, check this out:

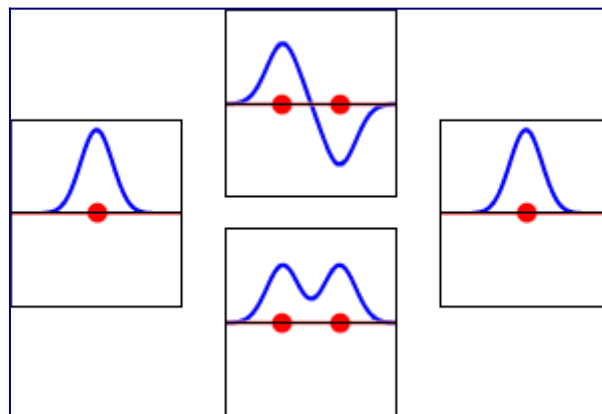


Figure 7: Standing waves or googly faces? You decide.⁶

- **Orbitals are the potential areas where electrons can live.** Think of an orbital as being like a drinking glass. You can express the area taken up by a drinking glass with a mathematical equation- your math teacher has probably already made you do that at some point or another. Whether or not you actually put water into the glass, the glass still represents a potential place where you *could* put water, if you were so inclined. Likewise, orbitals are conditions and properties that an electron will have *if* it ever decides to stop by.⁷
- **Electrons and orbitals aren’t the same thing.** It’s easy to want to say that they are, because if you know the properties of an orbital, you know the properties of any electron that’s occupying it. However, let’s go back to the glass example. You may know mathematically where the water will be if you were to put it in the glass, but it’s not until the water actually enters the glass that it will have those properties. In an atom, the orbital is the glass and the electron is the water.

There's a lot more to say about subatomic particles, but I'll save that for the next exciting tutorial!

Footnotes:

1. Particle physicists classify subatomic particles by their “flavors” and quarks are named after a passage from James Joyce’s *Finnegan’s Wake*. Quarks have traditionally been named in a somewhat haphazard way, with one called the “strange” quark and one called the “charmed” quark. Originally, the top and bottom quarks were called truth and beauty quarks, but that never really stuck (however, particle accelerators that are designed to make lots of bottom quarks are still referred to as B-factories or beauty factories).
2. Yes, and quarks and stuff. However, protons, neutrons, and electrons are the ones we care about in chemistry, so save it for your physics teacher.
3. The mass of a proton is actually 1.007 atomic mass units (amu or u), while neutrons weigh about 1.009 amu. This mass is incredibly tiny, with 1 amu equal to about 1.661×10^{-27} kg.
4. This image, as well as some awesome descriptions of what happens in an atom, can be found online in the free textbook titled, straightforwardly enough, [High School Chemistry](#). Unfortunately, the authors of this book haven’t gotten around to finishing it – hopefully they’ll get off their butts and back to work.
5. If you haven’t visited that link from footnote #4 yet, you really should. Their description of a standing wave is way better than the one I gave.
6. This is a public domain image by Sbyrnes321 (Own work) [CC0], via Wikimedia Commons.
7. Which leads to the question of whether or not orbitals are real? We certainly talk about orbitals as if they were real, and even use the analogy of ladders to describe the energy levels of different orbitals. The analogy breaks down here, though, because while a ladder may have physical rungs that exist no matter what else is going on, there’s no actual *thing* that comprises an orbital when an electron isn’t around. By this reasoning, I’d have to conclude that orbitals are not real and are instead ideas that describe potential realities of real things.