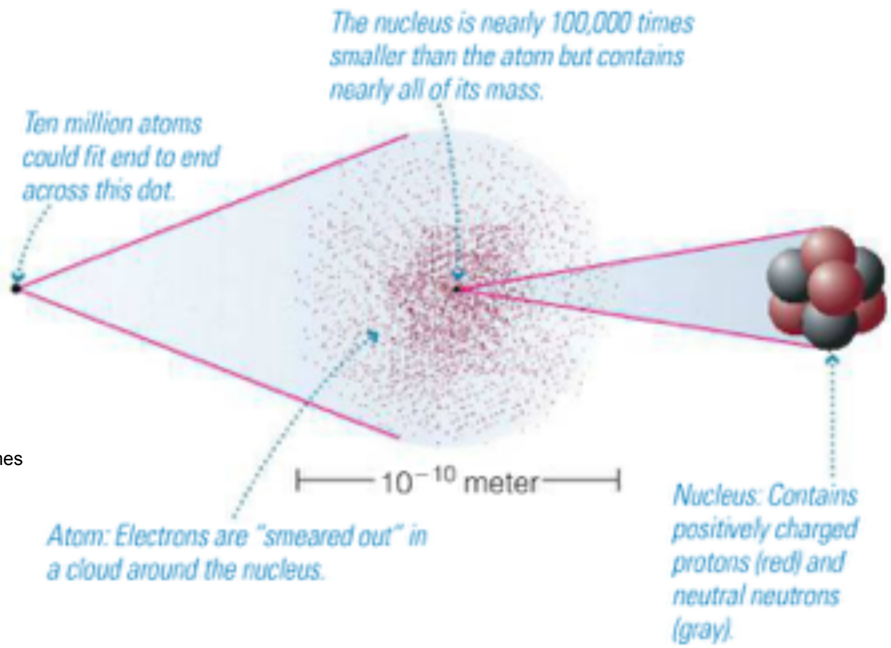
Scientists have odious manners, except when you prop up their theory;
then you can borrow money off them.

Mark Twain

Up And Down The Ladder

Hello. Let's roll. We've been covering the properties of light and what light is. In this module we'll cover what is the structure of matter, what are the phases of matter, and how is energy stored in atoms.



Credit: F.X. Timmes

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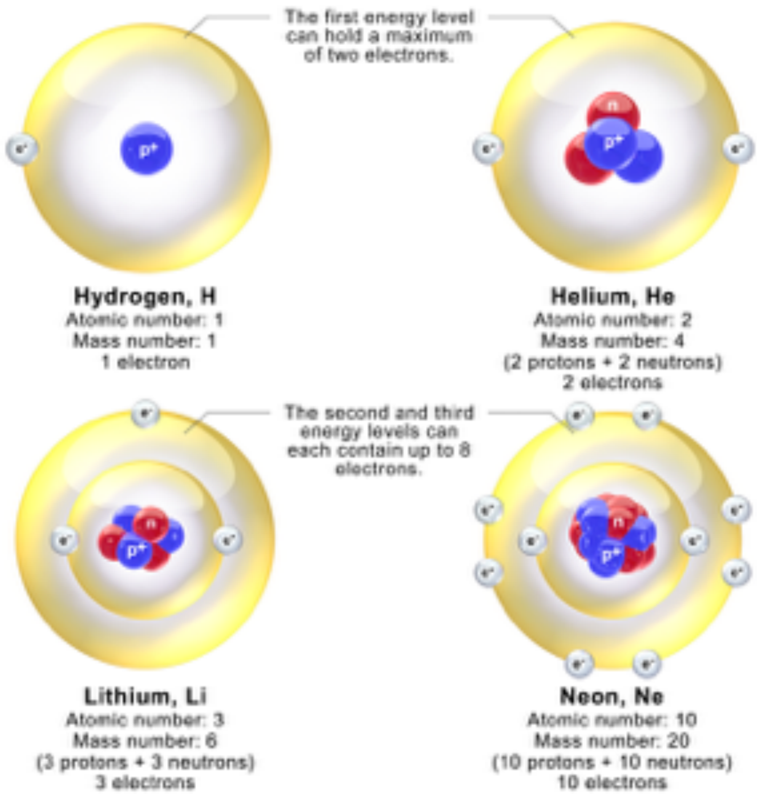
Ordinary matter is made of atoms, which are in turn made of protons, neutrons, and electrons. And that's as far down into the particle zoo as we will go. Of course when I say ordinary matter that must mean that there's unordinary matter! That's true. It's called dark matter. But we'll talk about ordinary matter in this module.

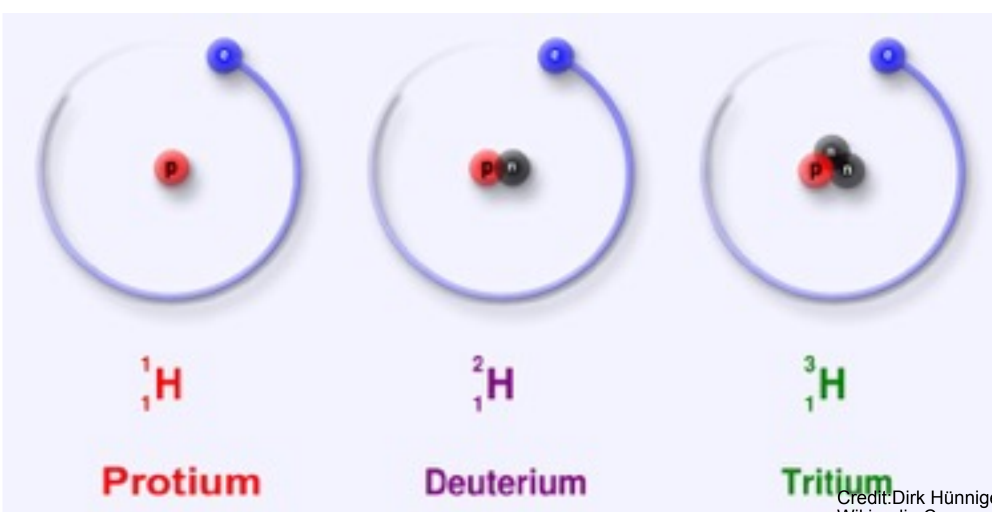
So ordinary matter, as shown in the image above. On a little tiny dot that you could draw with your pencil, you could probably fit on the order of 10 million to 100 million atoms, depending on the size of the dot that you draw. Each atom is composed of a cloud of electrons. You may have seen the picture of where the electrons sort of go around in these orbits as though it was a little planetary system with the nucleus as a tiny sun at the middle. That's not quite the right picture: there's really an electron cloud and the electrons loosely swirl around the nucleus.

The total size of an atom is about 10^{-10} m. The size of the nucleus is about 100,000 times smaller than that but holds most of the mass of the atom. While an atom doesn't really look like the Solar System, like the Solar System, an atom is mostly empty space.



Credit: BruceBlaus, Wikipedia Commons

Atoms of different chemical elements have different numbers of protons. Hydrogen, which makes up most of the universe, has one proton. Helium has two protons. Carbon has six protons, et cetera. The image above shows a few different chemical elements.



Credit:Dirk Hünniger, Wikipedia Commons

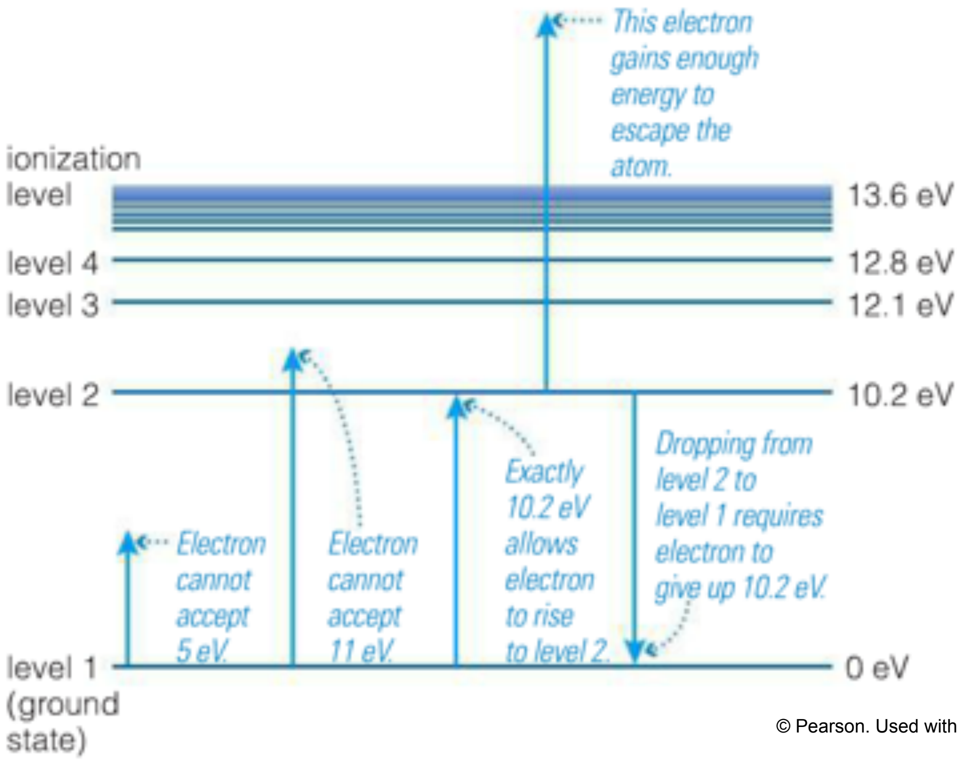
Every chemical element has isotopes. An isotope of a chemical element has a different numbers of neutrons. For example, the image above shows three isotopes of hydrogen. All have just one proton since it is still hydrogen, but each isotope has a different number of neutrons. Another example is carbon, which has six protons. “Regular” carbon, carbon-12, has six protons and six neutrons. Carbon-13 has six protons and seven neutrons. And carbon-14, the radioactive one that we use for various dating techniques here on Earth, has six protons and eight neutrons.

If you take these different elements, or different isotopes, and put two or more of them together, we have what we call molecules.

Matter is a collection of atoms or molecules, which can basically appear in four fundamental forms or phases. It can be composed of a solid, a liquid, a gas, or a plasma. Gas is always present with the solid or liquid phases because you get evaporation or sublimation off the surface of the solid or liquid. So if you have a solid phase, you most certainly have a gas phase right above it. And in a liquid phase, you have a gas phase right above it too. Solids basically sublimate into gas, and liquids evaporate into gas.

If you start at cold temperatures, as shown by the image above, you start off as a solid. And as you raise the temperature, you start disassociating some of the bonds of the solid until the matter takes on liquid form.

As you crank up the temperature even more, the liquid evaporates into a gas. Crank up the temperature some more and you break any molecules into atoms, though you still have a gaseous state. And at the highest temperatures, you start stripping the electrons from those atoms. So you'll have free electrons and free nuclei running around in what is called a plasma.



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Electrons in that fuzzy cloud round atoms exist only in particular, specific energy levels within an atom. This is an effect of quantum mechanics, which we won't talk about too much here. But the illustration above shows the essential picture. When an electrons move either up or down the ladder from one energy level to another, they can only do so if they have very specific amounts of energy. Not just any amount of energy. It has to be the exact amount of energy to transfer from one energy level in an atom to another energy level.

This is super crucial to understand because this is what is going to form what are called spectral lines. You see what are called absorption lines and emission lines in spectra, and they occur at very specific energies, and specific colors, corresponding to very specific energy levels within an atom.

The direction an electron moves in, up or down the latter, determines whether the spectrum is absorption or emission. Because of the conservation of energy, electrons have to give or take photons of light to move around the ladder. We'll talk about that in the next segment.

Energy has to be conserved, but because of quantum mechanics, we also have these exact energy levels, and the electrons can only have these precise amounts of energy. If an incoming photon tries to give the electron either too much or too little energy than what is needed to make it up to the next level, then it doesn't make it to that higher energy level. The electrons stays at the lower level, and ignores the incoming photon, which then zips past the atom as if it wasn't even there. You have to pay the exact price, not too little or too much.

If you give an electron a whole lot of energy, then you can completely remove the electron from the atom. Somewhat like giving enough energy to reach escape velocity from a planet's gravitational field. The atom is then "ionized". That's what we were talking about before, where you completely remove the electron from the atom.

If an electron comes in with exactly the right amount of energy, it will be promoted to the next energy level. This is going to suck energy out of the system, it’s going to absorb energy from the system. This is how energy is stored in atoms for later use.

On the other hand, nature's a lazy sod. It always likes to be in the ground state, the lowest possible energy state. So if you have something in an excited state, on some time scale, usually short, the electron is going to go from a high energy level to a low energy level. That energy difference usually comes off as a photon, a photon having an energy exactly equal to the difference in the two energy levels.

OK? This movement of energy in atoms is key for understanding how we use photons as spaceships to tell us all kinds of properties about distant planets without ever having to go there in person.

Thanks. Bye bye!