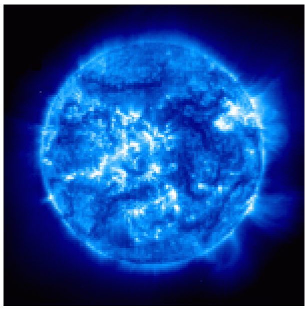
Textbook Reading

Lesson 1: Particle Physics



Matter is anything that has mass. Another way to think about it is that **matter is anything affected by gravity**. The matter you're familiar with is made up of atoms and ions, but that only makes up a small part of the matter in our universe. The matter in black holes is not necessarily made of the same stuff in your fridge.

A Overview of the Atom

All matter is made of some kind of particle. Visible matter (the chair, table, book, car, even you!) is made up of electrons and quarks. Quarks make up the nucleus of the atom. They are subatomic particles that you can arrange in certain ways to get protons and neutrons. Most of the mass is inside the atom's nucleus.

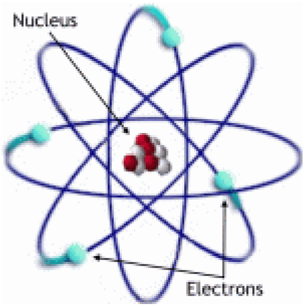
Zipping around the nucleus is the electron, which carries a negative electrical charge and very little mass. Atoms carry the same number of protons (positive charge) and electron (negative charge) so the charges cancel and the atom is usually neutral. If an atom loses or gains an electron, it becomes an ion and takes on a charge.

Free neutrons are generally unstable. It has to do with the way it's built, meaning how the quarks inside the neutron are arranged. If you could put a naked neutron by itself on a shelf, it wouldn't last more than fifteen minutes before it flipped and became a proton. Isn't science weird?

How to Turn Lead Into Gold

The number of protons inside the atom determines what type of element it is. For example, an atom with two protons in the core is a helium atom. An atom with eight protons is an oxygen atom. You can change the atom by adding or taking away protons. To turn lead (which has 82 protons) into gold (79 protons), you would take away three protons. It's that simple. (Or is it?)

What Keeps an Atom Together?



If you think about it, the nucleus of an atom (proton and neutron) really have no reason to stick together. The neutron doesn't have a charge, and the proton has a positive charge. And most nuclei have more than one proton, and positive-positive charges repel (think of trying to force two North sides of a magnet together). So what keeps the core together?

The strong force. Well, actually the *residual* strong force. This force is the glue that sticks the nucleus of an atom together, and is one of the strongest force we've found (on its own scale). This force binds the protons and neutrons together and is carried by tiny particles called pions. When you split apart these bonds, the energy has to go somewhere... which is why fission is such a powerful process (more on that later).

The **fundamental strong force holds the quarks together** inside the proton and neutron. Itty bitty particles called gluons hold the quarks together so the atom doesn't fly apart. This force is extremely strong - much stronger than the electromagnetic force. This force is also known as the color force (there is not any color involved - that is just the way it was named.)

The electromagnetic force keeps the electrons from flying away from the nucleus. When a plus (the nucleus) and minus (the electron) charge get close together, tiny particles called photons pull the two together.

What is Particle Physics?

Scientists love to smash things together and watch what happens. Galileo smacked bowling balls together, Newton was hit by an apple, and physicists today want to know what happens when you smack one tiny particle into another. By watching what happen when they collide and how they interact with each other, scientists can puzzle together what happens inside black holes, stars, and pulsars.

Antimatter

You know from science fiction that when matter and antimatter collide, they destroy each other and release a huge amount of energy. The question is, what *is* antimatter? And what makes it 'anti'?

Let's take the example of the electron. An electron is a small bit of matter with a negative charge and a certain amount of mass. The antimatter component to the electron is called the positron. The positron has the same mass as the electron, but its charge is positive. That's all there is to it. Antimatter counterparts have characteristics that are opposite from their companion particle.

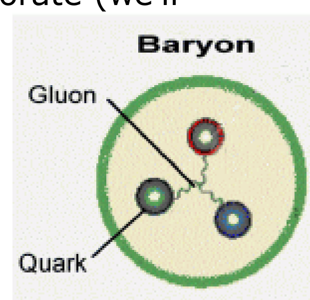
Dark Matter

When you look up at the stars tonight, notice how many bright stars you see. Is there more light or dark space in the night sky? Even though it seems that there's a lot of empty space out there, there is way more matter *inside* stars than anywhere else in our universe. All visible matter is made up of protons, neutrons, and electrons... but there are hundreds of other kinds of particles that make up matter as well.

This invisible mass is called dark matter, and some of it takes the form of MACHOs (massive compact halo objects) and WIMPs (weakly interacting massive particles). Scientists are still trying to figure out what they are and how they act. Most of these live only for a very short time (think less than a blink of an eye), so scientists have to be very fast at taking their data.

Surprise!

Matter and antimatter pairs are constantly popping in and out of existence in our universe. One minute, they don't exist, then next second *POP!* there they are... but then faster than you can blink, the pair smacks into each other and *POOF!* both are destroyed and give off a puff of energy. It's just one of the weird ways that the universe is wired. This is also the basis for how black holes evaporate (we'll talk about Hawking Radiation later).



What other particles are there?

Physicists gave these little bits of matter all sorts of odd names. Are you ready for these?

Here are the most common fundamental particles (meaning that you can't split it in half anymore - it's as small as it can get: leptons and quarks. There are six different types of leptons but only two of which are stable and show up in ordinary matter. There are also six different kinds (called 'flavors') of quarks, but only two can occur in ordinary matter ("up quark" and "down quark"). By the way, the person who named it 'quark' named it after his favorite type of cheese back in the day (quark cheese, anyone?).

There are several different composite particles (particles that have an internal structure - meaning that you can still split it in half): baryons, mesons, and positive pions. Baryons are larger particles containing quarks, mesons contain a quark and an antiquark, and a positive pion has one up quark and one anti-down quark. There are hundreds of different kinds of baryons and mesons.

The carrier particles are the ones that carry the force between the particles. Some of these we haven't really seen for ourselves - we're just guessing. They include: the gluon (glues together quarks inside a proton or neutron), the photon (carries the electromagnetic charge), the graviton (our best guess as to what causes gravity), and others.

Your head is probably about to explode, so I'll leave you with just one more thought - most of these particles also have an antimatter component... so there are quarks and anitquarks, protons and antiprotons, neutrons and antineutrons, neutrinos and antineutrinos... the list goes on and on! Remember, the positron has a positive charge while the electron has a negative charge. The antiproton has a negative charge and the proton has a positive charge. The antineutron still has no charge (like the neutron), but is made up of antiquarks instead of quarks.

Nuclear Fusion and Fission

In the 20th century, scientist figured out that the core of an atom can break apart or join together with others. If you split an atom (called fission), you get smaller parts and a whole lot of energy. When this happens in nature, it’s called radioactivity. Unstable atoms spontaneously break apart and release particles and energy.

Fusion is taking place inside the sun. The sun is not on fire, like a campfire or stove. So where does it get its energy from? The fusion process smacks particles together, which results in a big release of energy. The core of the sun is about one million degrees Celsius, which the surface temperature is a mere 15,000 degrees Celsius. The fusion process in the sun takes two naked protons (also known as a hydrogen nuclei) and smacks them together in a special sequence that results in the formation of helium. This complicated reaction is called the proton-proton chain, and occurs in all stars burning hydrogen in their core.

In chemistry, when you combine things together, you get different stuff out the other end. For example, when you mix together baking soda and vinegar, you get liquid water and sodium acetate precipitate in the cup, and carbon dioxide bubbles released into the atmosphere. When the core of a star fuses together in a supernova, it creates every element on the periodic table (yes, even gold!) and also spits out high-energy alpha, beta, and gamma particles.

Alpha particles were named long before we ever knew *what* they were. An alpha particle are two protons and two neutrons stuck together (also known as helium nuclei). Beta particles are either electrons or positrons. Gamma particles, also called gamma rays, are actually electromagnetic radiation (photons) of very, very high frequency and energy - high enough to damage living tissue. Fortunately, gamma ray bursts are rare and usually not pointed in our direction.

How Does a Nuclear Reactor Work?

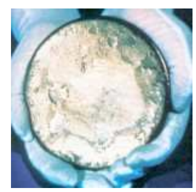
When people think of nuclear power, they often think of disaster-type scenes. Actually, power plants are very similar to coal-burning power plants. They both heat water into steam, which turn generators. The main difference between them is they way they heat the water. Some plants burn fossil fuels (like coal and oil), and nuclear plants use the energy from fission (splitting atoms apart) to heat water.

Remember when we talked when an atom spontaneously undergoes fission**,** it's called radioactivity? Uranium-235 is the perfect example of this kind of atom. U-235 decays naturally by spitting of an alpha particle or two neutrons and two protons bound together. However, U-235 is one of the few materials that can undergo fission both naturally and artificially, so it's a great choice for nuclear power plants. If a naked neutron zipping along by itself suddenly runs into the nucleus of a U-235 atom, the neutron gets absorbed by the core, which cases the atom to be unstable and split immediately.

Are Nuclear Weapons Different from Nuclear Power Plants?

Yes. Nuclear weapons allow the explosive energy in the atom to essentially run rampant, while power plants harness the atomic energy to heat water. The two types of nuclear weapons use energy from either fission (atomic bombs or A-bombs) or fusion (hydrogen bombs or H-bombs).

Atomic bombs get their explosive energy solely from the core of the atom. An atom by itself usually doesn't spontaneously split - you need to have a certain amount (called the critical mass) in order to start the fission process. In an atomic bomb, they separate a small chunk of material (usually plutonium or uranium) from the main lump so that the resulting lump mass is slightly *less* than the critical mass (so it doesn't explode before you want it to). The removed chunk is placed in a shotgun-looking device that will fire directly into sub-critical-mass lump when triggered.



Another way to get the reaction started is to detonate high-energy chemical reactions all around the lump of material, compressing it until it splits on its own.