



The Big Idea

All matter is composed of fundamental building blocks, called particles. These building blocks are much smaller than an atom, and so are sometimes referred to as *subatomic* particles. Particles interact with one another according to a set of rules. Sometimes particles interact by *exchanging* other particles. The set of particles and interactions we believe to exist is called the Standard Model. We know that this model is not complete, but it is as much as we know today.

The fifth of the five conservation laws is called CPT symmetry. The law states that if you reverse the spatial coordinates of a particle, change it from matter to anti-matter, and reverse it in time the new object is now indistinguishable from the original.

Matter

- Particles can be grouped into two camps: *fermions* and *bosons*. Typically matter is made up of fermions, while interactions (which lead to forces of nature such as gravity and electromagnetic) occur through the exchange of particles called bosons. (There are exceptions to this.) Electrons and protons are fermions, while photons (light particles) are bosons.
- Fermions (matter particles) can be broken into two groups: *leptons* and *quarks*. Each of these groups comes in three families.
- The first family of leptons consists of the *electron* and the *electron neutrino*. The second family consists of the *muon* and the *muon neutrino*. The third consists of the *tau* and the *tau neutrino*. Particles in each successive family are more massive than the family before it.
- The first family of quarks consists of the up and down quark. The second family consists of the charm and strange quarks. The third family consists of the top and bottom quarks.
- Up and down quarks combine (via the strong force) to form nucleons. Two ups and a down quark make a proton, while an up quark and two down quarks make a neutron. Different combinations of quarks are called *mesons*.
- Particles differ in their mass, their electric charge, their family (in the case of leptons), and their “spin.” Spin is a quantum mechanical concept we’re going to ignore for now.

Interactions

- There are four fundamental forces in nature. From weakest to strongest, these are the gravitational force, the weak nuclear force, the electromagnetic force, and the strong nuclear force.
- Each fundamental force is transmitted by its own boson(s): for gravity, they are called gravitons; for the weak nuclear force, they are called W^- , W^+ , and Z^0 bosons; for the electromagnetic force, they are called photons; and for the strong nuclear force, they are called gluons.
- In summary, the building blocks of matter and the interactions between matter consist of the following fundamental particles :

Fermions		Bosons	
<i>Leptons</i>	<i>Quarks</i>	<i>Force Transmitted</i>	<i>Associated Boson</i>
electron	up	gravity	graviton
electron neutrino	down	electromagnetic	photon
muon	strange	weak	W^- , W^+ , and Z^0
muon neutrino	charm	strong	gluons
tau	top		
tau neutrino	bottom		

Rules

- For any interaction between particles, the five conservation laws (energy, momentum, angular momentum, charge, and CPT) must be followed. For instance, the total electric charge must always be the same before and after an interaction.
- Electron lepton number is conserved. This means that the total number of electrons *plus* electron neutrinos must be the same before and after an interaction. Similarly, muon lepton number and tau lepton number are also (separately) conserved.
- Total quark number is conserved. Unlike leptons, however, this total includes *all* families.
- Photons can only interact with objects that have electric charge. This means that particles without charge (such as the electron neutrino) can never interact with photons.
- The strong nuclear force can only act on quarks. This means that gluons (the particle that carries the strong nuclear force) can only interact with quarks, or other gluons.
- The gravitational force can only act on objects with energy, and hence objects with mass.
- The weak nuclear force interacts with both quarks and leptons. However, the weak force is carried by any of three particles, called *intermediate vector bosons*: W^- , W^+ , and Z^0 . Note that the W particles carry electric charge. This means you have to be more careful in making sure that any weak force interaction conserves electric charge.
- Any interaction which obeys all of these rules, and also obeys the usual rules of energy and momentum conservation, is allowed. Due to the randomness of particle interactions (See Chapter 24.), any allowed interaction must eventually happen.

Antimatter

- In addition to all of this, there is a further complication. Each type of particle that exists (such as an electron or an up quark) has an antiparticle. Antiparticles are strange beasts: they have the same properties as their corresponding particles (mass, size, interactions) but their quantum numbers are exactly reversed (electric charge, electron, muon, or tau lepton number, and quark number).
- There are two ways to denote something as an antiparticle. The most common is to draw a horizontal line above the thing. So, for instance, the antiparticle of the up quark is the anti-up quark:

u	\bar{u}
up quark	anti-up quark

- For charged leptons, you can merely switch the charge. So, for instance, an electron has negative charge and is written e^- , while its antiparticle, the anti-electron (also called a *positron*) is written e^+ .

e^-	e^+
electron	anti-electron (<i>aka</i> positron)

- Particles and antiparticles annihilate each other, and convert their mass directly to energy in the form of gamma rays. Likewise, gamma rays can spontaneously revert to particle-antiparticle pairs. Matter and energy exchange places frequently in this process, with a conversion formula given by the famous equation $E = mc^2$.

Resources

- Ask your teacher to provide you with a copy of the Standard Model of Particles and Interactions. If there aren't any available, please download and print out a copy of the Standard Model of Particles and Interactions, available at <http://particleadventure.org/>

Standard Model of Particle Physics Problem Set

You will need a copy of the Standard Model to do this assignment. See above.

1. Which is more massive, the strange quark or the muon?
2. If you bound an up quark to an anti-strange quark using gluons, would the result be a proton, a neutron, an electron, or some type of meson?
3. Name three particles that do not interact with gluons.
4. Name three particles that do not interact with photons.
5. Which nucleon does not interact with photons? Why?
6. Does the electron neutrino interact with photons? Why or why not?
7. What quarks make up an anti-proton?
8. What rule would be violated if Dr. Shapiro attempted to turn an anti-electron (positron) into a proton?
9. Can any of the intermediate vector bosons (W^- , W^+ , and Z^0) interact with light? If so, which?
10. What force (of the four) **must** be involved in the process of beta decay, in which a neutron disappears and turns into a proton, an electron, and an electron anti-neutrino?
11. In the world-view provided by the Standard Model, the universe of the very small contains which of the following? (Choose any and all that apply.)
 - a. Boson-exchange interactions between different types of quarks and leptons
 - b. Annihilation and creation of particle-antiparticle pairs
 - c. Electromagnetic interactions between charged objects
 - d. Electromagnetic interactions between Z^0 bosons
 - e. Weak interactions involving quarks and leptons
 - f. Strong interactions between water molecules

Explain.

12. What is string theory? Why isn't string theory mentioned anywhere on the Standard Model? (If you are not already familiar with string theory, you may have to do some research online.)
13. Name three winners of the Nobel Prize who were directly investigating atomic and subatomic particles and interactions. Investigate online.