EP

The standard model

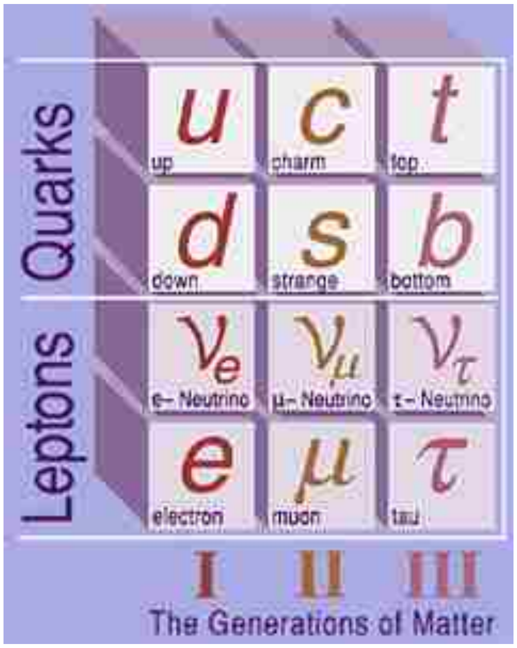
Physicists have developed a theory called The Standard Model that explains what the world is and what holds it together. It is a simple and comprehensive theory that explains all the hundreds of particles and complex interactions with only 6 quarks, 6 leptons, 6 antiquarks, 6 antileptons, and the force carriers.

The best-known lepton is the *electron*. **Force carrier particles**, are like the photon. We will talk about these particles later.

All the known matter particles are composites of quarks and leptons, and they interact by exchanging force carrier particles.

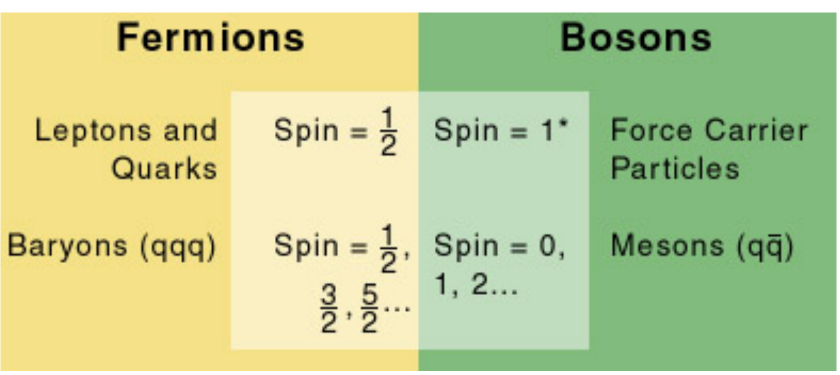
The charts below show the elementary bosons of the standard model, the exchange of which is responsible for the four different "forces" or interactions. The electromagnetic and weak forces are closely related in the standard model, with the "weakness" of the latter at low energy due to the massive nature of the W and Z bosons. The gluon carries color charge and therefore interacts directly with itself, unlike the neutral photon.

The chart below shows the elementary fermions of the standard model. These are divided into 3 "generations", each of which contains two quarks and two leptons. Note that the upper and lower quarks have charges $2/3$ and $-1/3$, respectively, while in each generation one of the leptons has a negative charge while the other (the neutrino) is neutral. Each of these fermions has an anti-particle with opposite quantum numbers, including "flavor" and charge.



Tables	Are					
quark	up	charm	top	down	strange	bottom
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$

The chart below displays the two different types of fermions and bosons involved in the standard model. These are the "elementary" ones described in the charts above, and the composite "everyday" baryons and mesons such as protons, neutrons and pions which are constructed from quarks and anti-quarks. Because of color confinement free quarks anf gluons do not exit in nature: only the color-neutral baryons and mesons can be found in isolation, along with the non-colored leptons and electroweak bosons.



Fermions are one of the two fundamental classes of particles, the other being bosons. Fermion particles are described by Fermi–Dirac statistics and have quantum numbers described by the Pauli exclusion principle. They include the quarks and leptons, as well as any composite particles consisting of an odd number of these, such as all baryons and many atoms and nuclei.

Fermions have half-integer spin; for all known elementary fermions this is 1⁄2. All known fermions, except neutrinos, are also Dirac fermions; that is, each known fermion has its own distinct antiparticle. It is not known whether the neutrino is a Dirac fermion or a Majorana fermion.[3] Fermions are the basic building blocks of all matter. They are classified according to whether they interact via the color force or not. In the Standard Model, there are 12 types of elementary fermions: six quarks and six leptons.

Hadrons, Baryons, and Mesons

Like social elephants, quarks only exist in groups with other quarks and are never found alone. Composite particles made of quarks are called **Hadrons**.

baryons are any hadron which is made of three quarks, Because they are made of two up quarks and one down quark (uud), **protons** are baryons. So are **neutrons** (udd).

mesons contain one quark q and one antiquark $\bar{q}$ One example of a meson is a pion π^+ , which is made of an up quark and a down anitiquark.

The antiparticle of a meson just has its quark and antiquark switched, so an antipion π^- is made of a down quark and an up antiquark.

Because a meson consists of a particle and an antiparticle, it is very unstable. The K meson lives much longer than most mesons, which is why it was called "strange" and gave this name to the strange quark, one of its components.

Lepton Decay

The heavier leptons, the muon and the tau, are not found in ordinary matter at all. This is because when they are produced they very quickly **decay**, or transform, into lighter leptons. Sometimes the tau lepton will decay into a quark, an antiquark, and a tau neutrino. Electrons and the three kinds of neutrinos are stable and thus the types we commonly see around us.

When a heavy lepton decays, one of the particles it decays into is always its corresponding neutrino. The other particles could be a quark and its antiquark, or another lepton and its antineutrino.

The number of members in each family must remain constant in a decay. (A particle and an antiparticle in the same family "cancel out" to make the total of them equal zero.)

Leptons are divided into three lepton families: the electron and its neutrino, the muon and its neutrino, and the tau and its neutrino. One important thing about leptons, then, is that electron number, muon number, and tau number are always conserved when a massive lepton decays into smaller ones.

example:

A muon decays into a muon neutrino, an electron, and an electron antineutrino.

	muon		muon neutrino		electron		e^- antineutrino
equation:	μ	$\rightarrow$	ν_μ	+	e^-	+	$\bar{\nu}_e$
electron number:	0	=	0	+	1	+	-1
muon number:	1	=	1	+	0	+	0
tau number:	0	=	0	+	0	+	0

As you can see, electron, muon, and tau numbers are conserved. These and other conservation laws are what we believe define whether or not a given hypothetical lepton decay is possible.

Which lepton decays are possible?

$$\tau^- \rightarrow e^- + \bar{v_e} + v_\tau$$

Yes! Charge, tau number, electron number, and energy are all conserved.

An electron decays into a muon, a muon antineutrino, and an electron neutrino

$$e^- = \mu^- + \bar{v_\mu} + v_e$$

No! Surprise! Although electron and muon numbers are both conserved, energy is not conserved. A muon has a lot more mass than an electron, and a lepton cannot decay into something more massive than it started out!

Force Carrying Particles

The carrier particle of the electromagnetic force is the **photon**. Photons of different energies span the electromagnetic spectrum of x rays, visible light, radio waves, and so forth.
Photons have zero mass, as far as we know, and always travel at the "speed of light", c, which is about $300,000,000$ meters per second, or $186,000$ miles per second, in a vacuum.

Color Charge

Quarks have electromagnetic charge, and they also have an altogether different kind of charge called color charge. The force between color-charged particles is very strong, so this force is "creatively" called the **strong**

force.

The **strong force** holds quarks together to form hadrons, so its carrier particles are whimsically called gluons because they so tightly "glue" quarks together.

Color charge behaves differently than electromagnetic charge. Gluons, themselves, have color charge, which is weird and not at all like photons which do not have electromagnetic charge. And while quarks have color charge, composite particles made out of quarks have **no net color charge** (they are color neutral). For this reason, the strong force only takes place on the really small level of quark interactions, which is why you are not aware of the strong force in your everyday life.

When two quarks are close to one another, they exchange **gluons** and create a very strong color force field that binds the quarks together. The force field gets stronger as the quarks get further apart. Quarks constantly change their color charges as they exchange gluons with other quarks.

There are three color charges and three corresponding anticolor charges. Each quark has one of the three color charges and each antiquark has one of the three anticolor charges.

Just as a mix of red, green, and blue light yields white light, in a baryon a combination of "red," "green," and "blue" color charges is color neutral, and in an antibaryon "antired," "antigreen," and "antiblue" is also color neutral. Mesons are color neutral because they carry combinations such as "red" and "antired".

Weak interactions are responsible for the decay of massive quarks and leptons into lighter quarks and leptons. When fundamental particles decay, it is very strange: we observe the particle vanishing and being replaced by two or more different particles. Although the total of mass and energy is conserved, some of the original particle's mass is converted into kinetic energy, and the resulting particles always have less mass than the original particle that decayed.

The carrier particles of the weak interactions are the $W+$, $W-$, and the Z particles. The W's are electrically charged and the Z is neutral.
The Standard Model has united electromagnetic interactions and weak interactions into one unified interaction called **electroweak**.

In addition, the gravity force carrier particle has not been found. Such a particle, however, is predicted to exist and may someday be found: the *graviton*.

useful quantum numbers

Electric charge - Quarks may have 2/3 or 1/3 electron charges, but they only form composite particles with integer electric charge. All particles other than quarks have integer multiples of the electron's charge.

Color charge - A quark carries one of three color charges and a gluon carries one of eight color-anticolor charges. All other particles are color neutral.

Flavor - Flavor distinguishes quarks (and leptons) from one another.

Spin - Spin is a bizarre but important physical quantity. Large objects like planets or marbles may have angular momentum and a magnetic field because they spin. Since particles also to appear to have their own angular momentum and tiny magnetic moments, physicists called this particle property spin. This is a misleading term since particles are not actually "spinning." Spin is quantized to units of 0, 1/2, 1, 3/2 (Times Planck's Constant) and so on.

Color - Color-charged particles cannot be found individually. For this reason, the color-charged quarks are confined in groups (hadrons) with other quarks. These composites are color neutral.

The quarks in a given hadron madly exchange gluons. For this reason, physicists talk about the color-force field which consists of the gluons holding the bunch of quarks together.