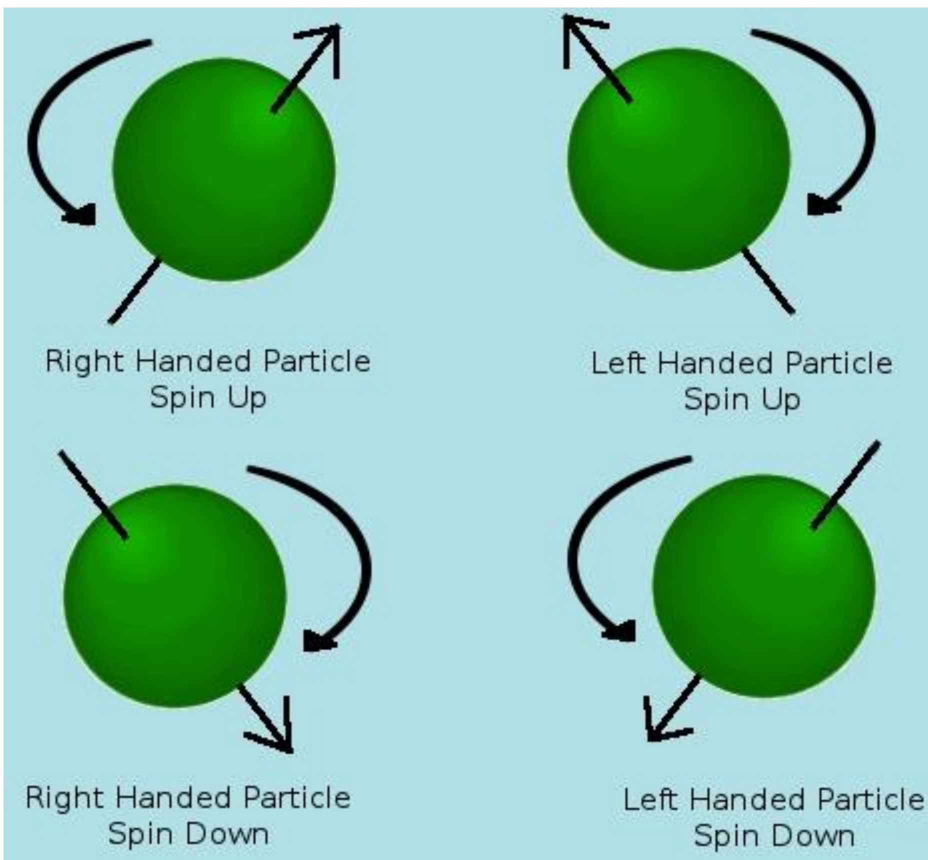
Particles and Forces

Particles

Spin

Before I get into the different types of particle there's a bit more back story you need. All particles can spin, like the earth on its axis, however it would be possible in theory to change the speed or direction of the earths spin. With particles the spin has a fixed value that depends only on the type of particle. Spin can also have direction, up or down and the particle carrying the spin can have a handedness, left or right. This gives four possible combinations shown below



I admit, this looks quite confusing but it can be possibly simplified with the help of your own left and right hands. If you get your right hand in a grip position with your thumb sticking straight up then your fingers represent the handedness of the particle, or direction of spin, and your thumb represents whether the particle is orientated up or down. For example, if a clock is thrown with its face directed forwards it's Left-handed. In order to represent its clock hands motion with your gripped fingers and the overall clock flying through the air motion with your thumb you have to use your left hand. There is a good image on wikipedia here. Although its describing a field you can just swap the arrow labels for spin (fingers) and direction (thumb).

Types of Particle

Throughout the whole of the known universe there are only 2 types of particle. Particles that make up matter, and particle that carry force. They are the only 2 types found so far. Now you may be thinking that, yes there may only be two categories but I bet they're filled with hundreds of different subgroups and types. Thankfully this isn't the case, particles follow specific rules and once you known them everything gets a lot easier.

The two groups are called Fermions and Bosons

Fermions

Fermions is the title that refers to all particles that make up matter. The name comes from the fact that all particles of matter follow a certain set of laws called Fermi-Dirac Statistics, developed by Enrico Fermi and Paul Dirac in 1926.

Another thing that distinguishes Fermions is the particles spin. Every electron in existence possesses a spin of 1/2. In fact all matter particles in existence possess half integer spin i.e. 1/2, 3/2, 5/2 etc. All Fermions have half integer spin. Spin can also have direction, up or down

Another thing that distinguishes Fermions is the fact that they obey the Pauli exclusion principle. This sounds complicated and probably is but it's relatively simple to describe. What it means is that only certain combinations of matter can exist in the same space, more specifically "It states that no two identical fermions may occupy the same quantum state simultaneously". For example take Helium. It's got a lowest energy shell for the electrons. You can put one electron in easy, however the Pauli Exclusion principle says 2 electrons can't occupy the same quantum state so the second one has to have the opposite spin. This then allows the 2 electrons because spin is part of the quantum state of the electron, so the two electrons are occupying different quantum states. The spin however can only be one of two things, up or down. If for example you had a lithium atom, which three electrons in orbit then the third electron can't fit into the 1st shell. So to fit it in it has to move up to the next shell. This way the entire Periodic table is built up from this principle. There are two different types of matter particles, Leptons and

Quarks.

Leptons

Leptons are a collection of 6 sub atomic particles, 2 types for each flavour. The Electron and the Electron Neutrino, the Muon and Muon Neutrino which are basically heavier versions of the Electron and the Electron Neutrino, and the Tau and the Tau Neutrino which are heavier versions still. The electron, muon and tau all have charges of -1 whereas all the neutrinos have charges of 0

Lepton Group	Name	Charge	Mass
1	Electron	-1	0.5 MeV/c^2
1	Electron Neutrino	0	< 2.2 eV
2	Muon	-1	105 MeV/c^2
2	Muon Neutrino	0	< 170 keV
3	Tau	-1	1776 MeV/c^2
3	Tau Neutrino	0	< 15.5 MeV

Quarks

Quarks are the other type of matter particle along with the leptons. Like the leptons there are 6 quarks, grouped in 3 sets of 2, with each successive group basically just a heavier version of the previous. Like the leptons the quarks in each set have a charge difference of 1, but instead of nice whole numbers the charges of quarks is fractions of e. The six quarks are named Up, Down, Charmed, Strange, Top and Bottom

Quark Group	Name	Charge	Mass MeV/c^2
1	Up (u)	+2/3	1.5-4
1	Down (d)	-1/3	4-8
2	Charm (c)	+2/3	1150-1350
2	Strange (s)	-1/3	80-130
3	Top (t)	+2/3	170900 ± 1800
3	Bottom (b)	-1/3	4100-4400

Hadrons

Physicists seem to love their labels and groups. As soon as you put quarks together in groups then the resultant particles are called Hadrons. But the names and classes don't stop there. If you make a Hadron out of 2 quarks it's called a Meson and if you make a Hadron out of 3 quarks it called a Baryon.

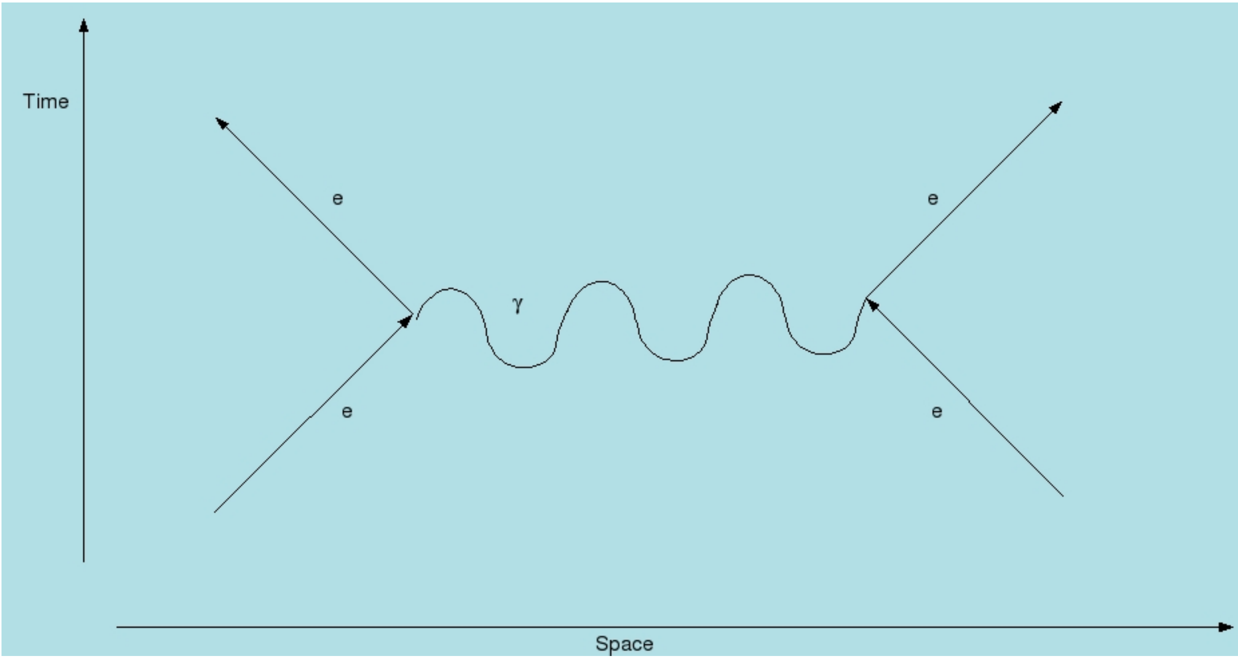
The reason you get groupings of 2 or 3 quarks is because of their colour. Quarks can be red, green or blue and anti quarks can be antired antigreen and antiblue. Quarks exist in groups that have no overall colour charge, so you can get groups that are red+blue+green=white, antired+antiblue+antigreen=white, red+antired=white, blue+antiblue=white or green+antigreen=white, i.e. either 3 quarks or anti quarks together or 1 quark and 1 anti quark together.

Particles like the proton and neutron are examples of Baryons as they are comprised of 3 quarks, while particles like the π^+ and π^- are Mesons as they are made from a quark and an anti quark, however all 4 of them are types of Hadron.

Bosons

Bosons are the particles that carry force. They are characterised by having whole integer spin e.g. -1, 0, 1, and don't obey the Pauli Exclusion Principle, so you can have loads of them in the same space. Each of the fundamental forces of nature has its own Boson(s).

For Electromagnetism the force carrier is the Photon. They are sometimes called virtual photons as they only exist for very small intervals of time or space. If an electron gets near another electron it emits a virtual photon which is absorbed by the second electron and lets it know it need to move away.



Feynman Diagram

This is a Feynman Diagram, named after the amazing physicist Richard Feynman. Its an easy way of describing or visualising particle interactions. Particles are represented as lines, either straight or wavy, and interactions are depicted as a vertex of the lines. Most of the time the lines will have arrows to show more specifically how the particles are moving. In the above example two electrons move towards each other, then we have the interactions with the boson of the electromagnetic force, then they move away from each other.

For The Strong Nuclear Force the boson is the Gluon. It has zero rest mass and zero charge. Despite there only being one boson for this force you can get different Colours. Now this bit may get a bit abstract so hold on. Colour is just like mass or charge, it's just the name for a property of the particle that we can measure. The particle aren't really red, but that was the label chosen for that specific quality that the particle has.

For Gravity the boson is the Graviton. Its is thought to have zero rest mass and zero charge

The Weak Nuclear Force is the odd one out. It's bosons are the W+, W- and the Z0. This force has 3 Bosons! And they're all bigger than protons! And 2 of them have charge!

Forces

What is stuff made of? Compounds, molecules, atoms, electrons and quarks. At the moment you can go no further. Forces are the same, there are loads of them about but really there just combinations of 4 fundamental forces. This isn't enough for most physicists (myself included) and so research has been going on for a long time now to try and find just one description of all of them. James Clerk Maxwell did it with Electricity and Magnetism, so why cant we do it with the rest. Actually we partially have, but more on that later . For now here are the 4 forces.

Gravity

Gravity is the weakest of all the forces, which seems odd at first. It holds planets together and holds them in their orbits. It is also the longest ranged force mainly because it is always attractive. You can easily overcome gravity just by jumping, that's how weak it is. Gravity is felt by anything with mass. If it has mass, gravity can act on it. Gravity works via the following law

$$F = -G\frac{m_1 m_2}{r^2}$$

It's an inverse square law so it gets weaker the further you move away, it also gets stronger for objects of larger mass.

Electromagnetism

Electromagnetism is 1 trillion, trillion, trillion times stronger than gravity. However unlike gravity which is always attractive, electromagnetism can be both attractive and repulsive. This is because there are 2 types of electromagnetic "matter", positive charge and negative charge. Electromagnetism follows the following law

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

You can see that its very similar to the law for gravity. It's inversely proportional to distance and is stronger for objects of larger charge. It's a long ranged force, however the mix of positive and negative charge cancel each other so its hardly ever felt on large scale, unlike gravity.

Weak Nuclear Force

Weak Nuclear Force 10 trillion, trillion times stronger than gravity. The weak nuclear force is responsible for nuclear decay, and can cause one of 3 types, Alpha, Beta or Gamma. Alpha decay is the emission of a helium nucleus from an atom, Beta decay is when an electron or positron is emitted from an atom, and Gamma decay is the emission of a high energy photon from an atom. The weak nuclear force is the odd one out of all the forces. Firstly because of its Bosons. The weak force has 3 Bosons unlike the others which only have 1 each. The bosons are also unlike the others as they have charge and mass, so much mass in fact that they are heavier that atoms of Iron!!! This is why the force only acts over small distances. In one type of decay an Up quark emits a W-, that is, a particle emits another particle that is 80000 times heavier! In order to do this the Up quark has to "borrow" energy from the universe. The weak force is also different as it only affects left handed particles or right handed antiparticles with flavour.

Strong Nuclear Force

Inside a nucleus you have protons and neutrons. Due to the electromagnetic force however all of the protons in the nucleus are pushing each other apart trying to break free, the thing that holds them together is the Strong Nuclear force. Its 100 times stronger that EM, an affects all particles with colour. Thats right. Colour!

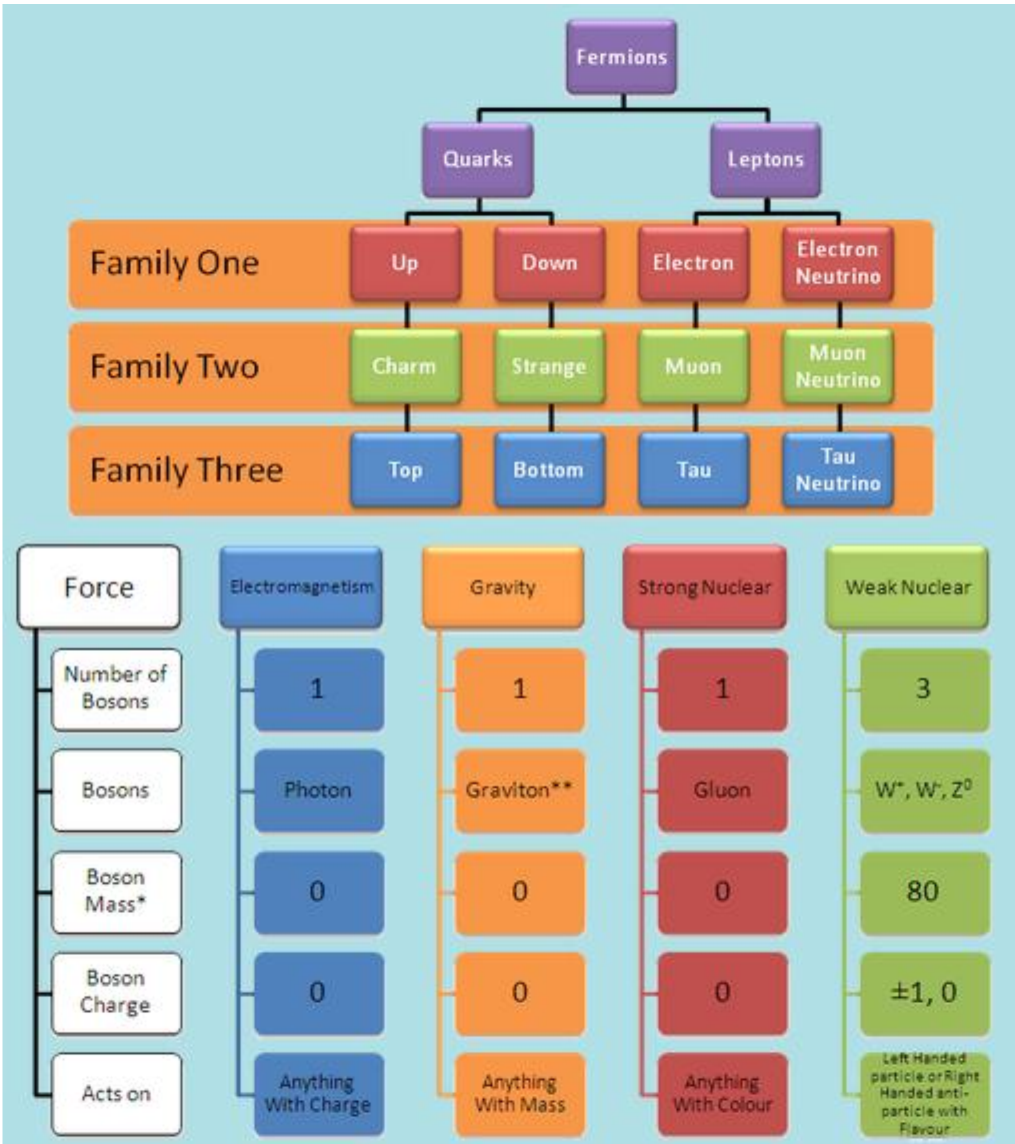
Colour is just a property that some particle posses, they aren't actually coloured. The main particles that have colour are the quarks. Any quark can have one of 3 colours, Red, Blue or Green while anti-quarks can be either Anti-Red, Anti-Blue or Anti-Green. Colour acts a bit like charges in that like colours repel unlike colours attract and colour anti-colour attract. The Strong Nuclear Force gets stronger with distance however is a very small ranged force only acting over a range of 10-15m

Only 3?

Recent work on the Electromagnetic and Weak Nuclear Forces have shown that at high enough energies the two forces are the same. Above the unification energy of about 100 GeV or 1015K(like at the Big Bang), they would merge into a single Electroweak force.

The Standard Model

I must preface that in the proper Standard Model there is no mention of the Graviton, however I have decided to add it in here to give a complete picture. Yes the theory may turn out to be wrong but in my opinion its better than leaving a gap, at least we know vaguely what we're aiming for. So here it is, every particle of matter, every fundamental force and carrier of said forces, even some that are thought to exist but haven't been found yet.



Most of the above should be quite easy to follow, however there are some bits that I'm still unsure on. How the Higgs Boson actually fits into the set of Bosons has never been explained to me, I know its meant to be the particle responsible for giving Fermions mass and thus I assume its got something to do with the Gravitational force, however I could be wrong. Also I have highlighted the weirdness of the Weak nuclear force on numerous occasions but have made no attempt to explain it. This is because I can't. I don't know why it seems to be the odd one out, maybe it isn't. In the Only 3 section I explained that it turns out to be just a low energy version of an Electroweak force and so maybe its ok for it not to match at low energies.

Source: http://www.physicsforidiots.com/particlesandforces.html