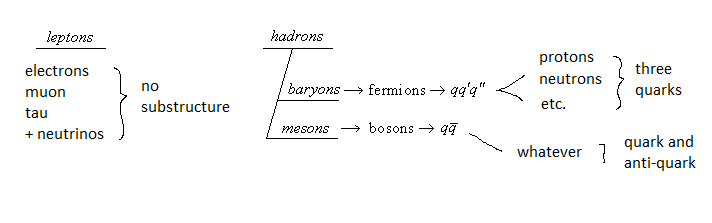
**Fundamental Forces and Particles**

Now let’s examine the fundamental forces and particles. There are two major types of particles: leptons and hadrons. All leptons have spin ½, and so are fermions. The hadrons themselves split into two subclasses: baryons and mesons. Baryons are fermions with spin ½, or 3/2 and Mesons are bosons with spin 0 or 1.



The leptons include the e-, and its anti-particle e+, the electron neutrino, νe, and its anti-particle, and similarly for the muon, μ, and the tau particle, τ. So all in all we have for the lepton family (note L is the lepton number of the particle). Note anti-lepton has anti lepton number.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Particle** | **Symbol** | **Anti-particle** | **Mass (MeV/c2)** | **Le** | **Lμ** | **Lτ** | **lifetime** |
| **Electron** | e- | e+ | 0.511 | 1 | 0 | 0 | stable |
| **Electron neutrino** | νe |  | 3×10-6 | 1 | 0 | 0 | stable |
| **Muon** | μ- | μ+ | 105.7 | 0 | 1 | 0 | 2.2μs |
| **Muon neutrino** | ν­μ |  | 0.19 | 0 | 1 | 0 | stable |
| **Tau** | τ- | τ+ | 1777 | 0 | 0 | 1 | 0.29 ps |
| **Tau neutrino** | ντ |  | 18.2 | 0 | 0 | 1 | stable |

And then we have hadrons, which include subclasses, baryons, and mesons. Baryons include the proton, neutron, and other so-called hyperons. Note anti-baryons have anti-baryon number. The meson family includes the pion, π, and other particles. There are over 250 known hadrons. Some are given below,

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Symbol** | **Mass** | **Charge** | **Spin** | **Isospin** | **Strangeness** | **lifetime** |
| **p** | 938 | 1 | 1/2 | 1/2 | 0 | stable |
| **n** | 939 | 0 | 1/2 | 1/2 | 0 | 886s |
| **π0** | 135 | 0 | 0 | 1 | 0 | 84 as. |

As for the fundamental forces. There is:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Force** | **Acts between** | **Mediated by** | **Conserved quantity** | **Range (m)** |
| Strong | Hadrons | π (meson) | Baryon number | 10-15 |
| Weak | Leptons | W,Z (meson) | lepton number | 10-18 |
| Electric | Charges | photon | charge | ∞ |
| Gravity | Masses | graviton | mass-energy | ∞ |

1. Strong force: It is mediated by the π meson. Note that the pion has a mass and this is what makes the strong force short ranged, and strongly exponentially damped past about 1fm (this is why nuclei are around this size). The strong force acts between hadrons, and as such (apparently?) this gives rise to the conservation of baryon number (a subset of hadrons). This is why the number of nucleons is always conserved in a nuclear reaction (or any other for that matter). Note how this is similar to conservation of charge by the electromagnetic force, and conservation of mass-energy in gravitational interactions. So might say that each fundamental force as a conserved quantity. The strong nuclear force saturates, which means that a given particle can only interact with a certain number of other particles simultaneously, not an infinite like the electric and gravitational forces. Also it favors pairing of protons and neutrons with opposite spins, and especially pairs of pairs, the simplest of which would be a He nucleus.
2. Weak force: It is mediated by the W, Z particles (which are super massive ~ GeV). And it seems to act between leptons roughly. It is responsible for the decay of leptons like μ into an e- and neutrino. Its also involved in the decay of some mesons into leptons. It is about 109 weaker than the strong force. The objects which exert this force, leptons, also obey a conservation law of lepton number (given in the first table).
3. Electromagnetic force: It is mediated by the photon. Note the photon has no mass, and therefore the EM force is long ranged. It is about 100 weaker than the strong force. The objects which feel the EM force are charged objects, and charge is a conserved quantity.
4. Gravitational force. It is supposedly mediated by the massless graviton, and is long ranged, just like the electric force. Note the conservation of mass law that we have – though this really turns into conservation of energy.

Note that the mass of the mediated particle is related to its range. By analogy recall in solid state physics how a mass gap produces an effective force exponentially decaying with a radius ~ mass-1. Massless excitations produce effective force of 1/r2 range (infinite radius). This is just like in fundamental physics. The graviton and photon are massless, resulting in an infinite effective range. Consider the nuclear force. If it exchanges a particle of mass m, then energy conservation will be violated by an amount ΔE = mc2. This can happen only for a time, Δt ~ ℏ/ΔE, and the furthest such a particle could go in this time is: R = cΔt = ℏc/mc2 = ℏ/mc. Thus the range of the force is limited by the mass of its mediator. This is why short range forces mediate large mass particles.

**Simplification of hadron structure**

Hadrons can be reduced to combinations of some of the 6 quarks. Particularly, mesons consist of a quark/anti-quark pair, and baryons of 3 quarks. This could be inferred on the basis of their spin properties alone. The quarks are given below,

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Particle** | **q/e** | **spin** | **baryon #** | **strangeness** | **charm** | **bottomness** | **topness** |
| **u** | 2/3 | ½ | 1/3 | 0 | 0 | 0 | 0 |
| **d** | -1/3 | ½ | 1/3 | 0 | 0 | 0 | 0 |
| **s** | -1/3 | ½ | 1/3 | -1 | 0 | 0 | 0 |
| **c** | 2/3 | ½ | 1/3 | 0 | 1 | 0 | 0 |
| **b** | -1/3 | ½ | 1/3 | 0 | 0 | 1 | 0 |
| **t** | 2/3 | ½ | 1/3 | 0 | 0 | 0 | 1 |

A proton is (uud), and a neutron is (udd).