Particle Organization

We are in a position now to try and be a bit more quantitative about particles and the nature of their interactions. We believe there are 4 fundamental forces (2 of which are kind of the same thing)

Gravity - all particles "feel" this and it is always attractive.

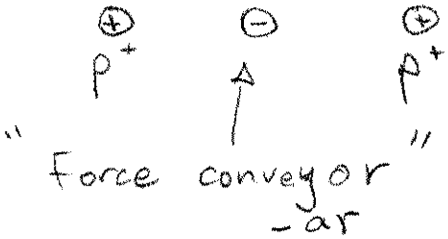
Electromagnetic - inverse square law
both attractive & repulsive
depends on charge

Strong - short ranged, but has a lower limit too
-so far restricted to protons and neutrons

(Electro) Weak - resposible for things like β decay

To get a feel for the last 2, it is necessary to think about force as an exchange of a quanta.

crazy? Think about the following



2 protons "sharing" an electron

& if you don't like this, can think of one p^+e^- as a dipole (not as important though)

potential $\propto \psi_e \sim \frac{e^{-ar}}{r}$

$a \propto m \qquad m=0$

$V \propto \frac{1}{r}$ like E & M

For things like the strong force, you replace the electron with a particle we mentioned last time, a pion, and you think of the pion as being emitted by one particle and absorbed by another. You can do this if you allow energy non-conservation for a short period of time. Long enough, say, for a pion to be emitted by a neutron and absorbed by a proton.

$n \Rightarrow p^+ \xrightarrow{\pi^-} p^+ \Rightarrow n$ < operational description

neutron "fluxuates" into a π^- & a p^+

the π^- is absorbed by the p & a neutron is created

} (and back again)

all occuring over a very short time scale

Length of strong force ~ 1.4×10^{-15} m

$$\Delta E \Delta t \sim \frac{h}{2\pi}$$

↑ identify with m of force carrier

$$c\Delta t = \text{Length} \approx \frac{hc}{mc^2\, 2\pi}$$

$$\text{or } mc^2 \sim \frac{1240 \text{ MeV fm}}{(2\pi)\, 1.4 \text{ fm}} = 141 \text{ MeV}$$

$$M(\pi) = 139.6 \text{ MeV}$$

in principle other particles could contribute but down be e^{-M} ish

Madness right? lets look at a bit of info

Force	Range	Strength $(\frac{1}{\alpha})$	time	
Gravity	∞	10^{-38}	years?	
EM	∞	$1/137$	10^{-16} s	annhiliation (neutral π^0 decays)
Weak	10^{-3} fm	10^{-7}	$10^{-8} \to 10^{-10}$ s	decays
strong	1 fm	1	10^{-23} s	widths of particle resonances

Using our same argument for the weak force

$$M_{weak} \sim 10^3 M_{strong} \sim 100\ GeV$$

$$\Rightarrow \text{Such a particle exists } \underset{80\,GeV/c^2}{W^\pm},\ \underset{91\,GeV/c^2}{Z^0}$$

Turns out there is a particle massive enough so that the $W^\pm$ is real & not virtual

The weak force is really thought to behave as the electromagnetic force, but with a massive force carrier ($M_\gamma = 0$). The strong force pion description though is more analagous to our 2 protons and an electron with a force carrier called a gluon (thought to be massless).

If you look @ the table in your book, integer spins are assigned to the force carriers, which suggests that we will be dealing with transitions between fermions again.

We described the lepton families last time

antiparticles

$$\begin{pmatrix} e^- \\ \nu_e \end{pmatrix} \quad \begin{pmatrix} \mu^- \\ \nu_\mu \end{pmatrix} \quad \begin{pmatrix} \tau^- \\ \nu_\tau \end{pmatrix} \quad \text{\&} \quad \begin{pmatrix} e^+ \\ \bar{\nu}_e \end{pmatrix} \begin{pmatrix} \mu^+ \\ \bar{\nu}_\mu \end{pmatrix} \begin{pmatrix} \tau^+ \\ \bar{\nu}_\tau \end{pmatrix}$$

170 GeV
(a <u>real</u> W)

the rest of matter can be described as being made up of spin $\frac{1}{2}$ particles with fractional charge, called quarks

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} \tau \\ b \end{pmatrix} \quad \begin{matrix} \text{Charge} \\ +\frac{2}{3} \\ -\frac{1}{3} \end{matrix}$$

so a proton is uud
& a neutron is ddu } particles with 3 quarks or 3 <u>quarks</u> called baryons

particles with $q\bar{q}$ are called mesons

π^+ $u\bar{d}$

π^0 $u\bar{u} + d\bar{d}$ it's own antiparticle

π^- $d\bar{u}$

<u>Question</u> how can you have uuu? (called an Ω particle) aren't there 3 fermions, at least 2 of which share same state?

$\Rightarrow$ extra degree of freedom in the quark model called color. Gluons exchange color. particles are color neutral. (Ask Med, he discovered the Ω!)