Chapter 14 - Elementary Particles

This chapter will qualitatively discuss the current ideas (Standard Model) of the fundamental particles and forces. (Chart of fundamental particles)

3 Families of leptons + quarks (with their antiparticles)

Leptons $e, \mu, \tau, \nu_e, \nu_\mu, \nu_\tau$] Spin ½ = Fermions
Quarks u, d, c, s, t, b

Force carriers

γ, W^+, W^-, Z^0, g spin 1] = Bosons
Graviton? spin 2

	Gravity	Weak	Electromagnetic	Strong
	graviton?	W^+, W^-, Z^0	γ	g
Book	$\sim 10^{-38}$	10^{-7}	10^{-2}	1
	∞	10^{-18} m	∞	10^{-15} m

Every particle has an antiparticle e^+, e^- (positron, electron)
$\bar{n}, n$ (anti neutron, neutron) $e^+ + e^- \rightarrow \gamma + \gamma$
The photon is its own antiparticle.

A particle and its antiparticle "should" have identical mass, exactly opposite charge and magnetic moment... (Chap 14 slide 1)

There is a huge mystery about antimatter. Where is it?
Standard Model doesn't predict that the universe is ~100% matter.

The physical size of fundamental particles ($e^-, \mu, \nu_e, \ldots$) have not been measured, only upper limits.
Composite particles have a size that depends on their fundamental particles and force holding them together atom ~ 10^{-10} m, nucleus ~ 10^{-14} m, nucleon/baryon/meson ~ 10^{-15} m

From the chart $M_{proton} = 938\ MeV/c^2$
$2M_u + M_d = 12\ MeV/c^2$] Why so different?

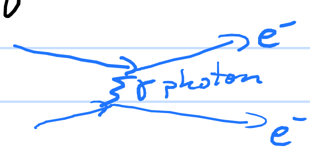
We currently think that the fundamental particles' mass comes from the Higgs mechanism → Higgs Boson. (Chap 14 slide 2)

Composite particles from quarks are baryons ($3q$) and mesons ($q\bar{q}$). Baryons have $S = 1/2$ or $3/2$. Mesons have $S = 0$ or 1. No stable Mesons. Only 1 stable Baryon.

Proton = uud (stable)
Neutron = udd (unstable) $n \rightarrow p + e^- + \bar{\nu}_e$ (see chart)
Neutron lifetime ~15 minutes 887.7 ± 2.2 sec or 878.5 ± 0.8 sec
Why no agreement? New physics?

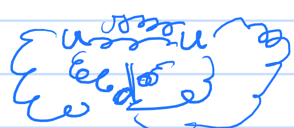
Pion $\pi^+ = u\bar{d}$

Fundamentally, interaction between particles arises from the exchange of a force carrier.

Two electrons 

Electric charge

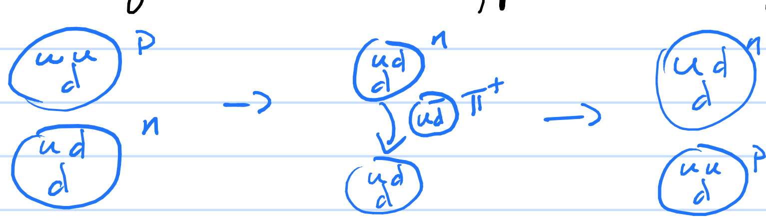
Relatively easy to calculate because relatively small force

Quarks 

Color charge

Hard to calculate because so strong. Need big computers and fancy technique. Lattice QCD (quantum chromodynamics)

The nuclear force can be approximated by the exchange of mesons

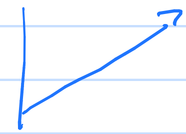


Quarks inside of baryons + mesons have been imaged by "deep inelastic" scattering. Particles with $\lambda < \sim 10^{-15} m$ needed.
Estimate energy for electron

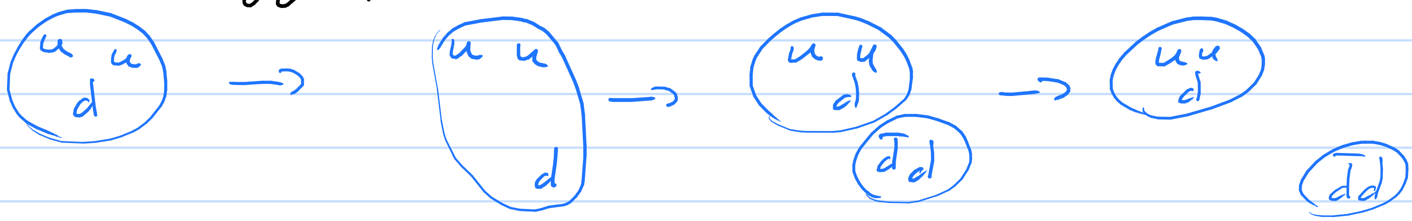
$p = h/10^{-15} m = 6.63 \times 10^{-19}\ kg\ m/s$ $\quad$ $p/m = 7.3 \times 10^{11}\ m/s$ relativistic

$E = pc = 2.0 \times 10^{-10}\ J = 1.2\ GeV$

Why no free quarks? Roughly $PE \propto r$



As 2 quarks separate it becomes less energy to make $q\bar{q}$ pair



Neutrino properties are uncertain. Are neutrinos their own antiparticle? Active research.
Neutrino mass? Until recently No! We now know they all have a mass but only upper limits on the value.

Neutrinos have a flavor $\quad \nu_e + {}^{37}_{17}Cl_{20} \rightarrow {}^{37}_{18}Ar^{+}_{19} + e^-$

$\nu_\mu + {}^{37}_{17}Cl_{20} \rightarrow {}^{37}_{18}Ar^{+}_{19} + \mu^-$

The flavor oscillates with time (the flavor label isn't an energy eigenstate).
Neutrinos from the sun was measured at ~ 1/3 the rate expected. Only ν_e detected. Only ν_e made in the sun. ~2/3 oscillate into other flavors. The other flavors aren't detected because $\nu_\mu + {}^{37}Cl \rightarrow {}^{37}Ar^{+} + \mu^-$ not energetically allowed.

Beyond the standard model? Quantum Gravity is not a thing.

Supersymmetry?

String Theory?