PHYS390 Lecture 10 - Elementary particles

What's important:
•classification according to interaction: hadrons, leptons, gauge bosons
•classification according to spin: fermions, bosons; baryons, mesons
•antiparticles
Text: PHYS 120 on-line, *From Quarks to Galaxies*

Lectures 10 and 11 are reviews of elementary particle properties, covered in PHYS 120. We introduce this material in preparation for cosmology and nucleosynthesis.

Interactions

Four fundamental interactions or forces govern the motion and decay of elementary particles:

- strong force - holds the nucleus together
- electromagnetic force - interaction between charges
- weak force - governs the decay of the neutron
- gravitational force - interaction between masses (more generally, states with energy).

A given particle may not necessarily be subject to all four interactions; for example, neutrinos experience only the weak and gravitational interactions.

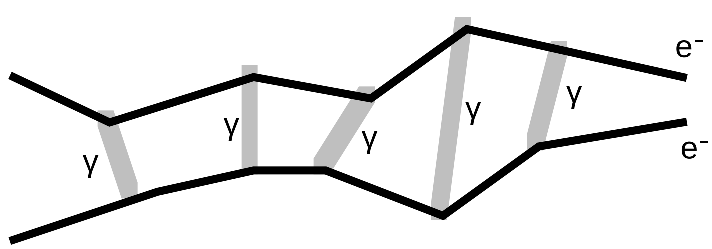
Particle characteristics

Bosons and fermions
Particles can be classified into two groups according to their spin quantum numbers:

J = 1/2, 3/2, 5/2, 7/2...... **fermions**
J = 0, 1, 2, 3, ... **bosons**.

where J is the spin quantum number. The spin angular momentum of a particle is $[J(J+1)]^{1/2}$ $(h/2\pi)$, where h is Planck's constant. In a group, no two fermions can have exactly the same quantum numbers; in contrast, two or more bosons are allowed to have the same quantum numbers.

Gauge bosons
Gauge bosons are a special group of particles that carry the fundamental interactions. For example, the interaction between two charged electrons is carried by the photon:



As the name implies, gauge bosons have spin J = 1, 2. A summary of the gauge bosons:

Symbol	Name	Interaction	Mass (kg)	J (spin)
g	gluon	strong	cannot be isolated	1
γ	photon	electromagnetic	$< 3.6 \times 10^{-52}$	1
W^+, W^-	W-boson	weak	$(1.43 \pm 0.007) \times 10^{-25}$	1
Z^o	Z-boson	weak	1.63×10^{-25}	1
	graviton	gravity	predicted to exist	2

Leptons and lepton number

- *leptons* are fermions and have no strong interactions
- leptons with non-zero mass are the electron, muon and tao, e, μ and τ, each of which has a distinct neutrino: ν_e, ν_μ and ν_τ.
- these leptons form three groups, each with their own ***lepton number***. For example, the lepton number associated with electrons is L_e:

  leptons: e^-, ν_e — $L_e = 1$
  hadrons, gauge bosons, other leptons: — $L_e = 0$.

Symbol	Mass (kg)	(proton mass)	J (spin)	L_e
ν_e	$< 5 \times 10^{-35}$		1/2	1
ν_μ	$< 3.4 \times 10^{-31}$		1/2	0
ν_τ	$< 3.2 \times 10^{-29}$		1/2	0
e^-	9.11×10^{-31}	~1/1800	1/2	1
μ^-	1.884×10^{-28}	~1/9	1/2	0
τ^-	3.18×10^{-27}	1.9	1/2	0

Hadrons

- *hadrons* are particles with strong interactions. Examples:

  p, n, π (pion, 1/7 of proton mass) — hadrons
  γ, e^-, ν — not hadrons
- hadronic bosons are called *mesons*. The pion (π) is a meson.
- hadronic fermions are called **baryons** and have a *baryon number* $|B| = 1$. All other particles have $B = 0$. Examples

  baryons: p, n — $B = 1$
  mesons, leptons, gauge bosons — $B = 0$.
- hadrons have many other characteristics such as strangeness, charm, beauty *etc*.

Examples of hadrons

Symbol	Mass (kg)	(proton mass)	*J*	Charge states	*B*
Mesons					
π^o	2.41×10^{-28}	1/7	0	o	0
π^+, π^-	2.49×10^{-28}	1/7	0	+, -	0
Baryons					
p, n	1.67×10^{-27}	1	1/2	+, o	1
Δ(1232)	2.20×10^{-27}	1.3	3/2	++, +, o, -	1

Antiparticles

Experimentally, there are many cases in which there are two particles with the same mass, but quantum numbers with opposite sign (in those situations where the quantum number can change sign). For example, both the electron and positron have the same mass but

electron = e^- $Q = -e$ $J = 1/2$ $L_e = 1$
positron = e^+ $Q = +e$ $J = 1/2$ $L_e = -1$.

These are said to be particle-antiparticle pairs. However, not all particles have distinct antiparticles. For example,

neutral pion = π^o $Q = 0$ $J = 0$ $L_e = 0$ $B = 0$
"anti-pion" $Q = 0$ $J = 0$ $L_e = 0$ $B = 0$

The anti-π^o and the π^o have the same quantum numbers and are indistinguishable.

Quarks and Gluons

Based upon scattering experiments, it is now commonly accepted that hadrons have constituents called *quarks*, whose strong interaction is mediated by *gluons*. No free quarks and gluons have been isolated in experiments. There are at least *six flavours* (or different types) of quarks:

Quark name	Quark symbol	*Q* (e)	*J*	*B*	L_e
up	*u*	+2/3	1/2	1/3	0
down	*d*	-1/3	1/2	1/3	0
strange	*s*	-1/3	1/2	1/3	0
charm	*c*	+2/3	1/2	1/3	0
bottom	*b*	-1/3	1/2	1/3	0
top	*t*	+2/3	1/2	1/3	0

While the absolute quark masses have not been determined, the relative masses appear to be ordered $u < d < s < c < b < t$. For example, the top quark has an apparent mass of approximately 190 proton masses, where the proton is made from *u* and *d*

quarks.
Note: Each of the *s*, *c*, *b* and *t* quarks carries a unique quantum number (strangeness, charm, beauty and truth respectively). The quarks have spin $J = 1/2$ and are therefore fermions.

The quark model for hadrons proposes that there are three quarks in a baryon and a quark/anti-quark pair in a meson. Some examples

p → (*uud*)
$Q = +2/3 + 2/3 + (-1/3) = +1$ $B = 1/3 + 1/3 + 1/3 = 1$
$L_e = 0 + 0 + 0 = 0$

π^+ → (*u*, anti-*d*)
$Q = +2/3 + 1/3 = +1$ $B = 1/3 + (-1/3) = 0$
$L_e = 0 + 0 = 0$

Each flavour of quark (*u*, *d*, *s*, *c*....) comes in three colours: red, green, and blue is the standard choice. In any given hadron, colour is exchanged among the quarks so that equal amounts of each colour are present. The colour is carried between the quarks by **gluons**, which are **eight** distinct neutral particles with $J = 1$.