Particle Physics

Quarks

Quarks

- 100's of hadrons (baryons and mesons) are known
- Classified in terms of their properties (mass, spin, parity, baryon number, strangeness, isospin ….)
- Development of a schematic classification scheme allowed one to predict the properties of particles
- (a Periodic Table for particles)
- Eventually showed that all hadrons can be constructed from fundamental, point-like particles called quarks (and anti-quarks)

Hadrons

- Particles having the same spin-parity (J^{π}) tend to have similar masses

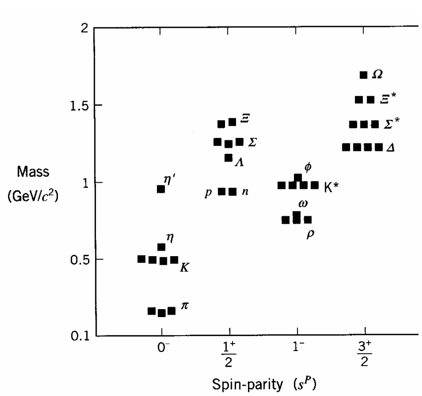
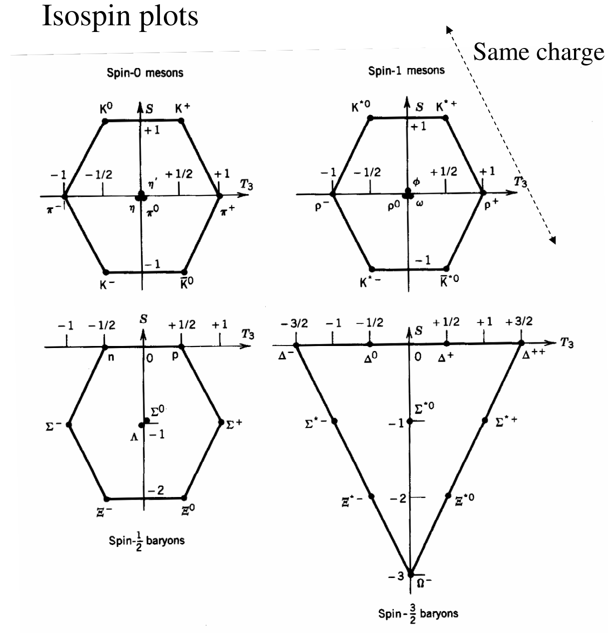


FIGURE 17-7 Classifying the hadrons by their mass, intrinsic angular momentum, and intrinsic parity.

Rohlf 17.7

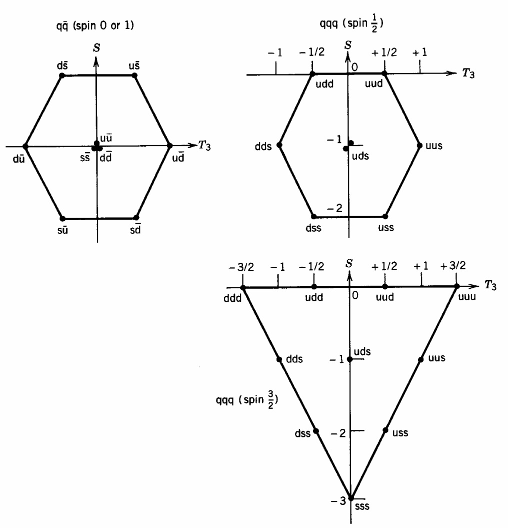
The Eightfold Way

- 1961: Gell-Mann, Ne'eman et al.
- Plot the known particles on Strangeness vs Isospin plots

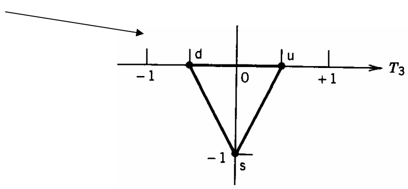


Krane 18.11

The Eightfold Way

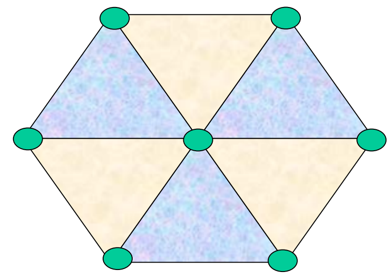


A building block ?



Krane 18.12 & 13

The Eightfold Way



Successful in predicting particles

Are quarks real or just nice maths ?

Quarks

- All quarks are spin-1/2 fermions
- Fractional charge $+\frac{2}{3}e \quad or \quad -\frac{1}{3}e$
- Baryon number = $+\frac{1}{3}$
- Intrinsic parity is +1
- Initially, 3 quark "flavours"

Flavour	Name	Charge (e)
u	Up	+2/3
d	Down	−1/3
s	Strange	– 1/3

Mesons

- A quark-antiquark pair $q\bar{q}$
- Mesons have B = 0. $\{+\frac{1}{3}-\frac{1}{3}=0\}$
- 9 bound states (mesons) from the 3 basic quarks:

$u\bar{u}$	$u\bar{d}$	$u\bar{s}$	$d\bar{u}$	$d\bar{d}$	$d\bar{s}$	$s\bar{u}$	$s\bar{d}$	$s\bar{s}$
η	π^+	K^+	π^-	π^0	K^0	K^-	$\bar{K}^0$	η'

- (The π^0, η, η' are in fact admixtures of $q\bar{q}$ pairs)
- "Pseudoscalar Mesons"

Mesons

- These 9 mesons form an Octet (8) and a Singlet (1 – the η′).
- Interchange quarks e.g.

$$d \leftrightarrow s \quad \& \quad \bar{d} \leftrightarrow \bar{s}$$

$$\eta' \Rightarrow (u\bar{u}, d\bar{d}, s\bar{s})$$

$$\eta' \to \eta'$$

Same particle

$$K^0 = d\,\bar{s} \quad \to \quad \bar{K}^0 = \bar{d}s$$

Different particles

Mesons

- Lowest energy state has the quark and anti-quark spins $\uparrow\downarrow$ with $l = 0$

$$\pi(\bar{q}) = -\pi(q)$$

fermions

$$\therefore \quad \pi(q\bar{q}) = \pi(q) \cdot \pi(\bar{q}) \cdot (-1)^l = -1$$

- The lowest energy state of a meson has

$$J^\pi = 0^-$$

- Excited energy state has the quark and anti-quark spins $\uparrow\uparrow$ with $l = 0$

$$J^\pi = 1^-$$

Baryons

- A quark triplet
- Baryons have B = +1. qqq
- Antiparticles have B = −1 $\bar{q}\,\bar{q}\,\bar{q}$

$$p = uud, \quad n = udd$$

$$\Lambda^0 = uds, \quad \bar{\Lambda}^0 = \bar{u}\,\bar{d}\,\bar{s}$$

Proton	u	u	d	uud
Q	+2/3	+2/3	−1/3	+1
Spin	+1/2	+1/2	+1/2	+1/2
B	1/3	1/3	1/3	+1
T	+1/2	+1/2	+1/2	+1/2
T_3	+1/2	+1/2	−1/2	+1/2

Baryons

- Lowest energy state has the quark spins $\uparrow\downarrow\uparrow$ with $l = 0$

$$\pi(\bar{q}) = -\pi(q)$$

fermions

$$\therefore \quad \pi(qqq) = \pi(q) = +1$$

$$\pi(\bar{q}\bar{q}\bar{q}) = \pi(\bar{q}) = -1$$

- The lowest energy state of a baryon has

$$J^\pi = \tfrac{1}{2}^+$$

- Excited energy state has the quark spins $\uparrow\uparrow\uparrow$ with $l = 0$

$$J^\pi = \tfrac{3}{2}^+$$

Colour

- 19** Discovery of the Ω^-
- Strangeness: $S = -3 \quad \Rightarrow \quad sss$
- Spin = 3/2 so $\uparrow\uparrow\uparrow$
- 3 ‘s’ quarks, in the same quantum state – violates Exclusion Principle.
- Introduce another property “Colour” or “Colour Charge”
- NOTHING to do with visual colour
- So, we have 3 quarks with the same ‘flavour’ i.e. ‘s’ but different ‘colours’.
- Red, Green & Blue so when they’re combined, the resulting baryon is White i.e. ‘Colour Neutral’.
- Mesons are also ‘Colour Neutral’ e.g. Red & Anti-Red

Charm

- 1974 Stanford and Brookhaven: Discovery of the J/ψ meson
- Cannot be constructed from the u, d, and s quarks and anti-quarks.
- Must be a fourth quark --- “Charm (c)”.

$$q = +\tfrac{2}{3}e$$

- Yet another introduced property, u, d and s quarks have charm = 0. The c quark has charm = +1

Bottom (“Beauty”)

- 1977 Fermilab: Discovery of the Υ
- Cannot be constructed from the u, d, s and c quarks and anti-quarks.
- Must be a fifth quark --- “Bottom (b) or Beauty”.

$$q = -\tfrac{1}{3}e$$

Top (“Truth”)

- Reason to suspect there are 3 families of quark pairs, just like the 3 generations of leptons
- 1997 Fermilab: Evidence for the top quark

$$q = +\tfrac{2}{3}e$$

Quarks

Flavour	Name	Charge (e)
u	Up	+2/3
d	Down	−1/3
s	Strange	−1/3
c	Charm	+2/3
b	Bottom	−1/3
t	Top	+2/3