Strong Interactions

The story so far:

- We have classified particles as fermions or bosons
- We have discussed general properties of interactions mediated by boson exchange. (Yukawa potential, propagators, Feynman diagrams, higher order corrections, conserved quantities.)
- We have looked at two forces in detail: Electromagnetism and Weak interactions.
- Today we will consider the Strong interaction.

Strong Interactions

The strong interaction binds the constituents of nucleons and other hadrons. Its properties can be summarised as follows:

- It acts only on quarks (or particles made of quarks).
- It is strong, overcoming the Coulomb repulsion in the nucleus.
- It binds quarks in only two configurations:
  - qqq for baryons ($\overline{qqq}$ for antibaryons)
  - $q\overline{q}$ for mesons
  - *never* qq or $qq\overline{q}$ etc.

The quarks in baryons can be described by a wavefunction with a spin and a spatial part.

However, it appears that the quarks violate the Pauli exclusion principle, in that the total wave function is symmetric under the interchange of two quarks.

Indeed, in some cases all three quarks have identical spin and orbital quantum numbers!

Example: the Δ^{++} baryon.

The Δ exists as Δ^{++}, Δ^{+}, Δ^{0}, Δ^{-}.

→ (It has an isospin of $^3/_2$ – see later).

It consists of 3 quarks, each with spin, *s*, ½, with no orbital angular momentum, *l*, and has a total (spin) angular momentum of $^3/_2$.

If we consider the Δ^{++}, it must have 3 identical u quarks, all with $j = ½$, $j_z = ½$, $l = 0$.

i.e. 3 identical fermions in the same state – same wave function, same quantum numbers.

→ This violates the Pauli exclusion principle!

Explanation – the quarks also carry an additional quantum number, which is <u>different</u> for all three quarks in a baryon.

This quantum number also corresponds to the source or "charge" of the strong interaction.

The fact that the sum of three equivalent but different "strong charges" are required to produce a neutral state has led to this charge being known as <u>colour</u>, in analogy with the addition of three primary colours, red, green and blue, making white light.

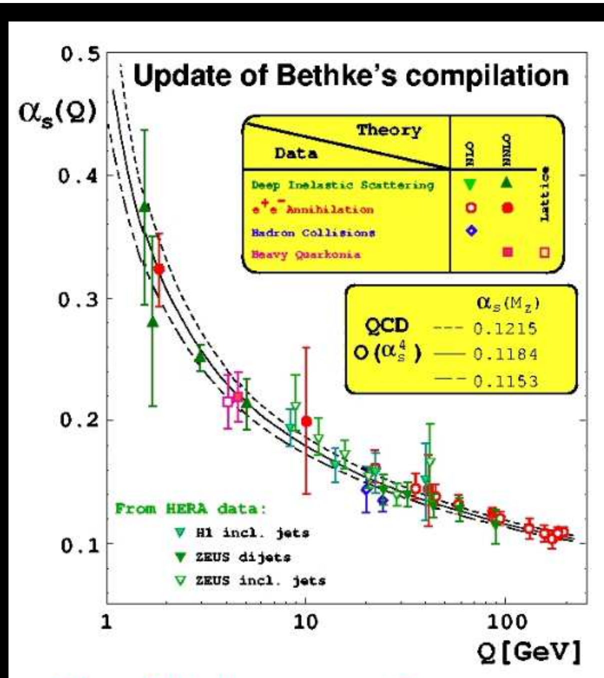
→ Each quark is labelled as red, green or blue, while antiquarks carry the equivalent "anticolours".

All hadrons, whether qqq or $q\bar{q}$, are therefore seen to be colour-neutral states.

→ The strong interaction is a gauge interaction mediated by a massless, spin 1 <u>gluon</u>, g, which is electrically neutral but carries a composite colour such as red-$\overline{\text{blue}}$.

→ The coupling constant is known as α_s (alpha-strong) and the theory is known as Quantum Chromodynamics or QCD in analogy with QED.

→ Note that, unlike in QED, the exchange quantum is also a source, so processes such as the branching of one gluon into two can occur. (The theory is said to be <u>non-Abelian</u>.)



The change in α_S as a function of *Q*. (Note the log scale.)

<u>The final point to note about the strong interaction is its strength!</u>

→ At small momentum transfer (or large distance) $\alpha_s \approx 1$.

At shorter distances, or large *q*, the value of $\alpha_s(q)$ decreases (enabling perturbation calculations to be done).

The origin of this variation with distance is the non-Abelian nature of the interaction.

At short distances, the gluon appears dissociated into a colour cloud, and the strength of the colour charge is diluted.

The strength explains why free quarks are never observed.

At large distances, the force becomes extremely strong and the quarks are said to be <u>confined</u>.

If a quark is ejected from a hadron, the colour field builds up until it becomes energetically favourable to create a quark-antiquark pair and reduce the field.

The new q and $\bar{q}$ are attracted to the original particles, and produce a colourless meson and baryon.

When many pairs are produced, this results in a jet of particles following the original quark direction.

These can be observed both in inelastic scattering of a lepton from a hadron (where the struck quark in the hadron is ejected) and in e^+e^- annihilation, where a $q\bar{q}$ pair is produced.

The Standard Model of Particle Physics

Fermions

Leptons		Quarks	
e	ν_e	d	u
μ	ν_μ	s	c
τ	ν_τ	b	t

Bosons

γ

$W^\pm$, Z^0

g

H^0

What you should have learned

- Combinations of quarks in baryons and mesons
- Apparent violation of Pauli's Exclusion Principle
  - resolved by introducing 3 colours, r g b
  - only colourless particles (hadrons) allowed
- Increasing strength of interaction with distance
- Confinement
- Jets of colourless particles
  - Deep inelastic scattering
  - $e^+ e^-$ annihilation

Reading for next topic from "Ideas of Particle Physics":

- *Chapter 7 – Mesons (already listed)*
- *Chapter 8 – Strange Particles*
- *Ch. 35.3–35.5 & 36* – Quarks, charm & beauty.*

(above are in 3rd edition! Chapters 36.3–36.5 & 37 in 2nd edition)*