Lecture 3: Antiparticles and Colour

Antiparticles

Every elementary particle type has a related anti-particle type. They have exactly the same mass but opposite electric charge and flavour.

Colour

All quarks carry a 'colour': red, gree, or blue. Anti-quarks carry anti-colour. Not the same as optical colour, but is analogous. Colour is the source of the strong interaction.

Composites of Quarks - Baryons and Mesons

There is a composition law or principle for quarks which states that any composite hadron must be colourless. There are two ways to achieve this:

1. Three quarks of any flavour, each of different colour - as in light: red + green + blue = white. Called a baryon. (e.g. proton, neutron)
2. A quark and an antiquark of any flavour but of equal and opposite colour. $\pi^+ = u\bar{d}$, $K^0 = d\bar{s}$. Called mesons.

This composition principle has got a name: **confinement**. The origin of this name is that colour is confined inside hadrons $\rightarrow$ quarks themselves are also **confined** inside hadrons. They are elementary particles, but cannot exist as free particles. Colour can be passed from quark to quark. Particle-antiparticle pairs can be produced from the vacuum by the conversion of energy into mass. Most baryons and mesons carry flavour but not colour. Quarks heavier than u and d are unstable and decay, usually into lighter quarks.

Neutrinos

Some nuclei are unstable, having too many neutrons. A neutron, under these circumstances, can transform itself into a proton. A d quark changes into a u quark and emits an electron and a light neutral particle called an antineutrino. This is beta decay.

[Image here]

$$n \rightarrow p + e + \bar{\nu_e}$$
$$d \rightarrow u + e + \bar{\nu_e}$$

(A neutron does not 'contain' p, e, $\bar{\nu_e}$.)

When first discovered, these electrons were named β-particles before being identified as electrons.

e and ν_e are examples of leptons (meaning 'light ones').

N. B. $\bar{\nu_e}$ was inferred because in β-decay the electron has a continuous spectrum (a frequency distribution of energy).

[Image here]

Without the $\bar{\nu_e}$, the final state, having only two particles, would show instead a single electron energy due to energy-momentum conservation.

[Image here]

With three particles in the final state, the continuous distribution is explained.

Leptonic Periodic Table and Lepton Flavour

In 1987, a heavy copy of the electron was discovered. It had all the properties of the electron, except that it was about 200 times heavier. It was named the muon.

$$m_\mu = 0.105 \frac{\text{GeV}}{c^2}$$

The muon is unstable, decaying with a lifetime of $\approx 2 \times 10^{-6}$s (to one electron and two neutrinos).

In 1962, the muon neutrino, ν_μ, was discovered - shown to be distinct from ν_e.

In 1976, the tau lepton (τ) was discovered, an even heavier copy of the electron, and in 2000, the tau neutrino was discovered, ν_τ.

The masses of the neutrinos are small ($< 1\frac{\text{eV}}{c^2}$) but not zero.

Leptons have no colour, and do not bind together as quarks do. They do not 'feel' the strong force and do not interact with gluons.

Lepton Number

There are three types of lepton number carried by leptons: electron number, muon number, and tauon number. These were thought to be conserved in all processes.