7.3a The Structure of Matter

Understanding

- Quarks, leptons, and their antiparticles
- Hadrons, baryons, and mesons
- The conservation laws of charge, baryon number, lepton number, and strangeness
- The nature and range of the strong nuclear force, weak nuclear force, and electromagnetic force
- Exchange particles
- Feynman diagrams
- Confinement
- The Higgs boson

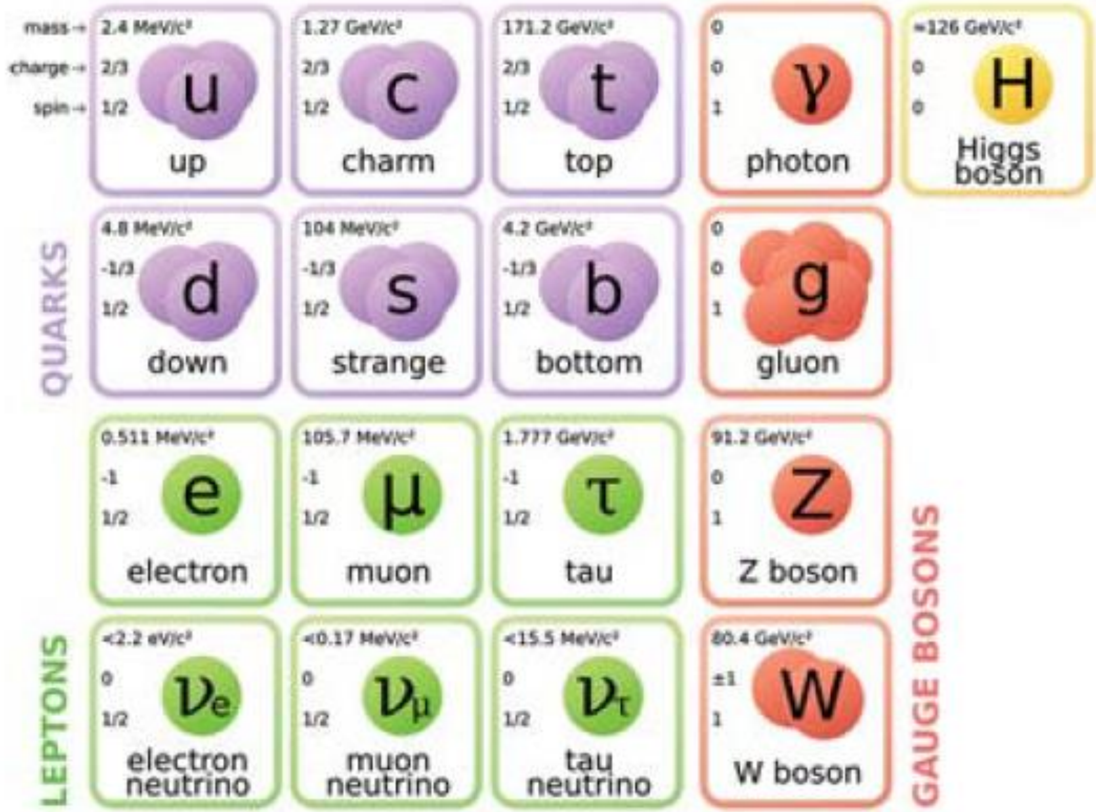
Applications and skills

- Describing the Rutherford–Geiger–Marsden experiment that led to the discovery of the nucleus
- Applying conservation laws in particle reactions
- Describing protons and neutrons in terms of quarks
- Comparing the interaction strengths of the fundamental forces, including gravity
- Describing the mediation of the fundamental forces through exchange particles
- Sketching and interpreting simple Feynman diagrams
- Describing why free quarks are not observed

Rutherford-Geiger-Marsden

- Read what you wrote in your notes about their experiment and be prepared to describe it.

Standard Model



▲ Figure 19 The Standard Model including the Higgs boson.

Leptons

Leptons				Charge/e	Lepton number (L)
Particle	e	μ	τ	-1	$+1$
Antiparticles	$\bar{e}$	$\bar{\mu}$	$\bar{\tau}$	$+1$	-1
Neutrinos	ν_e	ν_μ	ν_τ	0	$+1$
Antineutrinos	$\bar{\nu}_e$	$\bar{\nu}_\mu$	$\bar{\nu}_\tau$	0	-1

Charge	Leptons		
–1	e	μ	τ
0	ν_e	ν_μ	ν_τ
All leptons have a lepton number of 1 and antileptons have a lepton number of –1			

Quarks

Quarks with charge $+\frac{2}{3}e$	Quarks with charge $-\frac{1}{3}e$
u	d
c	s
t	b

Antiquarks carry the opposite charge and are denoted by $\overline{u}$, $\overline{d}$, $\overline{c}$, etc.

Charge	Quarks			Baryon number
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$
All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1				

Quark Confinement

- Quarks don’t exist on their own
- Explained by quantum chromodynamics (QCD)
- When the energy required to separate quarks is fed into the system, new quarks are produced (and the old ones aren’t separated)

Hadrons

- Composed of quarks
- 2 types
  - Baryons
  - Mesons

Baryons

- Made up of 3 quarks
- Protons and neutrons are examples
  - Proton (uud)
  - Neutron (ddu)

Mesons

- Made up of quark-antiquark pair
- Positive pion, π^+ $(u\bar{d})$

Conservation Rules

- Charge (Q) is conserved
- Baryon number (B) is conserved
- Lepton number (L) is conserved
- Strangeness
  - Strangeness is not conserved when strange particles decay through the weak interaction
  - Strangeness is conserved when there is a strong interaction (when strange particles are created)

Show that, when a proton collides with a negative pion ($\bar{u}d$), the collision products can be a neutron and an uncharged pion.

The equation for the interaction is

$p + \pi^- \rightarrow n + \pi^0$

Q: $+1 - 1 \rightarrow 0 + 0$ ✓

B: $+1 + 0 \rightarrow +1 + 0$ ✓

L: $0 + 0 \rightarrow 0 + 0$ ✓

This interaction is possible on the basis of conservation of charge, baryon number and lepton number.

Deduce the quark composition of the uncharged pion.

Writing the equation in terms of quarks:

$$uud + \bar{u}d \rightarrow ddu + ??$$

$?? = u\bar{u}$ in order to balance this equation.

This suggests that the neutral pion is very short lived – since the combination $u\bar{u}$ would mutually annihilate. In fact this particle has a lifetime of about 8×10^{-17} s and annihilates to form two gamma ray photons or, very occasionally, a gamma ray photon, an electron and a positron.

Explain whether a collision between two protons could produce two protons and a neutron.

Writing the equation for the baryons:

$$p + p \rightarrow p + p + n$$

$$\mathbf{Q}: +1 + 1 \rightarrow +1 + 1 + 0 \quad ✓$$

$$\mathbf{L}: 0 + 0 \rightarrow 0 + 0 + 0 \quad ✓$$

$$\mathbf{B}: +1 + 1 \rightarrow +1 + 1 + 1 \quad ✗$$

So this interaction fails on the basis of baryon number.