11.2 Fundamental particles

Name: ______________ Class: __________ Date: ____________ **Total: 27 marks**

KEY WORDS quark 夸克 • fundamental 基本粒子 • hadrons 强子 • baryons 重子 • mesons 介子

Objective

Build the skills to answer exam questions on **fundamental particles** — quarks, hadrons, antiparticles, and quark changes in β-decay.

You must be able to:

- recall the six **quark** flavours and their charges, and classify **hadrons** (baryons/mesons)
- give the **quark composition** of protons, neutrons and their **antiparticles**
- describe quark changes in β^- and β^+ decay; classify particles as **leptons**

1 Worked examples

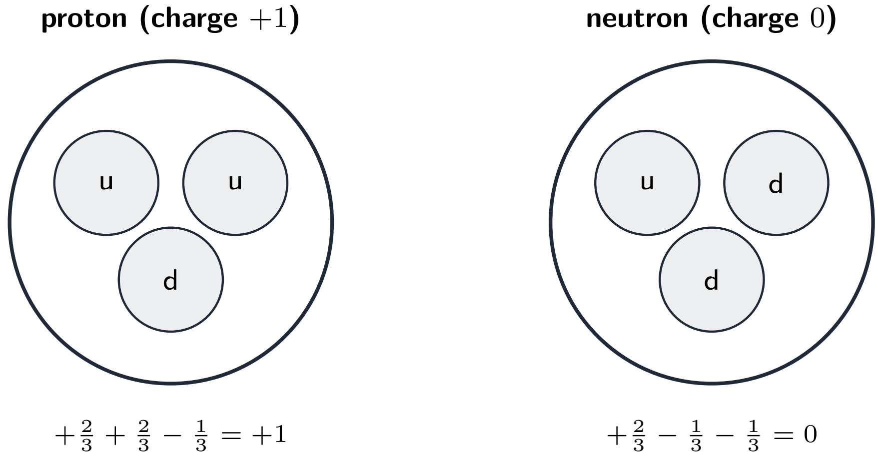
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

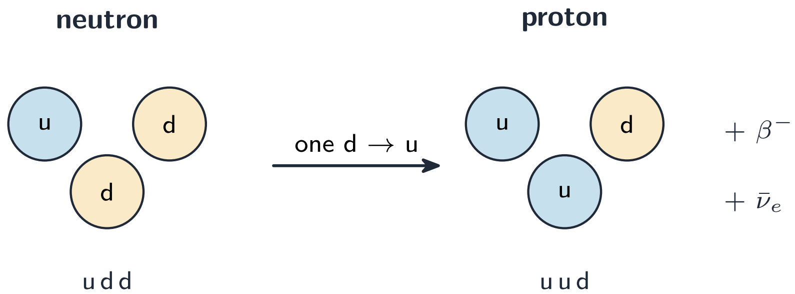
Quarks

A **quark** is a fundamental particle. Six flavours: **up, charm, top** (charge $+\frac{2}{3}e$) and **down, strange, bottom** (charge $-\frac{1}{3}e$). Each **antiquark** has the **opposite** charge ($\bar{\mathrm{u}} = -\frac{2}{3}e$, $\bar{\mathrm{d}} = +\frac{1}{3}e$).

Hadrons

Particles made of quarks are **hadrons**: a **baryon** = 3 quarks; a **meson** = 1 quark + 1 antiquark. Protons and neutrons are **baryons** (not fundamental):





Beta decay changes a quark and the nucleus

■ Antiparticles

Every particle has an **antiparticle** with the **same mass** but **opposite charge**. The **positron** is the antiparticle of the electron (charge $+e$, and like the electron it is a **lepton**). An **antiproton** is made of the **antiquarks** of a proton: $\bar{\mathrm{u}}\bar{\mathrm{u}}\bar{\mathrm{d}}$, charge $-\frac{2}{3}-\frac{2}{3}+\frac{1}{3}=-1$ (i.e. $-e$).

■ β-decay in quarks and leptons

- β^- decay: a **down** quark $\rightarrow$ **up** quark, so a neutron becomes a proton: $\mathrm{d} \rightarrow \mathrm{u}+\beta^-+\bar{\nu}_e$.
- β^+ decay: an **up** quark $\rightarrow$ **down** quark, so a proton becomes a neutron: $\mathrm{u} \rightarrow \mathrm{d}+\beta^++\nu_e$. In nuclear form, e.g. ${}^{12}_{7}\mathrm{N} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{0}_{+1}\beta + {}^{0}_{0}\nu$.

Electrons, positrons and neutrinos are fundamental particles called **leptons**.

2 Practice

Now apply the methods above.

2.1 State what a **quark** is, and name **two** flavours. [2]

2.2 State the charge of an **up** quark and a **down** quark. [2]

2.3 State the **quark composition** of a proton and of a neutron. [2]

2.4 State the charge of a **positron** and the class of fundamental particle it belongs to. [2]

3 Exam-style questions

3.1 A **baryon** consists of: [1]

- **A** two quarks
- **B** three quarks
- **C** one quark and one antiquark
- **D** one quark

3.2 Show that the quark composition **u u d** gives a total charge of +1. [2]

3.3 An **antiproton** is the antiparticle of a proton.

(a) State the **quark composition** of an antiproton. [1]

(b) Show that its total charge is $-e$. [2]

3.4 Describe the change in **quark composition** during β^- decay, and name the lepton emitted. [3]

3.5 A meson Q and a nucleus of radium-228 are studied in a particle laboratory. The unified atomic mass unit is 1.66×10^{-27} kg.

(a) **State** what is meant by a **fundamental particle**. [1]

(b) Q is a meson with a charge of zero. **Determine** one possible quark composition for Q, and explain why your answer gives zero charge. [2]

(c) Q has a mass of 0.67 u and a kinetic energy of 2.1×10^{-16} J. **Calculate** its speed. [3]

(d) **State** the number of electrons in a neutral atom of radium-228, $^{228}_{88}\text{Ra}$. [1]

(e) A radium-228 nucleus decays in a series of steps to a nucleus X, emitting **5** α-particles and **4** β^- particles in total. **Determine** the number of protons and the number of neutrons in X. [3]

Solutions

2.1 A **fundamental particle** (with no smaller parts); any two flavours of: up, down, charm, strange, top, bottom.

2.2 up $= +\frac{2}{3}e$; down $= -\frac{1}{3}e$.

2.3 proton = **u u d**; neutron = **u d d**.

2.4 charge $= +e$; it is a **lepton**.

3.1 **B** — three quarks.

3.2 $+\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = \frac{4}{3} - \frac{1}{3} = +1$.

3.3 (a) $\bar{\mathrm{u}}\,\bar{\mathrm{u}}\,\bar{\mathrm{d}}$ (the antiquarks of u u d).

3.3 (b) $\bar{\mathrm{u}} = -\frac{2}{3}e$ and $\bar{\mathrm{d}} = +\frac{1}{3}e$; total $= -\frac{2}{3} - \frac{2}{3} + \frac{1}{3} = -1$, i.e. $-e$.

3.4 A **down** quark changes into an **up** quark, so u d d (neutron) becomes u u d (proton); an **electron** (the β^- particle), together with an antineutrino, is emitted.

3.5 (a) A particle that **cannot be subdivided** into anything smaller.
(b) A meson is a **quark and an antiquark**; any pair such as $\mathrm{u}\bar{\mathrm{u}}$ $(+\frac{2}{3}e - \frac{2}{3}e = 0)$ or $\mathrm{d}\bar{\mathrm{d}}$ $(-\frac{1}{3}e + \frac{1}{3}e = 0)$ gives zero charge, because the antiquark carries exactly the opposite charge to the quark.
(c) $E_\mathrm{K} = \frac{1}{2}mv^2$ with $m = 0.67 \times 1.66 \times 10^{-27} = 1.11 \times 10^{-27}$ kg; $2.1 \times 10^{-16} = \frac{1}{2}(1.11 \times 10^{-27})v^2$; $v = 6.1 \times 10^5$ m s^{-1}.
(d) 88 — a neutral atom has as many electrons as protons.
(e) Each α removes 2 protons and 2 neutrons; each β^- turns a neutron into a proton, so it adds a proton and removes a neutron. Protons: $88 - (5 \times 2) + 4 = 82$. Nucleons: $228 - (5 \times 4) = 208$, so neutrons $= 208 - 82 = 126$.