

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.

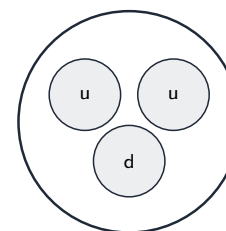
■ Quarks

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 ($\bar{u} = -\frac{2}{3}e$, $\bar{d} = +\frac{1}{3}e$).

■ Hadrons

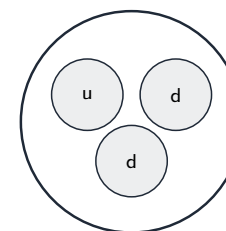
Particles made of quarks are **hadrons**: a **baryon** = 3 quarks; a **meson** = 1 quark + 1 antiquark. Protons and neutrons are **baryons** (not fundamental):

proton (charge +1)



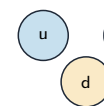
$$+\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$$

neutron (charge 0)



$$+\frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$$

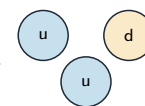
neutron



u d d

one d $\rightarrow$ u

proton



u u d

 $+\beta^-$ $+\bar{\nu}_e$

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: $\bar{u}\bar{u}\bar{d}$, 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: $d \rightarrow u + \beta^- + \bar{\nu}_e$.
- β^+ decay: an **up** quark $\rightarrow$ **down** quark, so a proton becomes a neutron: $u \rightarrow d + \beta^+ + \nu_e$. In nuclear form, e.g. ${}^{12}_7\text{N} \rightarrow {}^{12}_6\text{C} + {}^0_{+1}\beta + {}^0_0\nu$.

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 | B |
| C | D |
- 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]