A-LEVEL PHYSICS • EXERCISE SHEET

11.2 Fundamental particles

Name: _____ Class: _____ Date: _____ **Total: 16 marks**

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.

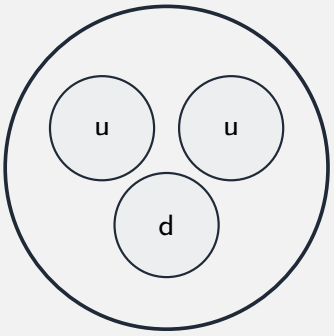
Quarks

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

Hadrons

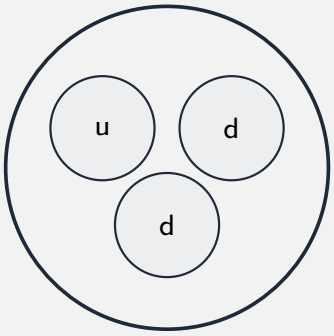
Particles made of quarks are **hadrons**: a **baryon** = 3 quarks; a **meson** = 1 quark + 1 antiquark. Protons and neutrons are **baryons** (not fundamental):

proton (charge +1)

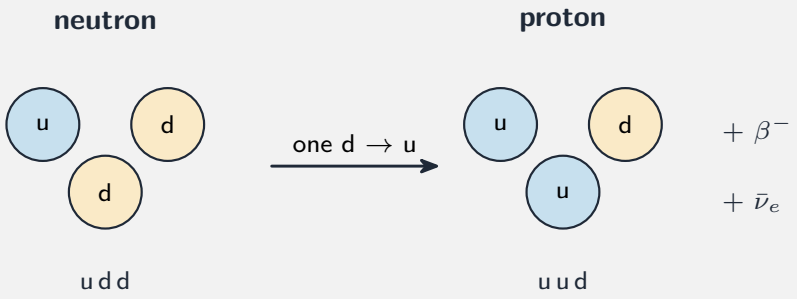


$+\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$

neutron (charge 0)



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



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: $\mathrm{d} \rightarrow \mathrm{u} + \beta^- + \bar{\nu}_e$.
- 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]

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4 Go further

You are now ready for the real exam questions on this subtopic. Open the **11.2 Fundamental particles** past-paper sheet in the Library, or try these in **Practice mode**:

- 9702/21 J25 —Q7 (antiparticles and antiquarks)
- 9702/23 J25 —Q8 (quark composition, calculation)
- 9702/21 N25 —Q6 (β decay and quark change)

- 9702/11 J25 —Q38 (quarks, multiple choice)
- 9702/12 J25 —Q40 (fundamental particles, multiple choice)

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) $\bar{\text{u}}\,\bar{\text{u}}\,\bar{\text{d}}$ (the antiquarks of u u d).

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