A-LEVEL PHYSICS • EXERCISE SHEET

11.1 Atoms, nuclei and radiation

Name: ______________ Class: __________ Date: ____________ **Total: 18 marks**

KEY WORDS nucleus 原子核 • proton 质子 • isotope 同位素 • nuclide 核素 • neutron 中子

Objective

Build the skills to answer exam questions on **atoms, nuclei and radiation** — the nuclear model, nuclide notation, decay equations, and conservation.

You must be able to:

- describe the **nuclear atom** and the α-scattering evidence
- use ${}^{A}_{Z}\mathrm{X}$ notation; find protons, neutrons and electrons
- complete α and β **decay equations** (including the (anti)neutrino)
- apply **conservation** (charge, nucleon number, momentum) to a decay

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.

■ The nuclear atom

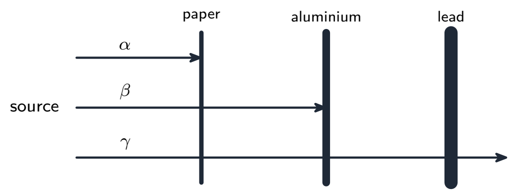
α-scattering showed the atom is **mostly empty space** (most pass straight through) with a **tiny, dense, positive nucleus** (rare large deflections). The atom has **protons** ($+e$) and **neutrons** (0) in the nucleus, with **electrons** ($-e$) around it.

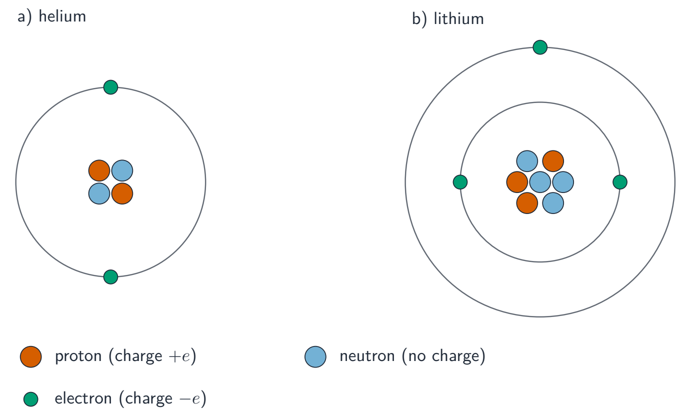
■ Notation and counting

${}^{A}_{Z}\mathrm{X}$: Z = **proton number** (fixes the element), A = **nucleon number** (protons + neutrons). For a nuclide: **protons** = Z, **neutrons** = $A-Z$, and a **neutral atom** has **electrons** = Z. **Isotopes** are the same element (Z) with different neutron numbers.

Worked example. Tritium ${}^{3}_{1}\mathrm{H}$: protons = 1, neutrons = 3 − 1 = 2, electrons (neutral) = 1.

■ Radiation





The nuclear model of the atom

	composition	charge	mass (u)
α	2 protons + 2 neutrons	$+2e$	4
β^-	an electron	$-e$	≈ 0
γ	EM photon	0	0

α has **discrete** energies; β has a **continuous** range (an (anti)neutrino shares the energy).

■ Decay equations

Balance the top numbers (A) and the bottom numbers (Z) on each side.

- α decay: ${}^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$.
- β^- decay (a neutron → proton): ${}^{3}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$. The **antineutrino** $\bar{\nu}$ carries away 0 charge and 0 nucleon number, so it does not change the balance.

■ Conservation and recoil

In any decay, **charge** (proton number), **nucleon number**, **(linear) momentum** and **mass–energy** are all conserved. If a **stationary** nucleus decays, the two products fly apart with **equal and opposite momentum**:

Worked example. A stationary nucleus emits an α-particle (mass 4 u) at 1.5×10^7 m s^{-1}; the daughter nucleus has mass 234 u. Momentum: $m_\alpha v_\alpha = m_R v_R$, so $v_R = \dfrac{4 \times 1.5 \times 10^7}{234} = 2.6 \times 10^5$ m s^{-1}.

2 Practice

Now apply the methods above.

2.1 State **two** conclusions Rutherford drew from the α-scattering experiment. [2]

2.2 For $^{14}_{6}$C, state the number of **protons**, **neutrons** and **electrons** (neutral atom). [2]

2.3 Define **isotopes**. [1]

2.4 Complete the β^- decay: $^{14}_{6}\mathrm{C} \rightarrow \quad \mathrm{N} + {}^{0}_{-1}\beta + ?$ — give the missing nuclide numbers and name the last particle. [2]

3 Exam-style questions

3.1 Which radiation is stopped by a sheet of **paper**? [1]

- **A** α
- **B** β
- **C** γ
- **D** X-rays

3.2 A stationary nucleus decays into a nucleus R and an α-particle.

(a) State **three** quantities that are conserved during the decay. [2]

(b) The α-particle (mass 4 u) leaves at 1.6×10^7 m s^{-1}; nucleus R has mass 222 u. Calculate the **speed** of R. [3]

3.3 Explain why β-particles are emitted with a **continuous range** of energies. [2]

3.4 State the **charge** and the **mass** (in u) of α, β^- and γ radiation. [3]

Solutions

Each answer shows the steps, then the **result**.

2.1

- any two: the atom is **mostly empty space**; there is a **tiny, dense nucleus**; the nucleus is **positively charged**; most of the atom's **mass** is in the nucleus

2.2

- protons $= Z = 6$; electrons (neutral atom) $= Z = 6$
- neutrons $= A - Z = 14 - 6 = \mathbf{8}$

2.3

- atoms of the **same element** (same proton number) with **different numbers of neutrons**

2.4

- nucleon number A and proton number Z both balance

$$^{14}_{6}\mathrm{C} \rightarrow \,^{14}_{7}\mathrm{N} + \,^{0}_{-1}\beta + \,^{0}_{0}\bar{\nu}$$

- the last particle is an (electron) **antineutrino**

3.1 A

- an α particle is a helium nucleus: massive and doubly charged, so it ionises heavily, loses energy fast and stops in a sheet of paper
- **B** β needs a few millimetres of aluminium; **C** γ and **D** X-rays need centimetres of lead. Heavier and more charged means *less* penetrating

3.2

(a) any three: **charge** (proton number), **nucleon number**, **(linear) momentum**, **mass–energy**

(b) the parent was stationary, so momentum is conserved: $m_\alpha v_\alpha = m_R v_R$

$$v_R = \frac{m_\alpha v_\alpha}{m_R} = \frac{(4\ \mathrm{u})(1.6 \times 10^{7}\ \mathrm{m\ s^{-1}})}{222\ \mathrm{u}} = \mathbf{2.9 \times 10^{5}}\ \mathbf{m\ s^{-1}}$$

3.3

- a β-decay also emits an (anti)**neutrino**
- the (anti)neutrino **shares** the released energy with the β-particle in varying proportions, so the β energy varies

3.4

- α: charge $+2e$, mass 4 u
- β^-: charge $-e$, mass ≈ 0 (1/1836 u)
- γ: charge 0, mass 0