

11.1 Atoms, nuclei and radiation

Name: _____ Class: _____ Date: _____

Total: 16 marks

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_ZX 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

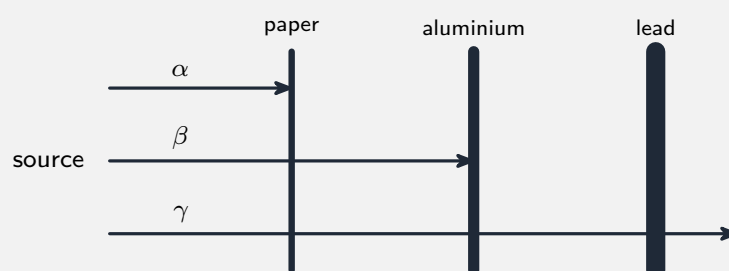
α -scattering showed the atom is **mostly empty space** (most pass straight through) with a **tiny, dense, positive nucleus** (rare large deflections). The atom has **protons** (+ e) and **neutrons** (0) in the nucleus, with **electrons** ($-e$) around it.

■ Notation and counting

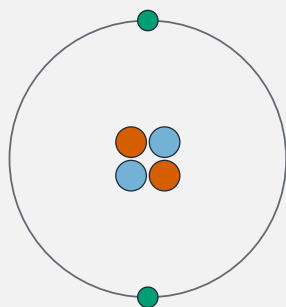
A_ZX : Z = **proton number** (fixes the element), A = **nucleon number** (protons + neutrons). For a nuclide: **protons** = Z , **neutrons** = $A - Z$, and a **neutral atom** has **electrons** = Z . **Isotopes** are the same element (Z) with different neutron numbers.

Worked example. Tritium ${}^3_1\text{H}$: protons = 1, neutrons = $3 - 1 = 2$, electrons (neutral) = 1.

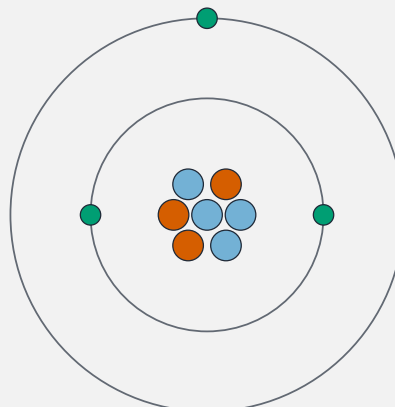
■ Radiation



a) helium



b) lithium



● proton (charge $+e$)

● neutron (no charge)

● electron (charge $-e$)

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: ${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^4_2\alpha$.
- β^- decay (a neutron $\rightarrow$ proton): ${}^3_1\text{H} \rightarrow {}^3_2\text{He} + {}^0_{-1}\beta + {}^0_0\bar{\nu}$. 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 $1.5 \times 10^7 \text{ m s}^{-1}$; the daughter nucleus has mass 234 u. Momentum: $m_\alpha v_\alpha = m_R v_R$, so $v_R = \frac{4 \times 1.5 \times 10^7}{234} = 2.6 \times 10^5 \text{ m s}^{-1}$.

2 Practice

Now apply the methods above.

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

2.2 For ${}^{14}_6\text{C}$, state the number of **protons**, **neutrons** and **electrons** (neutral atom). [2]

2.3 Define **isotopes**. [1]

2.4 Complete the β^- decay: ${}^{14}_6\text{C} \rightarrow \text{N} + {}^0_{-1}\beta + ?$ —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 $1.6 \times 10^7 \text{ m s}^{-1}$; 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]

4 Go further

You are now ready for the real exam questions on this subtopic. Open the **11.1 Atoms, nuclei and radiation** past-paper sheet in the Library, or try these in **Practice mode**:

- 9702/22 M25 —Q7 (decay: momentum and conservation)
- 9702/21 N25 —Q6 (tritium: counts and β decay)
- 9702/24 N25 —Q6 (nuclear decay, structured)
- 9702/11 N25 —Q38 (radiation, multiple choice)
- 9702/12 N25 —Q39 (nuclear model, multiple choice)

Solutions

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 = 6; neutrons = $14 - 6 = 8$; electrons = 6.

2.3 Atoms of the **same element** (same proton number) with **different numbers of neutrons**.

2.4 ${}^{14}_6\text{C} \rightarrow {}^{14}_7\text{N} + {}^0_{-1}\beta + {}^0_0\bar{\nu}$; the last particle is an (electron) **antineutrino**.

3.1 **A** $\rightarrow \alpha$.

3.2 (a) Any three: **charge** (proton number), **nucleon number**, **(linear) momentum**, **mass-energy**.

3.2 (b) Momentum is conserved and the nucleus was stationary: $m_\alpha v_\alpha = m_R v_R$; $v_R = \frac{4 \times 1.6 \times 10^7}{222} = 2.9 \times 10^5 \text{ m s}^{-1}$.

3.3 A β -decay also emits an (anti)**neutrino**, which **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.