Exercise walk-through

Atoms, nuclei and radiation ▪ 11.1

eXercise

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

Method — 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.

Method — Notation and counting

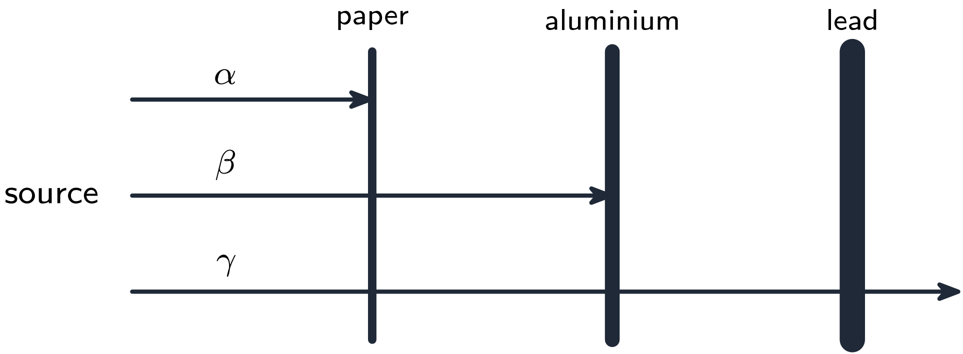
${}^{A}_{Z}\mathrm{X}$: $Z =$ **proton number** (fixes the element), $A =$ **nucleon number** (protons + neutrons). For a nuclide: **protons** $= Z$, **neutrons** $= A - Z$, and a **neutral atom** has **electrons** $= Z$. **Isotopes** are the same element (Z) with different neutron numbers. **Worked example.** Tritium ${}^{3}_{1}\mathrm{H}$: protons $= 1$, neutrons $= 3 - 1 = 2$, electrons (neutral) $= 1$.

Method — Radiation

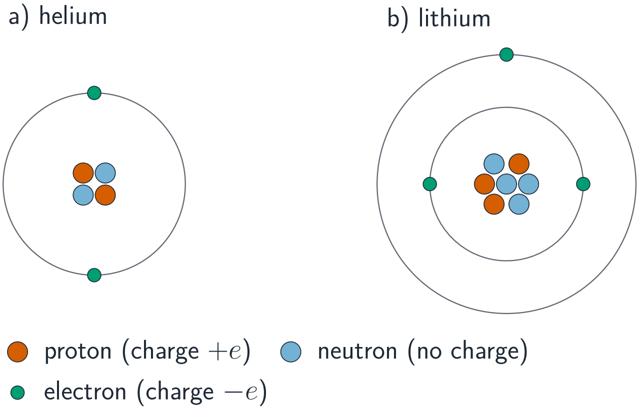
	composition	charge	mass (u)
α	2 protons + 2 neutrons	$+2e$	4
β^-	an electron	$-e$	≈ 0
γ	EM photon	0	0

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

Method — Radiation



Method — Radiation



The nuclear model of the atom

Method — Decay equations

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

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

Method — 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}.

Practice 2.1 ▪ 2 marks

State **two** conclusions Rutherford drew from the α-scattering experiment.

Solution 2.1

Method: The nuclear atom

Worked steps

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 **B1** **B1**.

Practice 2.2 ▪ 2 marks

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

Solution 2.2

Method: Notation and counting

Worked steps

protons $= 6$; neutrons $= 14 - 6 = 8$; electrons $= 6$ **B1** **B1** *for protons/electrons, for neutrons.*

Practice 2.3 ▪ 1 mark

Define **isotopes**.

Solution 2.3

Worked steps

Atoms of the **same element** (same proton number) with **different numbers of neutrons** B1.

Practice 2.4 ▪ 2 marks

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

Solution 2.4

Method: Decay equations

Worked steps

${}^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$ **B1** *for* ${}^{14}_{7}N$; the last particle is an (electron) **antineutrino** **B1**.

Exam-style 3.1 ▪ 1 mark

Which radiation is stopped by a sheet of **paper**?

A α

B β

C γ

D X-rays

Solution 3.1

Method: Radiation

A α ✓

B β

C γ

D X-rays

Worked steps

A — α.

Exam-style 3.2 ▪ 2 marks

A stationary nucleus decays into a nucleus R and an α-particle.
(a) State **three** quantities that are conserved during the decay.
(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.

Solution 3.2

Method: Conservation and recoil

Worked steps

(b) Momentum is conserved and the nucleus was stationary: $m_\alpha v_\alpha = m_R v_R$ **M1**;

$v_R = \dfrac{4 \times 1.6 \times 10^7}{222}$ **M1** $= 2.9 \times 10^5$ m s^{-1} **A1**.

Exam-style 3.3 ▪ 2 marks

Explain why β-particles are emitted with a **continuous range** of energies.

Solution 3.3

Method: Radiation

Worked steps

A β-decay also emits an (anti)**neutrino** B1, which **shares** the released energy with the β-particle in varying proportions, so the β energy varies B1.

Exam-style 3.4 ▪ 3 marks

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

Solution 3.4

Method: Radiation

Worked steps

α: charge $+2e$, mass 4 u; β^-: charge $-e$, mass ≈ 0 $(1/1836$ u$)$; γ: charge 0, mass 0 **B1** *each row*.