Exercise walk-through

4.4
Nuclear equations, half-lives and random decay (4.4.2.2–4.4.2.3)

AQA · GCSE · Physics

Nuclear equations

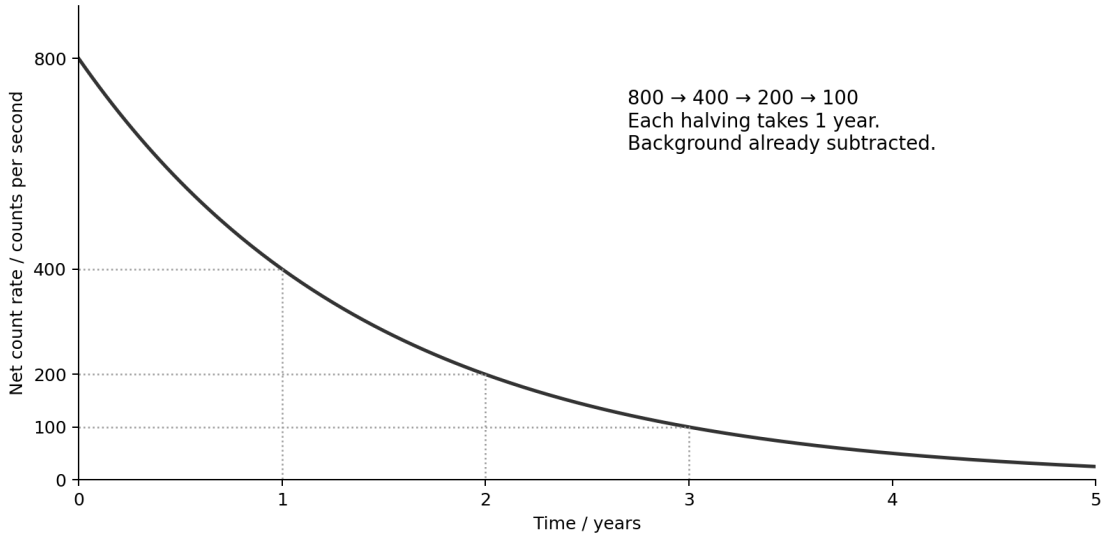
- **Alpha decay**: the mass number decreases by 4 and the atomic number by 2. An alpha particle is written ${}^{4}_{2}\mathrm{He}$.
- **Beta decay**: a neutron changes into a proton and an electron. The mass number stays the same and the atomic number increases by 1. A beta particle is written ${}^{0}_{-1}\mathrm{e}$.
- **Gamma emission** does not change the mass number or the atomic number; the nucleus loses energy.

$$ {}^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} $$

Half-lives and the random nature of decay

- **Radioactive decay** is random: you cannot predict when a particular nucleus will decay.
- But with very many nuclei, the overall pattern is predictable.
- The **half-life** of a radioactive isotope is the time it takes for the number of nuclei in a sample to halve, or the time it takes for the count rate (or **activity**) from a sample to fall to half its starting level.
- To find a **half-life** from a graph, read the time for the count rate to fall from any value to half that value.

Figure: Half-lives and the random nature of decay



- A decay curve: count rate halves every **half-life** (1 year in this example).
- Read the axes and units first.

Exercises 2.1·2.2

2.1 Radon-222 ($Z = 86$) decays by alpha emission. Write the balanced equation. [2]

$^{222}_{86}\mathrm{Rn}$ α decay

2.2 Strontium-90 ($Z = 38$) decays by beta emission. Write the balanced equation. [2]

$^{90}_{38}\mathrm{Sr}$ β decay

Exercises 2.1·2.2

2.1 Radon-222 ($Z = 86$) decays by alpha emission. Write the balanced equation. [2]

$^{222}_{86}\mathrm{Rn}$ α decay

2.1 A : $222 - 4 = 218$; Z : $86 - 2 = 84$.

$$^{222}_{86}\mathrm{Rn} \rightarrow {}^{218}_{84}\mathrm{X} + {}^{4}_{2}\mathrm{He}$$

(row balance B1, correct values B1)

2.2 Strontium-90 ($Z = 38$) decays by beta emission. Write the balanced equation. [2]

$^{90}_{38}\mathrm{Sr}$ β decay

2.2 A stays 90; Z : $38 + 1 = 39$.

$$^{90}_{38}\mathrm{Sr} \rightarrow {}^{90}_{39}\mathrm{X} + {}^{0}_{-1}\mathrm{e}$$

Exercises 2.3·3.1

2.3 A background-corrected count rate falls from 6400 counts/s to 800 counts/s in 24 hours. Calculate the half-life. [2]

6400 → 800 counts/s

in 24 h

3.1 Krypton-89 ($^{89}_{36}$Kr) decays by beta emission.

(a) Write the nuclear equation, using X for the daughter. [3]

(b) State the effect of this decay on the mass number and the atomic number. [2]

$^{89}_{36}$Kr

β decay

Exercises 2.3·3.1

2.3 A background-corrected count rate falls from 6400 counts/s to 800 counts/s in 24 hours. Calculate the half-life. [2]

6400 → 800 counts/s | in 24 h

2.3 Halvings: $6400 \to 3200 \to 1600 \to 800$: three halvings.

$$t_{1/2} = 24/3 = \mathbf{8} \text{ hours}$$

(counting halvings C1, answer A1)

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(a) Write the nuclear equation, using X for the daughter. [3]

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$^{89}_{36}\text{Kr}$ | β decay

3.1 (a)

$$^{89}_{36}\text{Kr} \to {}^{89}_{37}\text{X} + {}^{0}_{-1}\text{e}$$

(mass unchanged C1, $Z+1$ C1, balanced rows A1) (b) Mass number unchanged; atomic number increases by 1.

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Exercise 3.2

3.2 The activity of a sample falls from 1200 Bq to 150 Bq in 15 hours.

$1200 \to 150$ Bq | in 15 h

(a) Determine the half-life. Show the sequence of halvings. [3]

(b) (HT) Calculate the activity after a further 2 half-lives. [2]

3.3 A rock contains a radioactive isotope with a half-life of 2 hours. At 9:00 am its activity is known to be 5120 Bq.

$t_{1/2} = 2$ h | 9:00 am: 5120 Bq | 5:00 pm: ?

(a) Predict the activity at 5:00 pm the same day. [3]

(b) Explain why the activity can only be predicted for the whole sample, not for a single nucleus. [2]

(c) State one assumption used in the prediction. [1]

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3.2 (a) Halvings: 1200 → 600 → 300 → 150: three halvings in 15 h (C1).

$$t_{1/2} = 15/3 = \mathbf{5} \text{ hours}$$

Full solution on next slide

Full solution 3.2

3.2 (a) Halvings: 1200 → 600 → 300 → 150: three halvings in 15 h (C1).

$$t_{1/2} = 15/3 = \mathbf{5} \text{ hours}$$

(C1, A1) (b) Two more halvings: 150 → 75 → **37.5** Bq (each halving C1, answer A1).

3.3 (a) Time 9:00 to 5:00 = 8 hours = 4 half-lives (C1).

$$A = A_0 \left(\frac{1}{2}\right)^n = 5120 \text{ Bq} \times \left(\frac{1}{2}\right)^4 = \mathbf{320} \text{ Bq}$$

(halving chain C1, answer A1) (b) Decay is a random process: it cannot be predicted for any individual nucleus – only the statistical behaviour of large numbers. (c) The sample is unchanged: none of the radioactive material has been lost.