

Exercise walk-through

22.2

Radioactive decay (full E.3, HL)

International Baccalaureate · IB Diploma · Physics · HL

Nuclear · 2.1

Reasoning

Radioactive decay is spontaneous and random for an individual nucleus. Half-life describes the time for half the undecayed nuclei in a large population to decay, or for background-corrected activity to halve. half-life: Time for activity or undecayed population to halve; background radiation : Radiation measured apart from the investigated source.

Remove background before halving

- 1 Set the model** The detector reads 5200 counts/min; constant background is 200 counts/min. Wait three half-lives.
- 2 Calculate** Initial source count rate = 5000. After three halvings it is $5000/8 = 625$. Detector total = $625 + 200 = 825$ counts/min.

Decision

Half-life applies to the source contribution. It does not predict the decay time of an individual nucleus.

Activity needs seconds

- 1 Set the model** $\lambda = 0.20 \text{ h}^{-1}$ and $N_0 = 2.0 \times 10^{10}$. Find initial activity and fraction remaining after 5.0 h.
- 2 Calculate** $N/N_0 = e^{-0.20(5.0)} = 0.368$. Initial activity $= (0.20/3600)N_0 = 1.11 \times 10^6 \text{ Bq}$.

Decision

Becquerels mean decays per second. Convert the decay constant to inverse seconds before reporting activity in Bq.

Exercises 2.1·2.3

2.1 Define an isotope, and state what isotopes of an element share. [2]

2.2 State what is meant by the mass defect of a nucleus. [1]

2.3 Write the full nuclear equation for beta-minus decay of ${}^{14}_6\text{C}$. [2]

Exercises 2.1·2.3

2.1 Define an isotope, and state what isotopes of an element share. [2]

2.1 Nuclides of the same element with different neutron numbers; they share the same proton number Z (and chemical symbol).

2.2 State what is meant by the mass defect of a nucleus. [1]

2.2 The difference between the total mass of the separate nucleons and the mass of the assembled nucleus – the mass converted to binding energy.

2.3 Write the full nuclear equation for beta-minus decay of ${}^{14}_6\text{C}$. [2]

2.3 ${}^{14}_6\text{C} \rightarrow {}^{14}_7\text{N} + {}^0_{-1}\text{e} + \bar{\nu}$.

Exercises 2.4·3.1

2.4 Place alpha, beta and gamma radiation in order of increasing penetrating ability. [1]

2.5 A nuclide has decay constant 0.138 day^{-1} . Calculate its half-life, and the fraction remaining after 10 days. [3]

3.1 State the nuclear changes in A and Z for alpha decay, and write the equation for ${}^{226}_{88}\text{Ra}$ decaying by alpha emission. [3]

Exercises 2.4-3.1

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2.5 $T_{1/2} = \ln 2 / \lambda = 0.693 / 0.138 = 5.0 \text{ days}$; fraction = $e^{-\lambda t} = e^{-(0.138 \times 10)} = e^{-1.38} = 0.25$.

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3.1 A falls by 4 and Z falls by 2; ${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^4_2\alpha$.

Exercises 3.2-3.4

3.2 Two protons and two neutrons have total mass $4.0319\,u$; a helium-4 nucleus has mass $4.0026\,u$. Calculate the binding energy in MeV ($1\,u = 931.5\,\text{MeV}/c^2$) and the binding energy per nucleon. [4]

3.3 Explain why a medical tracer isotope is chosen with a short half-life and gamma emission, referring to penetration and ionizing ability. [3]

3.4 A source reads 4200 counts/min above a background of 200 counts/min. Calculate the count rate after two half-lives, and state one assumption. [3]

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3.2 $\Delta m = 4.0319 - 4.0026 = 0.0293\text{ u}$; $E = 0.0293 \times 931.5 = 27.3\text{ MeV}$; per nucleon: $27.3/4 = 6.8\text{ MeV}$.

3.3 Explain why a medical tracer isotope is chosen with a short half-life and gamma emission, referring to penetration and ionizing ability. [3]

3.3 Gamma penetrates body tissue to reach detectors outside while ionizing least along its path, minimizing damage; a short half-life means activity – and dose – fall quickly once the scan is done.

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3.4 Source alone: $4200 - 200 = 4000\text{ counts/min}$; after two half-lives: $4000/4 = 1000$; the meter reads $1000 + 200 = 1200\text{ counts/min}$, assuming the background rate stays constant.

Exercise 3.5

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3.5 If beta decay had only two products, conservation of energy and momentum would fix the electron's energy exactly – one value; the observed electrons span a continuous range, so a third, neutral, barely-interacting particle – the neutrino – must share the energy unpredictably; alpha and gamma photons instead appear with single sharp energies, meaning the emitting nucleus moves between definite energy levels, exactly as atomic line spectra mean atomic levels.