

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.

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 ${}_{88}^{226}\text{Ra}$ decaying by alpha emission. [3]

Exercises 2.4-3.1

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2.4 Alpha, beta, gamma.

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

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]

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.