

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

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

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

2.4 Alpha, beta, gamma.

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

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

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

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.

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

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.