E.3 Radioactive decay

Practice Worksheet — name: ________________________ date: _____________

FORMULAS FOR THIS TOPIC

MASS–ENERGY EQUIVALENCE $E = mc^2$ DECAY LAW (HL) $N = N_0 e^{-\lambda t}$ ACTIVITY (HL) $A = \lambda N = A_0 e^{-\lambda t}$

HALF-LIFE AND DECAY CONSTANT (HL) $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

SECTION A — MULTIPLE CHOICE

A1. A sample contains 8.0×10^{20} radioactive nuclei with a half-life of 6.0 hours. After one day, the number remaining is:

- (A) 4.0×10^{20}
- (B) 2.0×10^{20}
- (C) 1.0×10^{20}
- (D) 0.5×10^{20}

A2. In beta-minus decay, the emitted electrons show a continuous energy spectrum. This was evidence for:

- (A) Discrete nuclear energy levels
- (B) The existence of the antineutrino, sharing the decay energy
- (C) The quantisation of charge
- (D) The strong nuclear force

A3. The binding energy per nucleon curve peaks near iron ($A \approx 56$). This explains why:

- (A) Iron is the most abundant element
- (B) Fusion releases energy below iron and fission above it
- (C) Iron cannot undergo any nuclear reactions
- (D) All nuclei decay to iron eventually

SECTION B — SHORT ANSWER

B1. Complete and balance: ${}^{226}_{88}\text{Ra} \rightarrow ? + \alpha$, and ${}^{14}_{6}\text{C} \rightarrow ? + \beta^- + \bar{\nu}$. [4 marks]

B2. The deuteron ${}^{2}_{1}H$ has mass 2.013553 u; the proton 1.007276 u and neutron 1.008665 u. Calculate its binding energy in MeV. [3 marks]

B3. A detector reads 240 counts per minute near a source; background is 30 counts per minute. The source's half-life is 20 minutes. Predict the reading after one hour. [3 marks]

ANSWER KEY

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Section A

A1: 0.5×10^{20} — One day = 24 h = 4 half-lives, so the fraction remaining is $(1/2)^4 = 1/16$: $8.0 \times 10^{20}/16 = 0.5 \times 10^{20}$.

A2: The existence of the antineutrino, sharing the decay energy — A two-body decay would give the electron a single fixed energy. The observed spread means a third, undetected particle shares the energy randomly — Pauli's antineutrino, later confirmed directly. Alpha spectra, by contrast, ARE discrete, revealing nuclear energy levels.

A3: Fusion releases energy below iron and fission above it — Reactions release energy when the products climb towards the peak — fusing light nuclei or splitting heavy ones both increase binding energy per nucleon. Iron itself sits at the top: no energy can be extracted from it either way, which is why fusion in stellar cores stops there.

Section B

B1: Alpha decay reduces A by 4 and Z by 2: ${}^{226}_{88}\mathrm{Ra} \to {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\alpha$. Beta-minus converts a neutron to a proton (Z up by 1, A unchanged): ${}^{14}_{6}\mathrm{C} \to {}^{14}_{7}\mathrm{N} + \beta^- + \bar{\nu}$.

B2: Mass defect: $(1.007276 + 1.008665) - 2.013553 = 0.002388$ u. Binding energy: $0.002388 \times 931.5 \approx 2.22$ MeV — the energy needed to pull the deuteron apart.

B3: Source contribution now: $240 - 30 = 210$ cpm. One hour = 3 half-lives: $210/8 \approx 26$ cpm. Reading = source + background $= 26 + 30 \approx 56$ cpm. Subtract background before halving, add it back after.