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ANSWER BOOK

Radioactive decay and half-life

Nuclear physics · Year 13

AQA 3.8.1.3, 3.8.1.4 · CIE 11.1.6, 11.1.11, 23.2.1, 23.2.2, 23.2.3, 23.2.4, 23.2.5, 23.2.6
OCR A 6.4.2(h), 6.4.3(a), 6.4.3(c), 6.4.3(d), 6.4.3(e)(i), 6.4.3(f)(i), 6.4.3(f)(ii), 6.4.3(g), 6.4.3(h)

20 questions · 54 marks

NAVY EDITION

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SECTION A · Warm-up

A1 The average time taken for the number of undecayed nuclei in a sample to fall to half its initial value (1); equivalently, the time for the activity to halve (1). [2]

A2 $A = \lambda N = 0.02 \times 1.0 \times 10^{20}$ (1) [2]
$A = 2.0 \times 10^{18}$ Bq (1)

A3 $T_{½} = \ln 2/\lambda$ ($\approx 0.693/\lambda$) (1). [1]

A4 It is impossible to predict when a particular nucleus will decay, or which nucleus will decay next (1); each nucleus has a constant probability of decay per unit time, unaffected by temperature, pressure or chemical conditions (1). [2]

A5 Activity is the number of nuclei in the source that decay per unit time (1); its SI unit is the becquerel (Bq), one decay per second (1). [2]

A6 Both the proton number and the nucleon number are unchanged (1). The photon carries away the energy released as the nucleus falls from an excited state (a higher nuclear energy level) to a lower one (1). [2]

SECTION B · Standard

B1 $\lambda = \ln 2/T_{½} = 0.693/6.0$ (1) [2]
$\lambda = 0.1155\ \text{hour}^{-1}$ (1)

B2 15 days = 3 half-lives (1) [3]
$N = N_0/2^3 = (8.0 \times 10^{20})/8$ (1)
$N = 1.0 \times 10^{20}$ nuclei (1)

B3 $A = A_0/2^2 = 400/4$ (1) [2]
$A = 100$ Bq (1)

B4 $\lambda = \ln 2/8.0 = 0.0866\ \text{s}^{-1}$ (1) [3]
$A = \lambda N = 0.0866 \times 5.0 \times 10^{18}$ (1)
$A = 4.33 \times 10^{17}$ Bq (1)

B5 $\lambda = \ln 2/T_{½} = 0.693/(8.0 \times 86\,400) = 1.00 \times 10^{-6}\ \text{s}^{-1}$ (1) [4]
$N = (4.2 \times 10^{-6}/131) \times 6.02 \times 10^{23}$ (1)
$N = 1.93 \times 10^{16}$ nuclei (1)
$A = \lambda N = 1.9 \times 10^{10}$ Bq (1)

B6 A straight line of ln A against t shows the decay is exponential (1). The magnitude of the gradient equals the decay constant, so $\lambda = 0.046$ minute^{-1} (1) [4]
$T_{½} = \ln 2/\lambda = 0.693/0.046$ (1)
$T_{½} = 15$ minutes (1)

B7 ${}^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + {}^{0}_{-1}\beta$ + antineutrino: the nickel isotope has nucleon number 60 and proton number 28 (1); the beta particle is accompanied by an (electron) antineutrino (1). [2]

B8 Beta-plus (positron) emission (1); electron capture (1). In both, a proton is converted into a neutron, so the proton number falls by one and the neutron number rises by one, moving the nuclide towards the line of stability (1). [3]

SECTION C · Stretch

C1 $\lambda = \ln 2/10 = 0.0693$ hour^{-1} (1) [3]
$A = A_0e^{-\lambda t} = 600 \times e^{-0.0693} \times 25$ (1)
$A = 106$ Bq (1)

C2 $A_0/A = 800/50 = 16 = 2^4$ (1) [3]
So 4 half-lives have elapsed (1)
$t = 4 \times 3.0 = 12$ days (1)

C3 Beta-minus decay (1). A neutron changes into a proton, emitting an electron and an antineutrino (1); this reduces the neutron-to-proton ratio, moving the nuclide towards the line of stability (1). [3]

C4 $\lambda = \ln 2/6.0 = 0.1155$ hour^{-1} (1) [4]
$A = A_0e^{-\lambda t}$, so $t = \ln (A_0/A)/\lambda$ (1)
$t = \ln (6.4 \times 10^7/(1.0 \times 10^7))/0.1155$ (1)
$t = 16$ hours (1)

C5 P is rejected: alpha particles are absorbed by a few centimetres of air, let alone half a metre of soil, so nothing would reach the surface detector (1). R is rejected: a 30 year half-life would leave the ground and the water supply contaminated for decades (1). Q is chosen: gamma radiation is penetrating enough to reach the surface through the soil (1); an 8.0 hour half-life lasts long enough to complete the survey but decays to a low level within a few days (1). [4]

C6 After n half-lives the activity is $A_0/2^n$ (1) [3]
$2^9 = 512$ is not enough, but $2^{10} = 1024 > 1000$, so 10 half-lives are needed (1)
$t = 10 \times 30 = 300$ years (1)