A-Level Physics

Radioactive Decay

Mark Scheme

Time available: 58 minutes
Marks available: 52 marks

Mark schemes

1. (a) U-235 (absorbs) a neutron with added information ✓$_1$

$_1$ Possible added information :

To become U-236

absorbs a slow moving neutron

absorbs a thermal neutron

If no marks awarded but the first two marking points are made without identifying the isotope give one mark

U-235/6 then divides/splits and gives out more neutrons ✓$_2$

U-238 absorbs/scatters <u>neutrons</u> ✓$_3$

$_3$ If the answer implies that U-238 in any way is involved in fission this mark is lost

3

(b) Substitution into or manipulation of the equation $N_t = N_0 e^{-\lambda t}$ to give the ratio $\frac{N_0}{N_t}$

with N_t for the present day and N_0 being in the past ✓$_{1a}$

$$\left(\frac{N_0}{N_t} = e^{+\lambda t} = e^{+\left(1.54 \times 10^{-10} \times 2.0 \times 10^9\right)} = 1.36\right)$$

Mass of U-238 (= 1.36 × 0.993) = 1.35 kg (3 sf) ✓$_{2a}$

OR working with half-lives

(Half life = 4.50 × 10^9 year)

Number of half-lives = 4/9 or 0.44 ✓$_{1b}$

$$\left(\frac{N_0}{N_t} = 2^{(4/9)} = 1.36\right)$$

Mass of U-238 (= 1.36 × 0.993) = 1.35 kg (3 sf) ✓$_{2b}$

Must be to 3 sig figs

Calculation may be in grams

$_{1b}$ Half life = $ln2/1.54 \times 10^{-10}$

= 4.50 × 10^9 (year)

Number of half-lives = 2.00× 10^9/4.50 × 10^9

2

(c) Ratio $\left(\frac{N_{235}}{N_{238}+N_{235}}\right) = 3.6\%$ to 3.7%

so yes ✓ A valid calculation must be performed to gain the mark eg with an ecf from (b)

$$\left(\frac{N_{235}}{N_{238}+N_{235}} = \frac{52}{1400+52} \text{ using (b) data } = \frac{52}{1350+52}\right)$$

Condone using ratio $\frac{N_{235}}{N_{238}}$

$$\left(\frac{N_{235}}{N_{238}} = \frac{52}{1400} \text{ using (b) data } = \frac{52}{1350}\right)$$

= 3.7% to 3.9%

1

[6]

2. (a) 2.0 cm ✓ (allow 1.96 to 2.00 cm)

(Answer alone gains mark and ignore number of sig. figs)

(The depth halves in 19s. With the graph being exponential the depth will halve every 19s. 57/19 = 3 so the halving occurs 3 times. 16 cm → 8 cm → 4 cm → 2 cm)

1

(b) Use more water/greater depth/greater volume (in the existing cylinder)

(This should give the same half-life) ✓

Assume the word water is present in the answer if there is no reference to it. Eg 'greater depth' is taken as 'greater depth of water'.

1

(c) Closing the tap more

OR

Using a more viscous fluid (density is not the same as viscosity)

OR

Using a wider cylinder

OR

Use a smaller diameter capillary/narrow tube ✓

To decrease the decay constant the depth decrease rate should be reduced ie the cylinder should take longer to empty).

Changes to the tube need to be specific.

Also tube needs to be identified.

1

(d) (Using $T_{½} = \ln 2/\lambda = 0.693/1.42 \times 10^{-11}$)

$T_{½} = 4.9(4.88) \times 10^{10}$ (year) ✓

1

(e) (Use of $N = N_o e^{-\lambda t}$ mass is proportional to number so

$m = m_o e^{-\lambda t}$

$m_o = m\ e^{+\lambda t}$)

$\lambda t = 1.42 \times 10^{-11} \times 4.47 \times 10^9$ or 0.0635 ✓

($m_o = 1.23 \times 10^{-3}\ e^{1.42 \times 10^{-11} \times 4.47 \times 10^9}$)

$m_o = 1.31 \times 10^{-3}$ (g) ✓(allow and look out for unit being modified to mg)

Mark for 3 sig figs but must be attached to a final answer for mass with some attempt at a relevant exponential calculation ✓

May calculate N = 8.51(2) × 10^{18} and N_0 9.07 × 10^{18} but marks will be the same.

3

(f) (N = mass/87u = $1.23 \times 10^{-6} / (87 \times 1.661 \times 10^{-27}$)

$N = 8.5(1) \times 10^{18}$ ✓

(This does not have to be calculated out for the mark)

($\lambda = 1.42 \times 10^{-11} / (365 \times 24 \times 60 \times 60) = 4.50 \times 10^{-19}$)

($A = \lambda N = 4.50 \times 10^{-19} \times 8.51 \times 10^{18}$)

A = 3.8(4) ✓ (this calculation must use in seconds)

Bq, B/becquerel, counts s^{-1} or s^{-1} ✓

In first mark is obtainable from calculating number of moles and then multiplying by Avogadro's number.

{n = $1.23 \times 10^{-6}/87 = 1.41 \times 10^{-5}$

N = $1.41 \times 10^{-5} \times 6.02 \times 10^{23}$}

A power of 10 error will count as an AE and will allow an error carried forward.

Answer must follow working showing correct process as correct answer can come from incorrect working.

3

[10]

3. (a) $({}^{206}_{76}\text{X} \rightarrow {}^{206}_{82}Pb + \beta \times {}^{0}_{-1}\beta + \beta \times \overline{v_e})$

$\beta = 6$ ✓

1

(b) (i) the energy **required** to split up the nucleus ✓

into its individual neutrons and protons/nucleons ✓

(or the energy **released** to form/hold the nucleus ✓

from its individual neutrons and protons/nucleons ✓)

2

(ii) $7.88 \times 206 = 1620$ MeV ✓ (allow 1600-1640 MeV)

1

(c) (i) U, a graph starting at 3×10^{22} showing exponential fall passing through

0.75×10^{22} near 9×10^{9} years ✓

Pb, inverted graph of the above so that the graphs cross at 1.5×10^{22} near 4.5×10^{9} years ✓

2

(ii) (u represents the number of uranium atoms then)

$$\frac{u}{3 \times 10^{22} - u} = 2$$

$u = 6 \times 10^{22} - 2u$ ✓

$u = 2 \times 10^{22}$ atoms

1

(iii) (use of $N = N_o e^{-\lambda t}$)

$2 \times 10^{22} = 3 \times 10^{22} \times e^{-\lambda t}$ ✓

$t = \ln 1.5 / \lambda$

(use of $\lambda = \ln 2 / t_{1/2}$)

$\lambda = \ln 2 / 4.5 \times 10^{9} = 1.54 \times 10^{-10}$ ✓

$t = 2.6 \times 10^{9}$ years ✓(or 2.7×10^{9} years)

3

[10]

4. boron numbers correct: A = 11; Z = 5 B1

β^+ correct: A = 0; Z = (+)1 B1

v_e (not anti neutrino) with numbers correct: 0,0 B1

3

[3]

5. (a) correct numbers for beta+ (0, (+)1) and chromium (52) B1

(electron) neutrino with correct numbers (0,0) B1

2

(b) W^+/W/(intermediate vector) boson (not Z boson) B1

1

[3]

6. (a) plutonium is toxic/large mass of plutonium B1

harmful if released into atmosphere/explosion occurred B1

alphas dangerous when ingested/during launch etc B1

max2

(b) unaffected B1

chemical bonding involves electrons (atomic)
radioactivity is nuclear (owtte)/same number of nuclei
present B1

2

(c) (i) $T_{½} = \ln 2/\lambda$

C1

2.51×10^{-10}

A1

2

(ii) molar mass calculated (0.270 kg)

C1

use of 33 kg

C1

number of moles in sample (122.2)

C1

multiplication of value by Avogadro's number

C1

7.36×10^{25}

A1

5

(iii) (c) (i) × (c) (ii)

C1

1.83×10^{16} cao

A1

Bq

B1

3

(d) (i) uranium correct (234,92)

B1

alpha correct (4,2) – accept He or α symbol

B1

2

(ii) use of 1 g generating 500 mW

C1

16500 W total

C1

recognition that activity × energy of one alpha = power

C1

9.00×10^{-13} (J)

A1

4

[20]