

Exercise walk-through

5.4

Radiation, background and decay (137–142, CP15)

Pearson Edexcel · International A-Level · Physics

A fraction inside the logarithm

- 1 **Given** Half-life 3.0 years; target activity is 2.0% of its initial value.
- 2 **Model** $A/A_0 = e^{-\lambda t}$ and $\lambda = \ln 2/t_{1/2}$.
- 3 **Constant** $\lambda = \ln 2/(3.0 \text{ yr}) = 0.231 \text{ yr}^{-1}$.
- 4 **Solve** $t = -\ln(A/A_0)/\lambda = -\ln(0.020)/(0.231 \text{ yr}^{-1}) = 16.9 \text{ yr}$.

Decision

Use 0.020, not 2.0. For radioactive power, use $P = AE_{\text{decay}}$ with energy in joules.

CP15: attenuation is a thickness law

Action	Why it matters
Fix geometry and count time	Source contribution must be comparable across thicknesses.
Measure and subtract background	Background does not follow the absorber transmission law.
Repeat; plot log corrected rate versus lead thickness	Test exponential attenuation. Avoid near-background readings with large relative uncertainty.

Use the evidence

Three half-value thicknesses transmit $1/8$. Follow supervised source handling and shielding.

Check yourself

Question	Explanation
Constant temperature but increasing internal energy? Why remove background?	Molecular arrangements and potential energy can change during phase change. It does not obey the test source's distance or time-decay model.
a - x gradient -25 s^{-2} ?	$\omega = \sqrt{25 \text{ s}^{-2}} = 5.0 \text{ rad/s}$. The negative sign indicates restoring acceleration.

Exercise 2.1

2.1 A source gives $74 \text{ counts min}^{-1}$ at distance r , including background $10 \text{ counts min}^{-1}$. Predict the measured rate at $2r$, assuming inverse-square spreading. Explain why the whole measured rate cannot simply be divided by four. [4]

source



detector



r and $2r$; background $10/\text{min}$

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r and $2r$; background $10/\text{min}$

2.1 Subtract background before spreading the source contribution.

$$R_{s,1} = R_{m,1} - B = (74 - 10) \text{ min}^{-1} = 64 \text{ min}^{-1}$$

$$R_{s,2} = R_{s,1} \left(\frac{r}{2r} \right)^2 = 64 \text{ min}^{-1} / 4 = 16 \text{ min}^{-1}$$

Source result.

$$R_{m,2} = R_{s,2} + B = (16 + 10) \text{ min}^{-1} = 26 \text{ min}^{-1}$$

Measured result. Background is not radiation spreading from this source, so it is not divided by four.

Exercise 2.2

2.2 A source has initial activity 800 Bq and half-life 6.0 h. Find activity after 18 h. Explain what randomness means for an individual nucleus. [3]

$$A_0 = 800 \text{ Bq}$$

$$t_{1/2} = 6.0 \text{ h}$$

$$t = 18 \text{ h}$$

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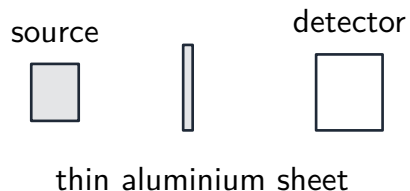
2.2 Three half-lives elapse.

$$A = A_0 2^{-t/t_{1/2}} = 800 \text{ Bq} 2^{-18/6} = 100 \text{ Bq}$$

Result. A single nucleus has an unpredictable decay time, although a large population follows a predictable statistical law.

Exercise 2.3

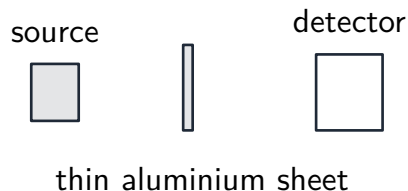
2.3 Complete beta-minus decay of carbon14, including the missing neutral particle. Explain why a thin aluminium thickness monitor needs a suitable penetrating radiation rather than alpha radiation. [4]



3 Exam-style questions

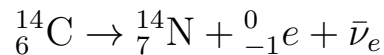
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3 Exam-style questions

2.3



Correct daughter, electron and antineutrino. Beta transmission varies measurably with thin aluminium thickness; alpha would be almost entirely absorbed and give little useful transmitted signal.

Exercise 3.1

3.1 A radioactive source has half-life 4.0 years. Derive the relation between half-life and decay constant, then find time until activity is 0.50% of its initial value. [5]

$$t_{1/2} = 4.0 \text{ years}$$

$$A/A_0 = 0.005$$

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$$A/A_0 = 0.005$$

3.1 Start with exponential decay at one half-life.

$$\frac{1}{2} = e^{-\lambda t_{1/2}} \quad \lambda = \frac{\ln 2}{t_{1/2}}$$

Log derivation.

$$\lambda = \frac{\ln 2}{4.0 \text{ years}} = 0.1733 \text{ year}^{-1}$$

Use fraction 0.005, not 0.50.

$$t = -\frac{\ln(A/A_0)}{\lambda} = -\frac{\ln 0.005}{0.1733 \text{ year}^{-1}} = 30.6 \text{ years}$$

Time and unit.

Exercise 3.2

3.2 An alpha source releases 5.0 MeV per decay. Its half-life is 30 years, sample mass 0.020 kg and nucleus mass 4.0×10^{-25} kg. Calculate initial nuclear power and power after 60 years. Use $1 \text{ year} = 3.15 \times 10^7 \text{ s}$ and $1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$. Explain why electrical output need not equal this result. [7]

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3.2 Count nuclei from sample mass.

$$N = \frac{m_s}{m_0} = \frac{0.020 \text{ kg}}{4.0 \times 10^{-25} \text{ kg}} = 5.0 \times 10^{22}$$

Use seconds for activity in Bq.

$$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{(30 \text{ years})(3.15 \times 10^7 \text{ s/year})} = 7.33 \times 10^{-10} \text{ s}^{-1}$$

Full solution 3.2

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Activity.

$$P_0 = A_0 E_d = (3.667 \times 10^{13} \text{ s}^{-1})(5.0 \text{ MeV})(1.60 \times 10^{-13} \text{ J/MeV}) = 29.3 \text{ W}$$

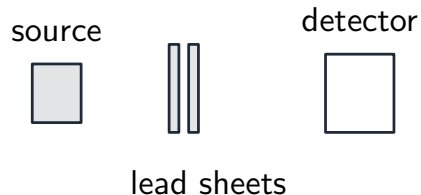
Power method/value.

$$P = P_0 2^{-t/t_{1/2}} = 29.3 \text{ W } 2^{-60/30} = 7.33 \text{ W}$$

Later power. Electrical conversion has losses/efficiency below 100%.

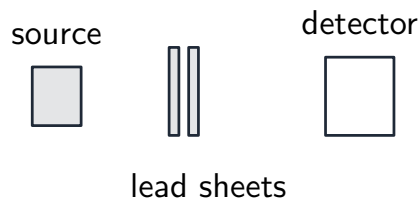
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3.3 Describe a gamma-absorption experiment with lead sheets. Include background, fixed geometry, counting time, a suitable graph, the effect of random counting variation and two radiation precautions. Explain why results near background are less reliable. [7]



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3.3 Measure background separately over a known time and subtract its rate. Keep source, detector and absorber positions fixed while adding measured lead thickness. Use equal counting intervals, repeating or increasing time to reduce relative counting fluctuation. Plot logarithm of corrected rate against thickness to test exponential attenuation. Near background, the corrected signal is small compared with counting fluctuations, so relative uncertainty is large. Handle with prescribed tools, minimise time and maximise distance; keep the source shielded when unused and never point it at people.