

Solutions

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

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.

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

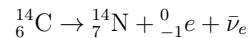
Measured result. Background is not radiation spreading from this source, so it is not divided by four.

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.

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.

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.

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.

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

$$A_0 = \lambda N = (7.33 \times 10^{-10} \text{ s}^{-1})(5.0 \times 10^{22}) = 3.67 \times 10^{13} \text{ Bq}$$

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%.

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.