LESSON 5.2.1

Radioactive Decay, Half-Life and Activity

An individual decay is unpredictable. A large population of unstable nuclei follows a predictable statistical pattern because each undecayed nucleus has the same constant decay probability per unit time.

RANDOM

You cannot predict which nucleus decays next or when a particular nucleus will decay. Counts fluctuate even when the average rate changes very little.

SPONTANEOUS

An unstable nucleus decays without an external trigger. Ordinary changes in temperature, pressure or chemical state do not appreciably change its decay rate.

ACTIVITY IS THE RATE OF NUCLEAR DECAYS

$$A = -\frac{dN}{dt} = \lambda N$$

N is the number of undecayed parent nuclei. Activity A is positive and measured in becquerels: 1 Bq means one decay per second. The minus sign accounts for N decreasing.

$$N = N_0 e^{-\lambda t} \qquad A = A_0 e^{-\lambda t}$$

The decay constant λ has units of inverse time. For a short interval Δt, a nucleus has decay probability approximately λΔt. Use matching units for λ and t so the exponent is dimensionless.

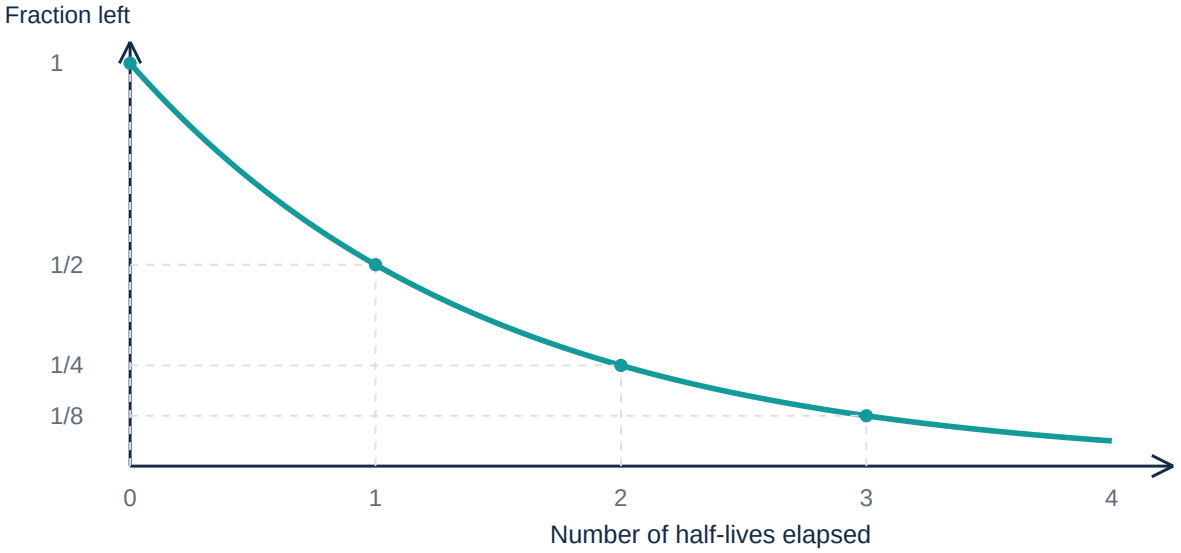
If $N = 2.00 \times 10^{12}$ and $\lambda = 1.50 \times 10^{-4}\ s^{-1}$:

$$A = \lambda N = 3.00 \times 10^{8}\ Bq$$

1 A constant fraction, not a fixed number

Half-life is the time for the expected number of undecayed nuclei, or the activity of a single radionuclide, to fall to half its initial value.

NORMALISED DECAY CURVE



$$\text{At } t = t_{1/2}: \quad \frac{1}{2} = e^{-\lambda t_{1/2}}$$

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

WORKED EXAMPLE: HALF-LIFE 6.00 h, INITIAL ACTIVITY 800 Bq

$$\lambda = \frac{0.693}{6.00} = 0.1155\ \text{h}^{-1} = 3.21 \times 10^{-5}\ \text{s}^{-1}$$

After 18.0 h, three half-lives have passed:

$$A = 800 \times (1/2)^3 = 100\ \text{Bq}$$

The expected remaining fraction is 1/8; the decayed fraction is 7/8. The same half-life applies to 800 → 400 Bq and 200 → 100 Bq, even though the number of decays differs.

Exponential curves describe the statistical mean. Real finite samples do not lose exactly half their nuclei in every half-life.

2 Correct the counts, then find the half-life

A detector records only some emissions. Background-corrected count rate is proportional to activity when geometry, efficiency and absorption stay unchanged.

EXAMPLE: STEADY BACKGROUND = 20 COUNTS PER MINUTE

Time / min	Measured (counts/min)	Net (counts/min)
0	820	800
4	420	400
8	220	200
12	120	100

The corrected rate halves every 4 min. Do not halve the raw reading of 820.

$$R = R_{measured} - R_{background}$$

USE NATURAL LOGS FOR A STRAIGHT-LINE TEST

$$\ln\left(\frac{A}{A_0}\right) = -\lambda t; \quad \ln\left(\frac{R}{R_0}\right) = -\lambda t$$

The subscript 0 denotes the initial value. Plot the natural log of net rate divided by its initial value against time. Use positive, corrected rates: the slope is -λ and the ideal intercept is zero.

$$\lambda = \frac{\ln(800/100)}{12.0} = 0.173 \text{ min}^{-1}$$

Then half-life = 0.693/0.173 = 4.00 min (using unrounded values).

Measure background separately over a long enough time, convert counts to a rate, and subtract that rate. Use short counting intervals compared with the half-life and keep source-detector distance fixed. Repeat or fit several readings to reduce random scatter.

At low net rates, relative uncertainty grows; a zero or negative corrected rate cannot be logged. Very high rates can be underestimated because of detector dead time. Mixed isotopes or radioactive daughters may not follow one exponential.

Source: Pearson IAL Physics, Unit 5 p. 34, points 137 and 141-142.

Illustrative data. Next: absorption, ionising radiation and safety.