Radioactivity

Matthew Williams • Physics • May 20, 2026

Radioactivity

Radioactive decay is the spontaneous emission of radiation from an unstable nucleus. The process is **random**, it is impossible to predict when any particular nucleus will decay, but for a large sample, the average rate of decay follows a predictable exponential pattern.

The Three Types of Radiation

Property	**Alpha ([Math: \alpha])**	**Beta ([Math: \beta])**	**Gamma ([Math: \gamma])**
Nature	Helium-4 nucleus ([Math: {}^{4}_{2}\text{He}])	Fast electron	High-energy electromagnetic wave
Charge	+2	−1	0
Mass (relative)	4	~0	0
Speed	Slow (~5% of [Math: c])	Fast (up to ~90% of [Math: c])	[Math: c] (speed of light)
Ionising ability	Very high (dense ionisation)	Medium	Low
Penetrating ability	Stopped by 5 cm of air or a sheet of paper	Stopped by 3-5 mm of aluminium	Reduced by several cm of lead or metres of concrete
Deflection by electric field	Toward negative plate	Toward positive plate	Not deflected
Deflection by magnetic field	Yes (using left-hand rule for positive charge moving)	Yes (in opposite direction to alpha)	Not deflected

Diagram showing the penetrating ability of alpha, beta, and gamma radiation: alpha particles are stopped by a sheet of paper, beta particles are stopped by a few millimetres of aluminium, and gamma rays are only partially attenuated by a thick block of lead

Nuclear Equations

In a nuclear equation, both the mass number (A) and the atomic number (Z) must be conserved.

Alpha Decay

An alpha particle (${}^{4}_{2}\mathrm{He}$) is emitted. A and Z both decrease:

$$ {}^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\mathrm{He} $$

Example: Ra-226 undergoes alpha decay:

$$ {}^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He} $$

Beta Decay

A beta particle (electron, ${}^{0}_{-1}\mathrm{e}$

) is emitted. A stays the same; Z increases by 1 (a neutron converts to a proton):

$$ {}^{A}_{Z}\mathrm{X} \rightarrow {}^{A}_{Z+1}\mathrm{Y} + {}^{0}_{-1}\mathrm{e} $$

Gamma Emission

A gamma ray (γ) is emitted. A and Z are unchanged, only the nucleus loses energy.

Half-Life

The **half-life**($t_{1/2}$

) of a radioactive substance is the time taken for the activity (or the number of undecayed nuclei) to fall to

halfof its initial value.

Half-life is a characteristic of each isotope and does not change with temperature, pressure, chemical form, or sample size.

After n half-lives, the fraction of activity remaining is $\left(\frac{1}{2}\right)^n$.

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Half-life from a graph (2016 Paper 02, Q1)

Activity data for a sample:

Time (h)	Activity (disintegrations/s)
0	80.0
1	50.0
2	34.5
3	20.0
4	13.0
5	7.5
6	5.0

From the smooth decay curve: activity falls from 80 to 40 between $t = 0$ and approximately $t = 1.5$ h. Activity falls from 40 to 20 between $t \approx 1.5$ h and $t \approx 3$ h.

Both intervals give approximately the same half-life: $t_{1/2} \approx 1.5$ h.

Time for activity to reach 10 disintegrations/s: Read from the graph, at $A = 10$, $t \approx 3$ h.

The decay is not a perfectly smooth curve because radioactive decay is **random**, individual decays occur by chance, producing statistical fluctuations in the measured activity.

Applications of Radioisotopes

Application	Radioisotope used	Reason for choice
Medical imaging (thyroid scan)	Iodine-123 ([Math: {}^{123}_{53}]I)	Absorbed by thyroid; short half-life minimises patient dose
Cancer treatment (radiotherapy)	Cobalt-60, gamma knife	High-energy gamma kills tumour cells
Carbon dating	Carbon-14 ([Math: {}^{14}_{6}]C), half-life 5730 years	Living organisms maintain constant C-14 level; ratio to C-12 decreases after death
Industrial thickness gauging	Beta emitters	Absorption through material gives thickness measurement
Sterilisation of medical equipment	Gamma sources	Gamma penetrates packaging to kill bacteria

📝 **Exam Tip**

In a half-life calculation: if the activity falls to 1/16 of its original value, that is $(1/2)^4$, so four half-lives have passed. Divide the total elapsed time by 4 to find one half-life.

In nuclear equations, check both the top numbers (A) and the bottom numbers (Z) balance on each side. The most common error is forgetting to adjust Z when writing the daughter nucleus.