

Unstable nuclei, decay and half-life

Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Lesson

Quick answer: Radioactivity is the random decay of unstable nuclei, which emit alpha particles, beta particles or gamma rays. Half-life is the time for the activity of a sample to halve. Fission splits large nuclei and fusion joins small ones, both releasing energy, and exposure is limited by time, distance and shielding.

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What is radioactivity and why do nuclei decay?

Every atom has a nucleus of protons and neutrons. Atoms of the same element with different numbers of neutrons are **isotopes**, for example carbon-12 (6 protons, 6 neutrons) and carbon-14 (6 protons, 8 neutrons). Some isotopes have unstable nuclei, and these emit radiation to become more stable.

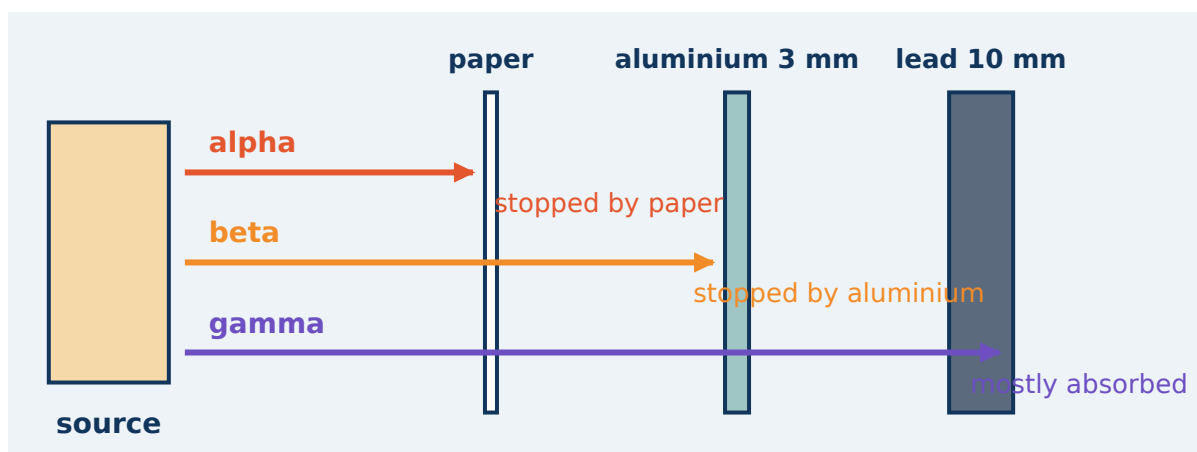
Definition

Radioactive decay is the random process in which an unstable nucleus emits alpha, beta or gamma radiation. The activity of a source is the number of decays per second, measured in becquerel (Bq). 1 Bq is 1 decay per second.

Decay is **random**: you cannot predict when one particular nucleus will decay, only how many will decay in a given time. It is also **spontaneous**, so heating, pressure or chemical reactions do not change it. A Geiger-Müller (GM) tube counts the radiation entering it. Even with no source there is **background radiation** from radon gas, rocks, cosmic rays and medical scans, so you subtract the background count from every reading.

What are alpha, beta and gamma radiation?

Radiation	What it is	Charge	Ionising power	Stopped by
Alpha (α)	2 protons + 2 neutrons (helium nucleus)	+2	very strong	paper, skin, a few cm of air
Beta (β^-)	fast electron from the nucleus	-1	moderate	a few mm of aluminium
Gamma (γ)	electromagnetic wave	0	weak	thick lead or concrete



Penetrating power: alpha is stopped by paper, beta by a few millimetres of aluminium, gamma needs thick lead.

These radiations are **ionising**: they knock electrons off atoms. That is why they can damage living cells. In a nuclear equation the mass numbers and the atomic numbers must balance on both sides.

Key law: decay changes

Alpha decay: mass number falls by 4, atomic number falls by 2.

Beta decay: mass number stays the same, atomic number rises by 1 (a neutron turns into a proton and an electron).

Gamma emission: no change in either number.

Worked example 1: alpha decay

Radium-226 (atomic number 88) emits an alpha particle. Find the new nucleus.

Mass number: $226 - 4 = 222$. Atomic number: $88 - 2 = 86$, which is radon.

Answer: **radon-222**.

Worked example 2: beta decay

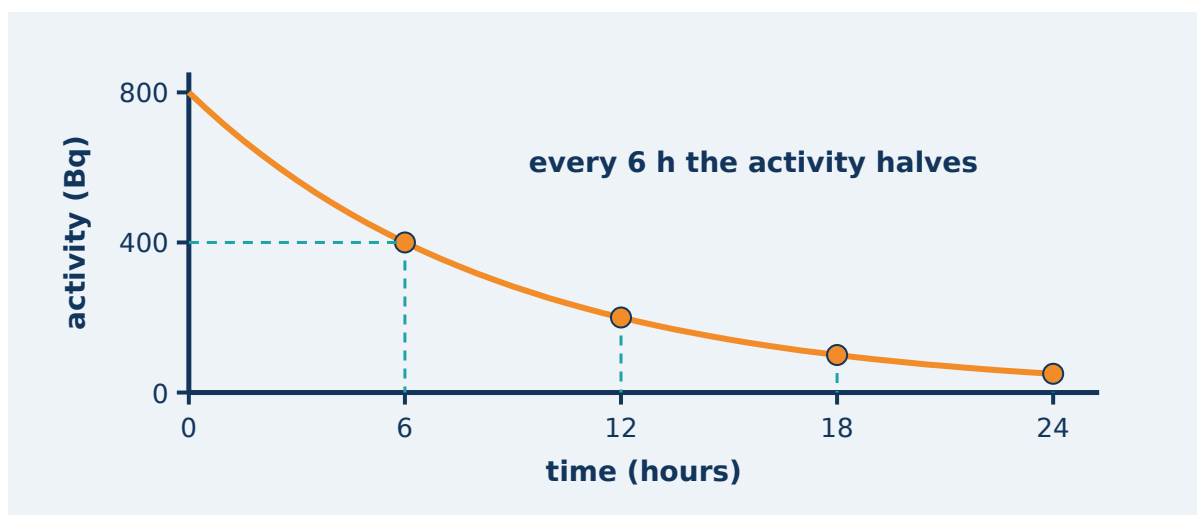
Carbon-14 (atomic number 6) emits a beta particle. Mass number stays at 14 and the atomic number becomes $6 + 1 = 7$, which is nitrogen. **Nitrogen-14**.

What is half-life and how do you use it?

Definition

The half-life of a radioactive isotope is the time taken for its activity (or the number of undecayed nuclei) to fall to half of its starting value.

Because decay is random but the numbers are huge, the pattern is predictable. Each half-life, the remaining activity is halved again: after 1 half-life one half remains, after 2 one quarter, after 3 one eighth. Half-lives range from fractions of a second to billions of years.



Decay curve of a sample with a half-life of 6 hours: 800, 400, 200, 100, 50 Bq.

Worked example 3: using half-life

A sample has an activity of 800 Bq and a half-life of 6.0 hours. Find its activity after 18 hours.

Number of half-lives = $18 \div 6.0 = 3$.

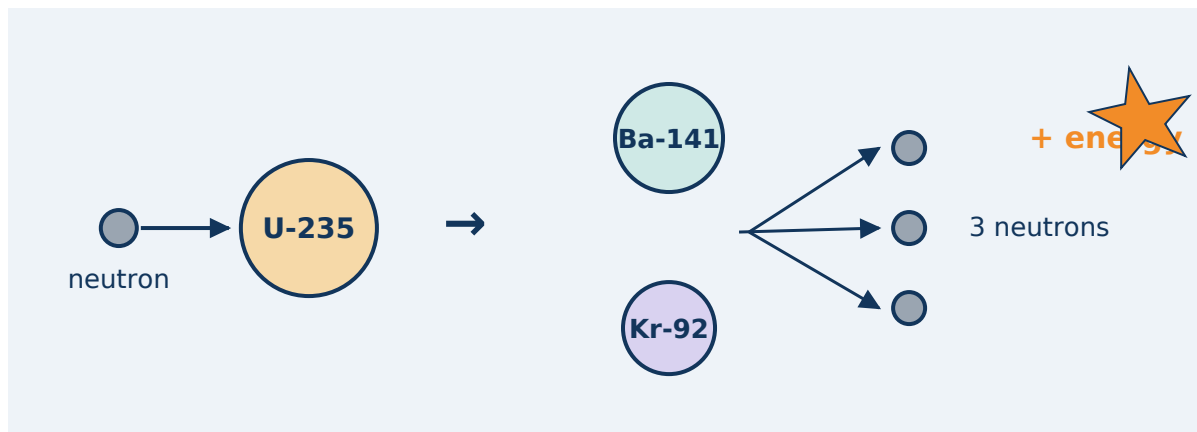
800 → 400 → 200 → 100. **Activity = 100 Bq.**

Common mistake

After two half-lives a sample is not completely gone. One quarter is still left, and the activity never reaches exactly zero. Also remember to subtract the background count rate before you look for the half-life.

What are nuclear fission and fusion?

In **fission** a large nucleus such as uranium-235 absorbs a neutron and splits into two smaller nuclei, releasing two or three neutrons and a lot of energy. These neutrons can split more nuclei, starting a **chain reaction**. In a nuclear reactor, control rods absorb neutrons to keep the reaction steady.



Fission: a neutron splits a uranium-235 nucleus into two smaller nuclei, releasing neutrons and energy.

In **fusion** two light nuclei, such as hydrogen isotopes, join to form a heavier nucleus like

helium. Fusion powers the Sun but needs temperatures of millions of degrees, because the nuclei are positively charged and repel each other. In both processes a small amount of mass disappears and appears as energy, $E = m c^2$, where $c = 3.0 \times 10^8$ m/s.

How do you stay safe around radiation?

Irradiation means being exposed to radiation from outside; **contamination** means radioactive atoms get on or into the body. Alpha sources are most dangerous inside the body, while gamma is the most penetrating outside it. Reduce the risk with three rules: keep the *time* short, keep the *distance* large (use tongs), and use *shielding* such as lead. Workers wear badges that record their dose, and sources are stored in lead-lined boxes.

Lina's tip

For half-life questions, first divide the total time by the half-life to get the number of halvings, then halve the starting value that many times. For decay equations, check that the mass numbers and atomic numbers each add up on both sides.

Key points to remember

- Alpha = helium nucleus (stopped by paper); beta = fast electron (stopped by aluminium); gamma = wave (needs thick lead).
- Alpha decay: mass number -4 , atomic number -2 . Beta decay: atomic number $+1$, mass number unchanged.
- Activity is measured in becquerel (Bq): 1 Bq = 1 decay per second.
- Half-life: the time for activity to fall to half; after n half-lives, $(1/2)^n$ remains.
- Fission splits heavy nuclei; fusion joins light nuclei; both convert a little mass into energy.

Unstable nuclei, decay and half-life: frequently asked questions

Can you change the half-life of an isotope?

No. Half-life depends only on the nucleus, so heating, cooling, pressure or chemical reactions do not change it. This is why radioactive decay is used as a steady clock.

Which type of radiation is the most dangerous?

It depends on where the source is. Alpha is the most ionising, so it is most harmful inside the body. Gamma is the most penetrating, so it is the biggest hazard from outside.

What is background radiation?

It is the low level of radiation always present from radon gas, rocks, cosmic rays, food and medical scans. You measure it without the source and subtract it from your count rate.

What is the difference between fission and fusion?

Fission splits a large nucleus such as uranium-235 into smaller ones and is used in power stations. Fusion joins small nuclei such as hydrogen to make helium, as in the Sun, and needs

extreme temperatures.

Why is the decay of a nucleus described as random?

You cannot predict when a particular nucleus will decay. You can only state the probability, so in a large sample the number of decays per second is predictable.