Radioactive decay and nuclear radiation

4.4.2.1 · Atomic structure · revision notes

Why some nuclei are unstable, what alpha, beta, gamma and neutron radiation are, and how alpha, beta and gamma compare in penetration, range in air and ionising power. Expect recall, 'compare' questions, and 'explain which radiation is best for a use' questions.

Key facts

- Activity = decays per second, unit becquerel (Bq)
- Count rate = decays recorded per second by a detector
- Alpha α = 2 protons + 2 neutrons (helium nucleus), charge +2
- Beta β = high-speed electron from the nucleus (neutron → proton), charge −1
- Gamma γ = electromagnetic radiation from the nucleus, no mass, no charge
- Absorbed by: α paper; β a few mm aluminium; γ reduced by thick lead or concrete
- Range in air: α a few cm; β about 1 m; γ very far
- Ionising power: α > β > γ

Notes

Radioactive decay

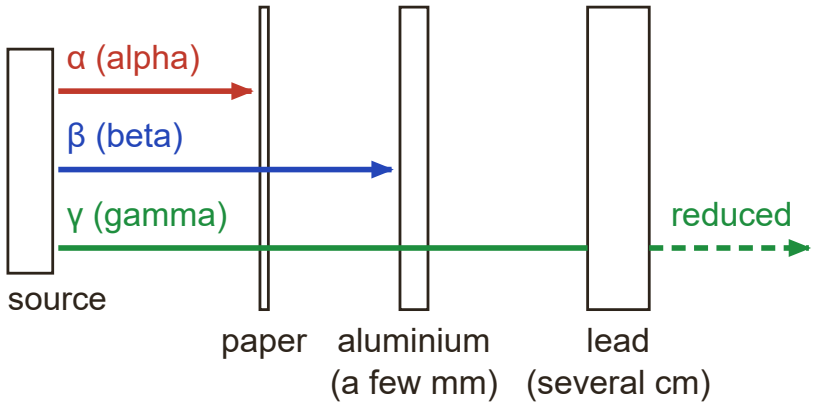
- Some atomic nuclei are **unstable**. The nucleus gives out radiation as it changes to become more stable. This is **radioactive decay**.
- Decay is **random**: you cannot predict which nucleus will decay next, or when.
- **Activity** is the rate at which a source of unstable nuclei decays. It is measured in **becquerels (Bq)**: 1 Bq = 1 decay per second.
- **Count rate** is the number of decays recorded each second by a detector, such as a **Geiger–Müller tube**.
- On a graph of the number of undecayed nuclei against time, the activity at any time is the size of the gradient of the tangent at that time, in Bq. Grade 8+ only

Types of nuclear radiation

- **Alpha particle (α)**: two protons and two neutrons, the same as a helium nucleus. Relative charge +2.
- **Beta particle (β)**: a high-speed electron ejected from the nucleus when a neutron turns into a proton. Relative charge −1.
- **Gamma ray (γ)**: electromagnetic radiation from the nucleus. No mass and no charge.
- **Neutron (n)**: some nuclei emit a neutron. It has no charge.

Comparing alpha, beta and gamma

- Penetration: alpha is stopped by a sheet of paper or the outer layer of skin; beta by a few millimetres of aluminium; gamma is only reduced by several centimetres of lead or thick concrete.

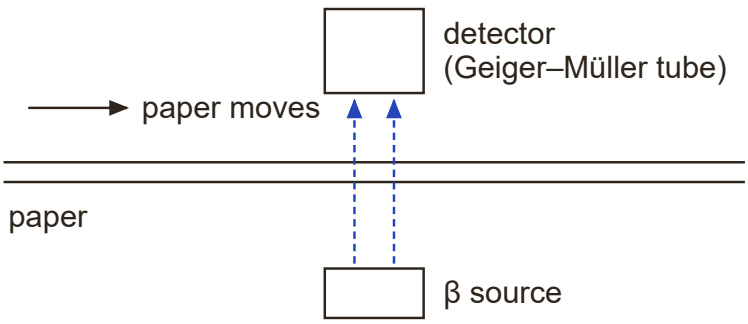


What stops each type of radiation.

- Range in air: alpha travels a few centimetres; beta about a metre; gamma a very long way.
- Ionising power: alpha is strongly ionising, beta is less ionising, gamma is weakly ionising.
- The more ionising a radiation is, the more quickly it loses its energy as it passes through a material. That is why alpha has the shortest range and gamma the longest. Grade 7+ only
- To find what a source emits: measure the background count rate, then the count rate with a Geiger–Müller tube close to the source. Put paper, then aluminium, then lead between them, recording the count rate each time.
- A fall when paper is added shows alpha; a further fall with aluminium shows beta; a count above background that only lead reduces shows gamma.

Choosing a source for a use

- Smoke alarms use alpha: it strongly ionises the air inside the alarm, so a small current flows. Smoke absorbs the alpha particles, so the current falls and the alarm sounds. Alpha's short range keeps it inside the alarm.
- Thickness gauges for paper use beta: some passes through, and the amount changes when the thickness changes. Alpha would all be absorbed; gamma would nearly all pass through whatever the thickness.



Thickness gauge: if the paper gets thicker, more beta is absorbed and the count rate falls.

- Sterilising medical equipment uses gamma: it passes through the packaging and kills microorganisms.

How to answer each type of question

Identify a radiation from absorption data

2 marks | Grade 5

1. See which material stops the radiation (count rate falls to background).
2. Match it: paper → alpha; a few mm of aluminium → beta; only thick lead reduces it → gamma.
3. Quote the evidence from the question as your reason.

Example. A radioactive source emits one type of radiation. A sheet of paper placed in front of the source does not change the count rate. A 3 mm sheet of aluminium reduces the count rate to the background level.
Which type of radiation does the source emit? Give a reason for your answer.

Model answer. Beta (1). It passes through paper but is absorbed by 3 mm of aluminium (1).

Describe what each radiation is

1 to 3 marks | Grade 5

1. Alpha: say what particles it is made of.
2. Beta: say it is an electron AND that it comes from the nucleus.
3. Gamma: say it is electromagnetic radiation from the nucleus.

Example. (a) Describe the structure of an alpha particle. (1 mark)
(b) Describe how a beta particle is produced. (2 marks)

Model answer.

(a) Two protons and two neutrons (1)

(b) A neutron in the nucleus changes into a proton (1) and a high-speed electron is ejected from the nucleus (1).

Explain which radiation is best for a use

3 to 4 marks | Grade 7

1. State the property the use needs (e.g. partly absorbed, penetrates packaging).
2. Explain why the chosen radiation has that property.
3. Explain why each of the other radiations would not work.

Example. A paper mill uses a radioactive source and a detector on opposite sides of a sheet of paper to monitor its thickness.
Explain why a beta source is used rather than an alpha source or a gamma source.

Model answer. Alpha would be completely absorbed by the paper, so the count rate would not change with thickness (1). Gamma would pass through almost completely, so small changes in thickness would hardly change the count rate (1). Beta is partly absorbed, and more is absorbed when the paper is thicker, so the count rate shows changes in thickness (1).

Explain: ionising power and range 2 marks **Grade 8**

1. Compare the ionising power of the radiations.
2. Link strong ionisation to losing energy quickly, and so a short range.

Example. Explain why alpha particles have a much shorter range in air than gamma rays.

Model answer. Alpha particles are much more strongly ionising than gamma rays (1), so they lose their energy over a much shorter distance (1).

Don't lose marks

- Saying beta particles are electrons from outside the nucleus. They are created in the nucleus.
- Saying gamma is 'stopped' by lead. Thick lead greatly reduces it, but some still gets through.
- Confusing activity (decays per second in the source) with count rate (what the detector records).
- Saying gamma rays have mass or charge. They are electromagnetic waves.
- In 'best source' questions, only explaining why the chosen one works, and not why the others do not.

More tips

Memory tricks

- **PAL**: **P**aper stops alpha, **A**luminium stops beta, **L**ead reduces gamma.
- Ionising power and range go opposite ways: the most ionising (alpha) travels the least far.
- Alpha is heavy with a +2 charge, so it ionises everything it passes and is stopped quickly.
- Beta is an electron, but it is made in the NUCLEUS, not taken from the electron shells.

Exam technique

- Use comparatives in 'compare' questions, e.g. 'alpha is more ionising than beta'.
- Quote data from the question, such as the thickness of material or count rates, in your answer.
- Give activity in Bq and name the detector (Geiger–Müller tube) if asked how radiation is measured.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 **Name the types of nuclear radiation**
Alpha particles (α), beta particles (β), gamma rays (γ) and neutrons (n).

Grade 4 **Define radioactive decay and activity**
Unstable nuclei give out radiation to become more stable; activity is decays per second, in becquerels (Bq).

Grade 4 **State what absorbs each radiation**
Alpha: paper; beta: a few mm of aluminium; gamma: reduced by thick lead or concrete.

Grade 4 **Compare penetration, range and ionising power**
Alpha is the most ionising with the shortest range; gamma is the least ionising with the longest range.

Grade 5 **Describe what each radiation is**

Alpha: 2 protons and 2 neutrons; beta: a fast electron from the nucleus; gamma: electromagnetic radiation.

Grade 6 **Explain how a beta particle is formed**

A neutron in the nucleus turns into a proton, and a high-speed electron is ejected.

Grade 7 **Choose the best radiation for a use**

Justify the choice using penetration and ionising power, and say why the others are unsuitable.

Grade 8 **Link ionising power to range**

The more strongly a radiation ionises, the faster it loses energy, so the shorter its range.

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