

Exercise walk-through

5.2

Radioactivity

IGCSE Physics

Radioactivity

An **unstable** nucleus
decays , giving out radiation.
Decay is **spontaneous** and **random**.

Background radiation

(radon, rocks, cosmic rays) is
always present – subtract it:

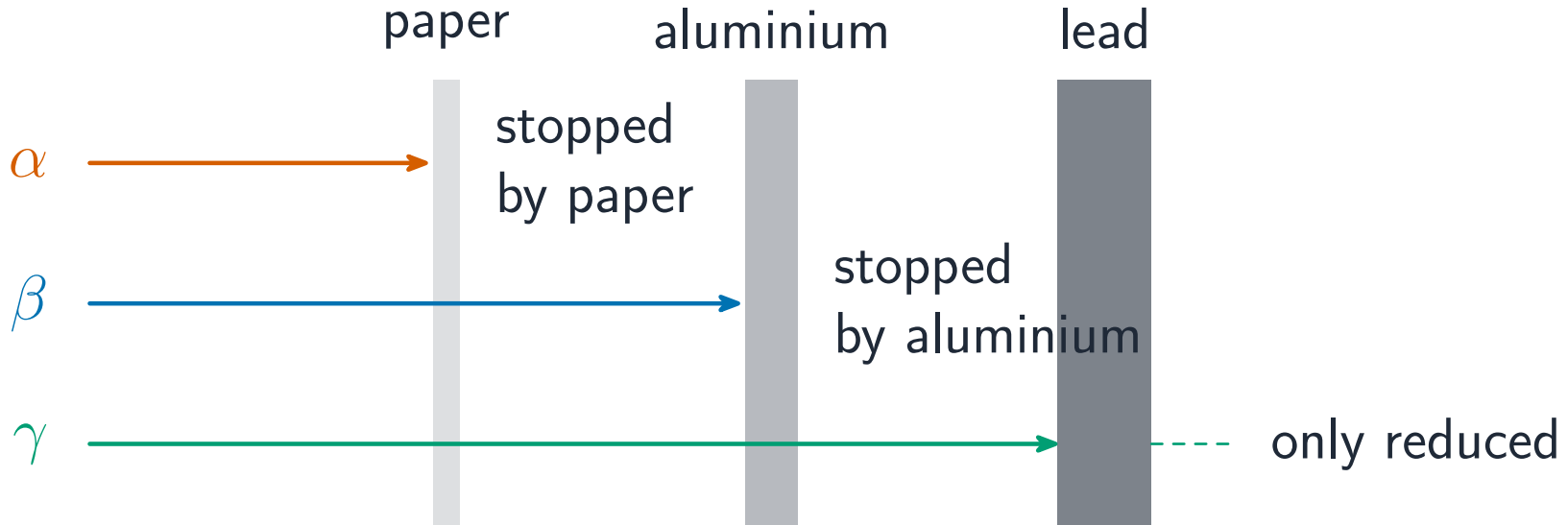
250 next to source, 30 back-
ground

corrected = 220 counts/min



Three types of radiation

- α – He nucleus (+2): most **ionising**, stopped by paper
- β – fast electron (−1): aluminium
- γ – EM wave (0): least ionising, only reduced by lead



Why alpha ionises most and penetrates least

alpha

charge +2, and **slow and heavy** – so it interacts strongly and often

the consequence

most ionising, and **least penetrating**: stopped by paper or a few cm of air

beta

charge -1 , fast and light – moderate on both counts; stopped by a few mm of aluminium

gamma

no charge, an electromagnetic wave – least ionising, most penetrating; reduced by thick lead or concrete

the explanation

ionising power comes from **charge** and from how long the particle spends near each atom

deflection

in a field alpha and beta bend in **opposite** directions, and gamma not at all

Ionising power and penetration are **inversely** related, and both follow from the same cause. Explain from charge and speed, never by listing.

Why the three radiations differ

Alpha

Charge $+2$, slow and heavy: it pulls hard on the electrons it passes, so it is the most **ionising** and the least penetrating – easily **absorbed** by paper or skin.

Beta

Charge -1 , fast and light: it ionises less and travels further, stopped by a few millimetres of aluminium.

Gamma

No charge, no mass – a wave. Least ionising, most penetrating; only thick lead or concrete reduces it much.

The reasoning

Explain from charge and **kinetic energy**, not from a memorised list: it is the charge that does the ionising and the mass that stops the particle.

Ionising power and penetration run in opposite directions – an ionising particle loses its energy quickly, which is exactly why it stops.

Deflection in fields

Charged α and β bend **opposite** ways; the lighter β bends more. Uncharged γ is **not** deflected.

α is ${}^4_2\text{He}^{2+}$; β is an electron (or positron); γ is a photon. Charge and mass decide the bend.

Exercises 2.1-2.3

2.1 State what material stops beta radiation.

[1]

2.2 Name two sources of background radiation.

[2]

2.3 A detector reads 250 counts/min; the background is 30 counts/min. Find the corrected count rate.

[2]

Exercises 2.1-2.3

2.1 State what material stops beta radiation. [1]

2.1

- a few millimetres of aluminium
-

2.2 Name two sources of background radiation. [2]

2.2

- any two of: radon gas in the air; rocks and buildings; food and drink; cosmic rays from space
-

2.3 A detector reads 250 counts/min; the background is 30 counts/min. Find the corrected count rate. [2]

2.3

- $\text{corrected} = 250 - 30$
- **220 counts/min**

Exercises 2.4·2.5

2.4 State the nature and the charge of an alpha particle and of a beta particle. [2]

2.5 Complete this decay equation, giving both numbers for the new nucleus: ${}_{84}^{210}\text{Po} \rightarrow$
 ${}_{?}^{?}\text{Pb} + {}_2^4\alpha$. [2]

Exercises 2.4·2.5

2.4 State the nature and the charge of an alpha particle and of a beta particle. [2]

2.4

- alpha: a helium nucleus (2 protons and 2 neutrons), charge +2
- beta: a fast-moving electron, charge -1

2.5 Complete this decay equation, giving both numbers for the new nucleus: ${}_{84}^{210}\text{Po} \rightarrow {}_?^{?}\text{Pb} + {}_2^4\alpha$. [2]

2.5

- nucleon number $210 - 4 = 206$
- proton number $84 - 2 = 82 \Rightarrow {}_{82}^{206}\text{Pb}$

Exercises 2.6·2.7

2.6 A source has a half-life of 6 hours. Its corrected count rate is now 960 counts/min.
Find the count rate after 18 hours. [3]

2.7 State two precautions a scientist should take when working with a radioactive source, and explain why each one lowers the dose. [4]

Exercises 2.6-2.7

2.6 A source has a half-life of 6 hours. Its corrected count rate is now 960 counts/min. Find the count rate after 18 hours. [3]

2.6

- $18 \div 6 = 3$ half-lives
- $960 \rightarrow 480 \rightarrow 240 \rightarrow 120$
- **120 counts/min**

2.7 State two precautions a scientist should take when working with a radioactive source, and explain why each one lowers the dose. [4]

2.7

- any two, each with its reason: reduce the time spent near the source, because the dose received rises with the exposure time; stand further away (use tongs), because the radiation spreads out so the intensity falls with distance; work behind lead shielding, because the lead absorbs the radiation before it reaches the body

Exercise 3.1

3.1 A source of radiation is placed near a detector. A sheet of paper between them makes no difference to the count rate, but a 5 mm sheet of aluminium reduces it almost to the background level. Which radiation is the source emitting? [1]

☐

A alpha only

B beta only

C gamma only

D alpha and gamma

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A alpha only

B beta only

C gamma only

D alpha and gamma

3.1 B

- paper stops alpha, so there is no alpha; aluminium stops beta and would not stop gamma, so the source emits beta only
- **A** and **D** would have been blocked by the paper; **C** would still pass through the aluminium

Exercise 3.2

3.2 A nucleus emits a beta particle. Which row is correct?

[1]

☐

A nucleon number unchanged, proton number $+1$

B nucleon number unchanged, proton number -1

C nucleon number -4 , proton number -2

D nucleon number -1 , proton number unchanged

Exercise 3.2

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A nucleon number unchanged, proton number $+1$

B nucleon number unchanged, proton number -1

C nucleon number -4 , proton number -2

D nucleon number -1 , proton number unchanged

3.2 A

- a neutron becomes a proton, so the proton number rises by one while the total number of nucleons is unchanged
- C describes alpha decay

Exercise 3.3 (a)

3.3 A student investigates a radioactive source. Before using it she records a count rate of 24 counts/min with the source in its lead box. With the source in place the detector reads 824 counts/min.

(a) Explain why she measured the count rate before bringing out the source, and calculate the corrected count rate. [3]

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(a) Explain why she measured the count rate before bringing out the source, and calculate the corrected count rate. [3]

(a) the reading with the source shut away is the background radiation, which is always present and must be subtracted so the count rate is due to the source alone

- $\text{corrected} = 824 - 24 = \mathbf{800}$ counts/min

Exercise 3.3 (b)

3.3 A student investigates a radioactive source. Before using it she records a count rate of 24 counts/min with the source in its lead box. With the source in place the detector reads 824 counts/min.

(b) The corrected count rate falls to 100 counts/min after 12 hours. Determine the half-life of the source. [3]

Exercise 3.3 (b)

3.3 A student investigates a radioactive source. Before using it she records a count rate of 24 counts/min with the source in its lead box. With the source in place the detector reads 824 counts/min.

(b) The corrected count rate falls to 100 counts/min after 12 hours. Determine the half-life of the source. [3]

(b) $800 \rightarrow 400 \rightarrow 200 \rightarrow 100$ is 3 half-lives

- half-life = $12 \div 3 = 4$ hours

Exercise 3.3 (c)

3.3 A student investigates a radioactive source. Before using it she records a count rate of 24 counts/min with the source in its lead box. With the source in place the detector reads 824 counts/min.

(c) The source emits beta particles. Describe what happens inside a nucleus when a beta particle is emitted.

[2]

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(c) The source emits beta particles. Describe what happens inside a nucleus when a beta particle is emitted. [2]

(c) a neutron in the nucleus changes into a proton

- and an electron, which is emitted as the beta particle

Exercise 3.3 (d)

3.3 A student investigates a radioactive source. Before using it she records a count rate of 24 counts/min with the source in its lead box. With the source in place the detector reads 824 counts/min.

(d) Suggest, with a reason, whether this source would be suitable for a smoke alarm. [2]

Exercise 3.3 (d)

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(d) Suggest, with a reason, whether this source would be suitable for a smoke alarm. [2]

(d) **no**

- beta passes through smoke without being absorbed, so the current would not change when smoke entered – an alarm needs an alpha source

Exercise 3.4 (a)

3.4 A smoke alarm contains a small americium-241 source, which decays by alpha emission to an isotope of neptunium (Np).

(a) Complete the nuclide equation: ${}^{241}_{95}\text{Am} \rightarrow \dots\dots\text{Np} + \dots\dots\alpha$. [3]

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(a) ${}^{237}_{93}\text{Np}$ and ${}^4_2\alpha$

Exercise 3.4 (b)

3.4 A smoke alarm contains a small americium-241 source, which decays by alpha emission to an isotope of neptunium (Np).

(b) Describe how the alpha particles ionise the air inside the alarm. [3]

Exercise 3.4 (b)

3.4 A smoke alarm contains a small americium-241 source, which decays by alpha emission to an isotope of neptunium (Np).

(b) Describe how the alpha particles ionise the air inside the alarm. [3]

(b) the alpha particles are emitted from the americium

- and collide with (or pass close to) molecules in the air between the plates
- knocking electrons out of them so the air contains ions and conducts

Exercise 3.4 (c)

3.4 A smoke alarm contains a small americium-241 source, which decays by alpha emission to an isotope of neptunium (Np).

(c) Suggest and explain two reasons why the alarm uses an alpha emitter rather than a gamma emitter.

[4]

Exercise 3.4 (c)

3.4 A smoke alarm contains a small americium-241 source, which decays by alpha emission to an isotope of neptunium (Np).

(c) Suggest and explain two reasons why the alarm uses an alpha emitter rather than a gamma emitter. [4]

(c) any two, each with its explanation: alpha is easily absorbed by smoke particles, so the current drops as soon as smoke enters, while gamma would pass straight through and the alarm would not respond; alpha is much more ionising, so it makes the air conduct well enough to give a steady current; alpha has a very short range and is stopped by the plastic case, so it is far less harmful to people in the house than gamma would be

Exercise 3.4 (d)

3.4 A smoke alarm contains a small americium-241 source, which decays by alpha emission to an isotope of neptunium (Np).

(d) The half-life of americium-241 is 432 years. Explain why this long half-life is an advantage for a smoke alarm. [1]

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(d) The half-life of americium-241 is 432 years. Explain why this long half-life is an advantage for a smoke alarm. [1]

(d) the activity stays almost constant for the whole life of the alarm, so it does not need replacing

Exercise 3.5 (a)

3.5 A hospital uses a gamma-emitting isotope with a half-life of 6 hours as a medical tracer.

(a) Explain why a gamma emitter, and not an alpha emitter, is used inside the body. [2]

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3.5 A hospital uses a gamma-emitting isotope with a half-life of 6 hours as a medical tracer.

- (a) Explain why a gamma emitter, and not an alpha emitter, is used inside the body. [2]
- (a) gamma is the most penetrating, so it passes out of the body to the detector outside
- alpha would be absorbed within a few centimetres of tissue, giving a large dose to the patient and no signal outside

Exercise 3.5 (b)

3.5 A hospital uses a gamma-emitting isotope with a half-life of 6 hours as a medical tracer.

(b) Explain why a half-life of 6 hours is more suitable than one of 6 years. [2]

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(b) Explain why a half-life of 6 hours is more suitable than one of 6 years. [2]

(b) a 6-hour half-life means the activity falls to a safe level within a day, so the patient's dose is small

- a 6-year half-life would keep irradiating the patient long after the scan

Exercise 3.5 (c)

3.5 A hospital uses a gamma-emitting isotope with a half-life of 6 hours as a medical tracer.

(c) A sample contains $80\ \mu\text{g}$ of the isotope. Calculate the mass that has decayed after 24 hours. [3]

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(c) A sample contains $80 \mu\text{g}$ of the isotope. Calculate the mass that has decayed after 24 hours. [3]

(c) $24 \div 6 = 4$ half-lives

- mass left $= 80 \div 2^4 = 80 \div 16 = 5.0 \mu\text{g}$
- mass decayed $= 80 - 5.0 = \mathbf{75} \mu\text{g}$

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(d) any two of: cell death; mutation of the genes; cancer