8.1 Alpha, Beta & Gamma Radiation

PHYSICS

AQA A Level Revision Notes

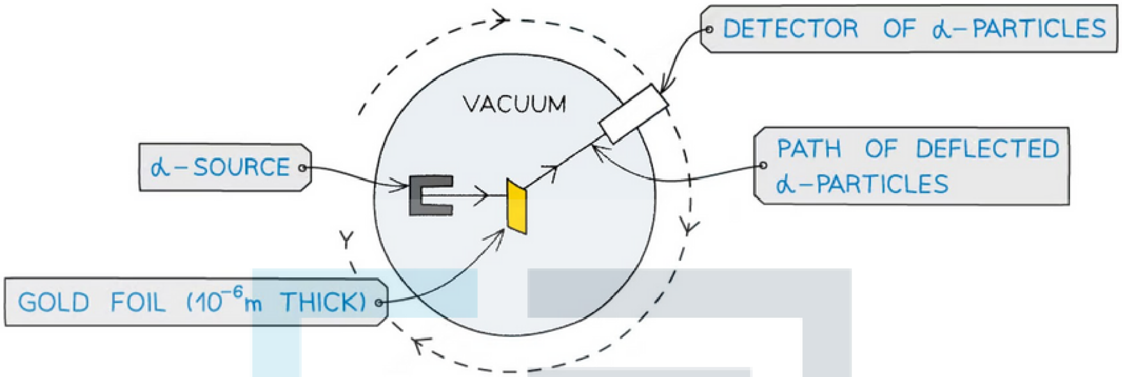
A Level Physics AQA

8.1 Alpha, Beta & Gamma Radiation

CONTENTS

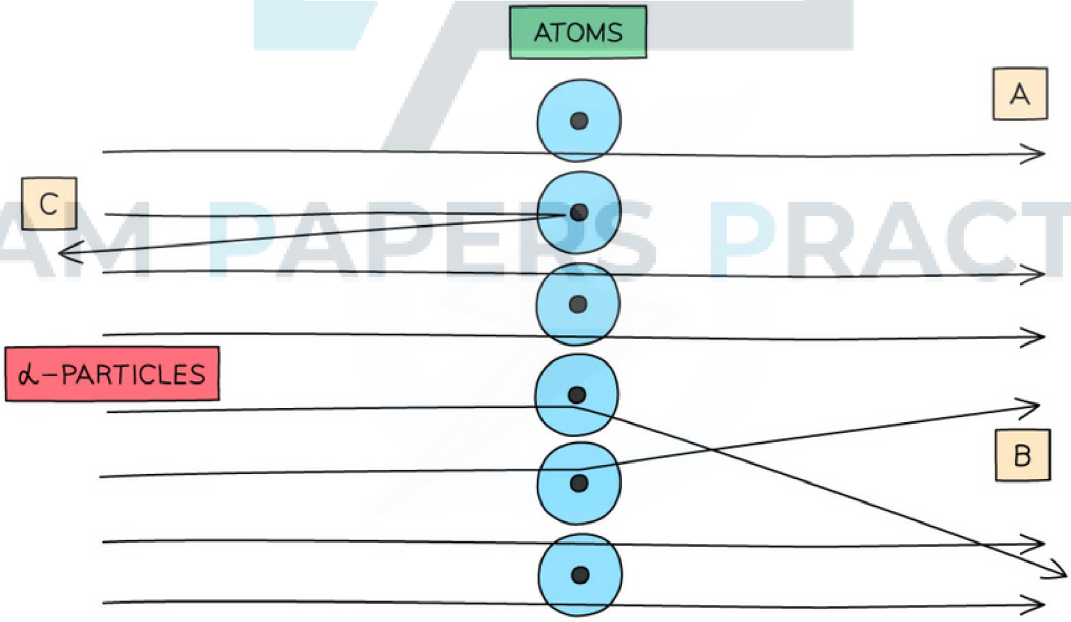
Rutherford Scattering

- Evidence for the structure of the atom was discovered by Ernest Rutherford in the beginning of the 20th century from the study of **α-particle scattering**
- The experimental setup consists of alpha particles fired at thin gold foil and a detector on the other side to detect how many particles deflected at different angles



α-particle scattering experiment set up

- α-particles are the nucleus of a helium atom and are positively charged

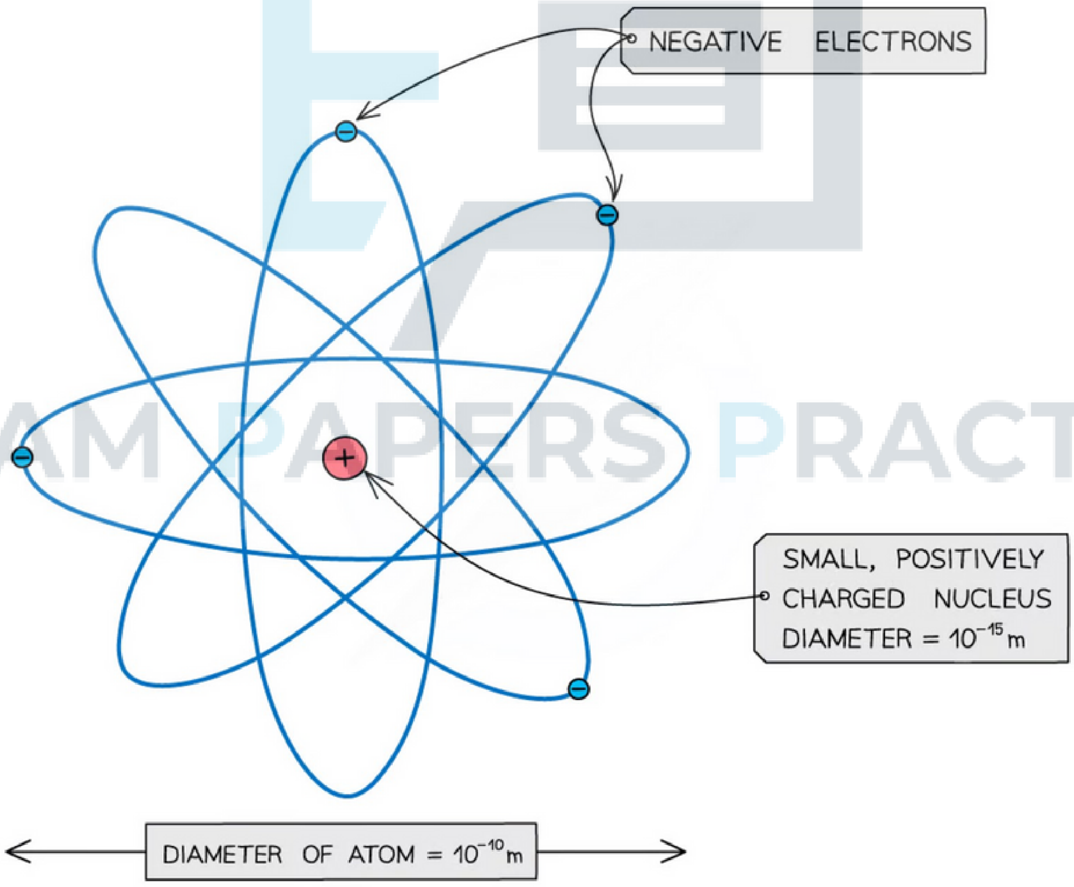


When α-particles are fired at thin gold foil, most of them go straight through but a small number bounce straight back

- From this experiment, Rutherford results were:
- **The majority of α-particles went straight through (A)**

  - This suggested the atom is mainly empty space
- **Some α-particles deflected through small angles of < 10° (B)**
  - This suggested there is a positive nucleus at the centre (since two positive charges would repel)
- **Only a small number of α-particles deflected straight back at angles of > 90° (C)**
  - This suggested the nucleus is extremely small and this is where the mass and charge of the atom is concentrated
  - It was therefore concluded that atoms consist of ***small dense positively charged nuclei***

- Since atoms were known to be neutral, the negative electrons were thought to be on a positive sphere of charge (plum pudding model) before the nucleus was theorised
- Now it is known that the negative electrons are orbiting the nucleus. Collectively, these make up the atom

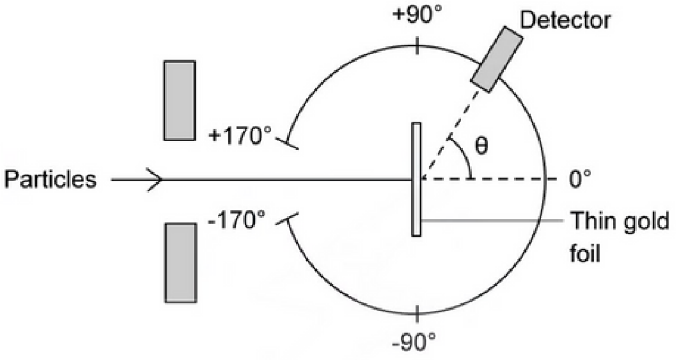


An atom: a small positive nucleus, surrounded by negative electrons

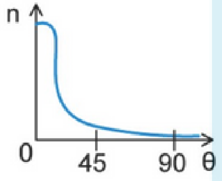
- Note: The atom is around 100,000 times larger than the nucleus!

Worked Example

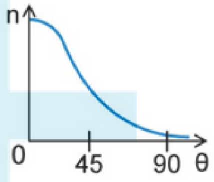
In an α-particle scattering experiment, a student set up the apparatus below to determine the number n of α-particle incident per unit time on a detector held at various angles θ.



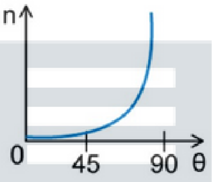
Which of the following graphs best represents the variation of n with θ from 0 to 90°?



A.



B.



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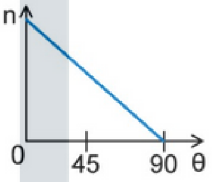


D.

ANSWER: A

- The Rutherford scattering experiment directed parallel beams of α-particles at gold foil
- The observations were:
    - Most of the α-particles went straight through the foil
    - The largest value of n will therefore be at small angles
    - Some of the α-particles were deflected through small angles
    - n drops quickly with increasing angle of deflection θ

- These observations fit with graph **A**

8.1.2 Changing Models of the Nucleus

Changing Models of the Nucleus

John Dalton's Model (1803)

- Dalton imagined that all matter was made of tiny solid particles called atoms
- Dalton's model proposed:
    - Atoms are the smallest constituents of matter and cannot be broken down any further
    - Atoms of a given element are **identical** to each other and atoms of different elements are **different** from one another
    - When chemical reactions occur, the atoms rearrange to make different substances

J.J. Thomson's Model (1897)

- Thomson discovered the electron
- He then went on to propose the 'plum pudding' model of the atom
- In this model:
    - The atom consists of positive and negative charges in equal amounts so that it is neutral overall
    - They were modelled as spheres of positive charge with uniformly distributed charge and density. The negatively charged electrons were thought to be stuck to the sphere like currants in a plum pudding

Rutherford's Gold Foil Experiment (1909 – 1911)

- Hans Geiger and Ernest Marsden set out to test the plum pudding model
- They aimed beams of positively charged particles (alpha particles) at very thin gold foil
- According to the plum pudding model, these particles should have passed straight through, However, many of them were backscattered
- Ernest Rutherford explained these results in his 'planetary model of atom' which states:
    - Atoms have a central, positively charged nucleus containing the majority of the mass
    - Electrons orbit the nucleus, like planets around a star

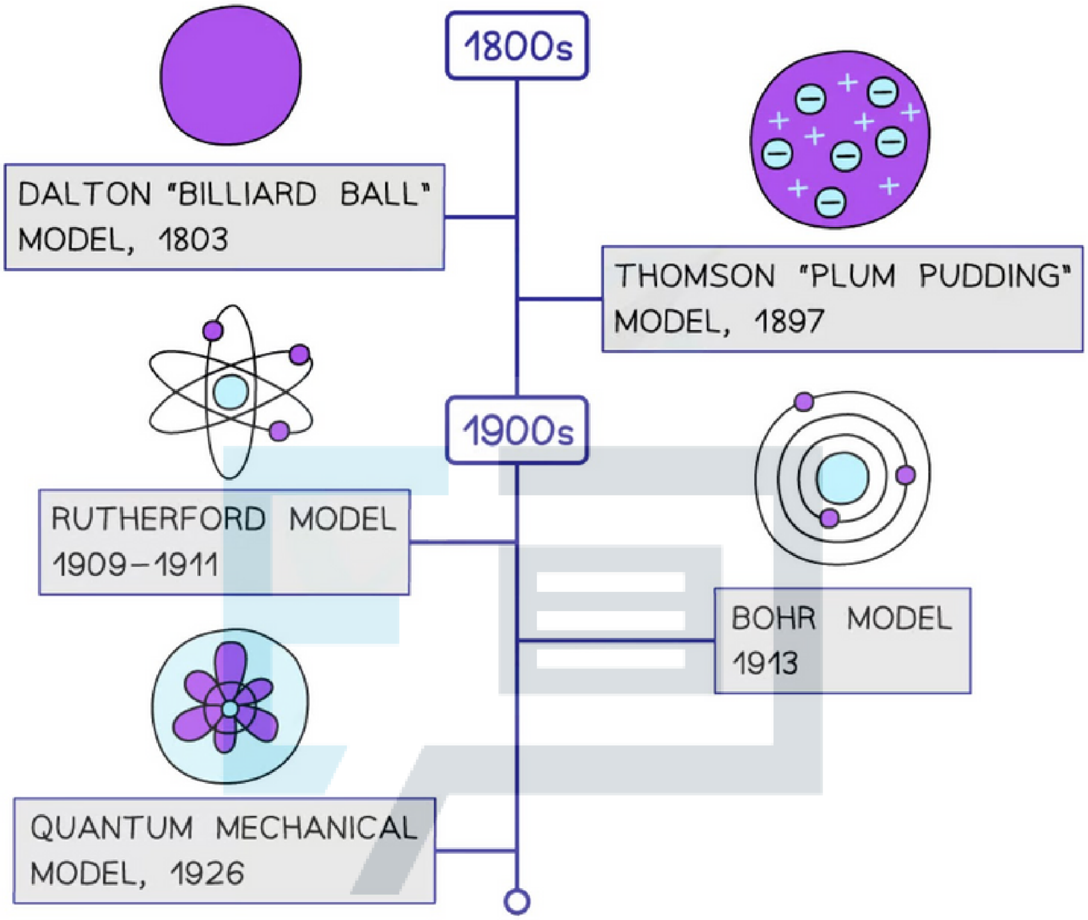
Neils Bohr's Model (1913)

- Bohr improved upon Rutherford's planetary model
- Using mathematical ideas, he showed that electrons occupy **shells** or **energy levels** around the nucleus
    - These are at particular distances from the nucleus

Quantum Mechanical Model (1926)

- Erwin Schrödinger took Bohr's model further and used equations to calculate the likelihood of finding an electron in a certain position
- This model can be portrayed as a nucleus surrounded by an electron cloud. Where the cloud is most dense, the probability of finding the electron is greatest and vice versa

- The atom was thought to only have a positively charged nucleus surrounded by negatively charged electrons. James Chadwick then discovered the neutron in 1932, which completes the model of the atom we know today



Timeline of the changing models of the nucleus

8.1.3 Alpha, Beta & Gamma Radiation

Alpha, Beta & Gamma Radiation

Alpha Particles

- **Alpha (α) particles** are high energy particles made up of **2 protons and 2 neutrons** (the same as a helium nucleus)
- They are usually emitted from nuclei that are too large

$${}^{4}_{2}\alpha \quad \text{OR} \quad {}^{4}_{2}\text{He}$$

Nuclear notation for an alpha particle (a helium nucleus)

- Alpha is the **most** ionising type of radiation
  - This is due to it having the highest charge of +2e
  - This means it produces the greatest number of ion pairs per mm in air
  - This also means it is able to do more damage to cells than the other types of radiation
- Alpha is the **least** penetrating type of radiation
  - This means it travels the shortest distance in air before being absorbed
  - Alpha particles have a range of around 3–7 cm in air
- Alpha can be stopped by a single **piece of paper**

Beta Particles

- **Beta (β^-) particles are high energy electrons** emitted from the nucleus
- **Beta (β^+) particles are high energy positrons** (antimatter of electrons) also emitted from the nucleus
  - β^- particles are emitted by nuclei that have too many **neutrons**
  - β^+ particles are emitted by nuclei that have too many **protons**

$${}^{0}_{-1}\beta \qquad {}^{0}_{+1}\beta$$

BETA MINUS

BETA PLUS

Nuclear notation for beta minus and beta plus particle

- Beta is a **moderately** ionising type of radiation
  - This is due to it having a charge of +1e
  - This means it is able to do some slight damage to cells (less than alpha but more than gamma)

- Beta is a **moderately** penetrating type of radiation
    - Beta particles have a range of around 20 cm - 3 m in air, depending on their energy

- Beta can be stopped by a few millimetres of **aluminium** foil

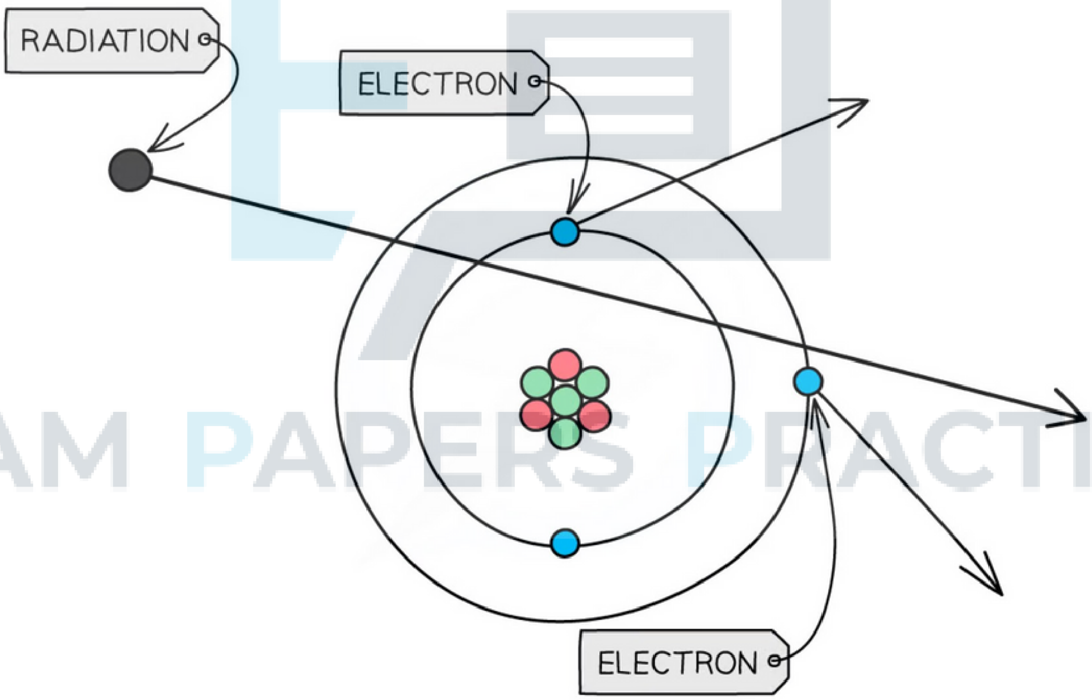
Gamma Radiation

- **Gamma (γ) rays are high energy electromagnetic waves**
- They are emitted by nuclei that need to lose some energy

$$^{0}_{0}\gamma$$

Nuclear notation for gamma rays

- If these particles hit other atoms, they can knock out electrons, **ionising the atom**
- This can cause chemical changes in materials and can damage or kill living cells

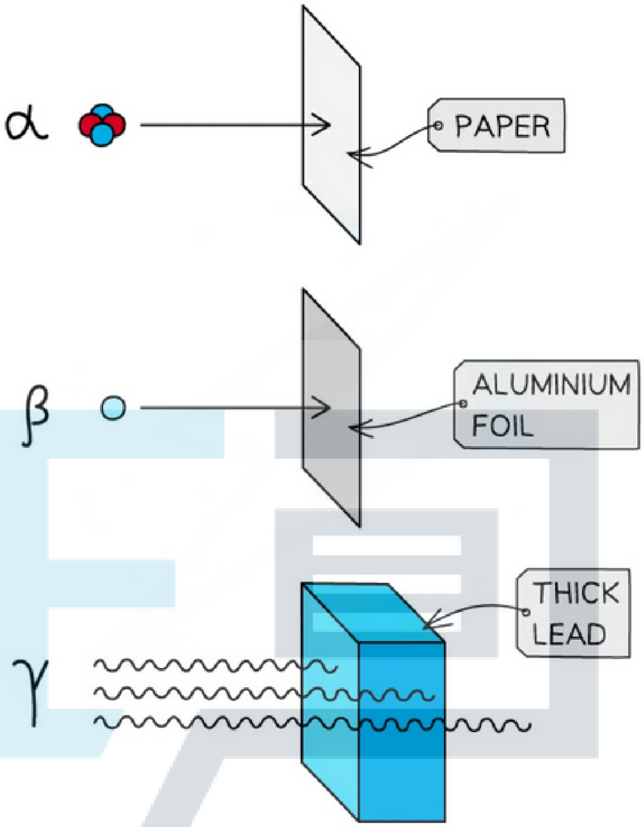


When radiation passes close to atoms, it can knock out electrons, ionising the atom

- Gamma is the **least** ionising type of radiation
    - This is because it is an electromagnetic wave with no charge
    - This means it produces the least number of ion pairs per mm in air
    - It can still cause damage to cells, but not as much as alpha or beta radiation. This is why it is used for cancer radiotherapy

- Gamma is the **most** penetrating type of radiation

  - This means it travels the furthest distance in air before being absorbed
  - Gamma radiation has an infinite range and follows an **inverse square law**
- Gamma can be stopped by several **metres of concrete** or several **centimetres of lead**

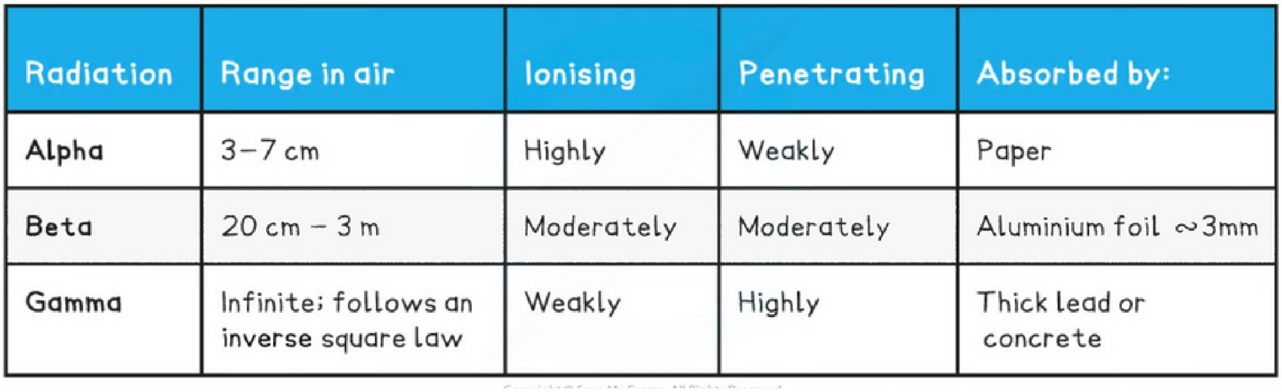


Different types of radiation are stopped by different materials

Comparing Alpha, Beta & Gamma

- The properties of the different types of radiation are summarised in the table below:

Comparing Different Types of Radiation Table



Radiation	Range in air	Ionising	Penetrating	Absorbed by:
Alpha	3–7 cm	Highly	Weakly	Paper
Beta	20 cm – 3 m	Moderately	Moderately	Aluminium foil ~3mm
Gamma	Infinite; follows an inverse square law	Weakly	Highly	Thick lead or concrete

Worked Example

Three successive radioactive decays are shown in the diagram below; each one results in a particle being emitted.
The first decay results in the emission of β-particle. The second decay results in the emission of an α-particle. The third decay results in the emission of another β-particle.

$$\begin{tikzcd}
 & \beta- & & \alpha & & \beta+ \\
{}^{237}_{92}W \arrow[r] \arrow[ur] & X \arrow[r] \arrow[urr] & & Y \arrow[r] \arrow[ur] & Z &
\end{tikzcd}$$

Nuclides W and Z are compared.
Which nuclide of Z is formed at the end of this decay?

A. ${}^{237}_{90}Z$ **B.** ${}^{233}_{92}Z$ **C.** ${}^{237}_{89}Z$ **D.** ${}^{233}_{90}Z$

ANSWER: D

STEP 1

BETA MINUS DECAY

A $\beta-$ IS AN ELECTRON

THE NUCLEON NUMBER STAYS THE SAME

$${}^{237}_{92}W \longrightarrow {}^{237}_{93}X + {}^{0}_{-1}\beta$$

THE PROTON NUMBER INCREASES BY 1

STEP 2

ALPHA DECAY

A α PARTICLE IS A HELIUM NUCLEUS

THE NUCLEON NUMBER REDUCES BY 4

$${}^{237}_{93}X \longrightarrow {}^{233}_{91}Y + {}^{4}_{2}\alpha$$

THE PROTON NUMBER REDUCES BY 2

STEP 3

BETA PLUS DECAY

A $\beta+$ PARTICLE IS A POSITRON

THE NUCLEON NUMBER STAYS THE SAME

$${}^{233}_{91}Y \longrightarrow {}^{233}_{90}Z + {}^{0}_{+1}\beta$$

THE PROTON NUMBER REDUCES BY 1

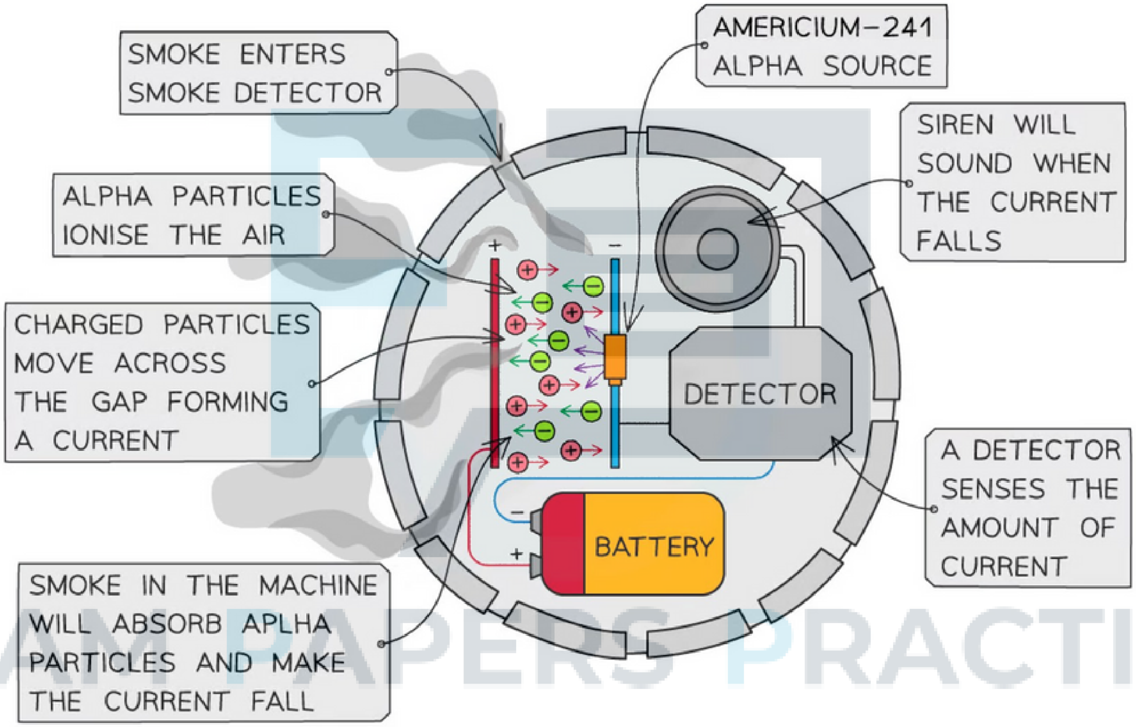
STEP 4

THE FINAL NUCLEON WILL BE ${}^{233}_{90}Z$

Applications of Alpha, Beta & Gamma

Smoke Detectors

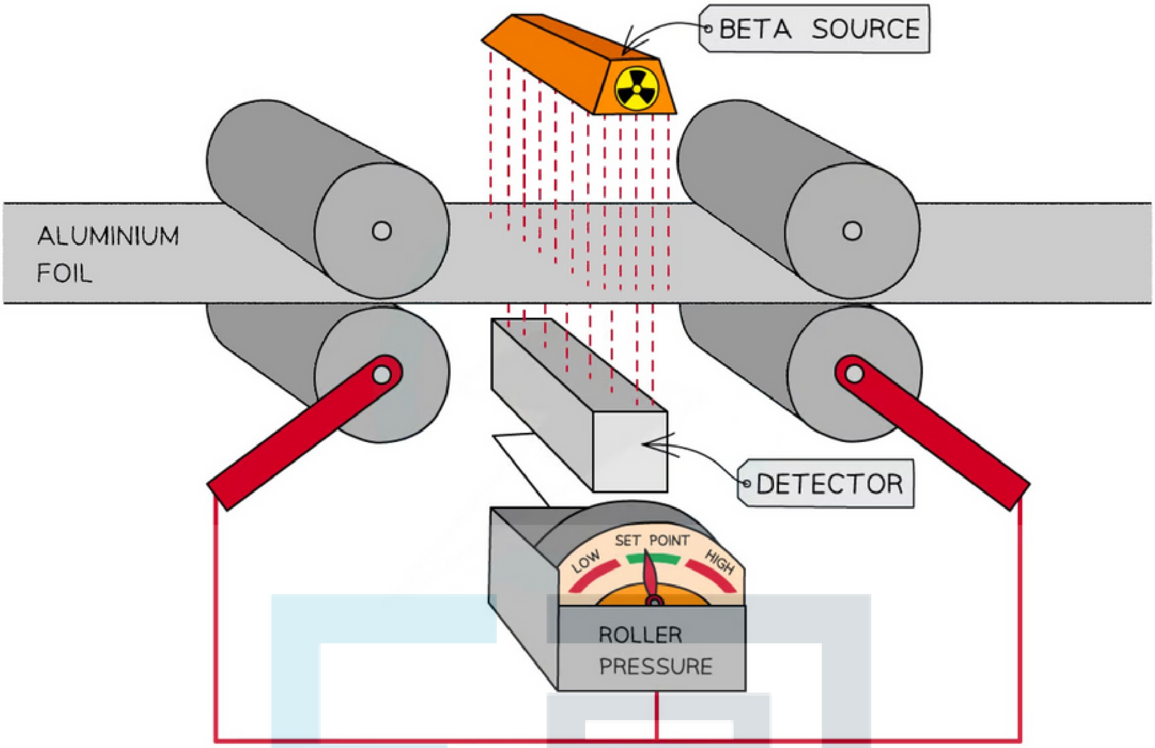
- Smoke detectors contain a small amount of Americium-241, which is a weak alpha source
- Within the detector, alpha particles are emitted and cause the ionisation of nitrogen and oxygen molecules in the air
- These ionised molecules enable the air to conduct electricity and hence a small current can flow
- If smoke enters the alarm, it absorbs the alpha particles, hence reducing the current which causes the alarm to sound
- Am-241 has a half-life of 460 years, meaning over the course of a lifetime, the activity of the source will not decrease significantly and it will not have to be replaced



The operation of a smoke detector

Thickness Controls

- Beta radiation can be used to determine the thickness of aluminium foil, paper, plastic, and steel
- The thickness can be controlled by measuring how much beta radiation passes through the material to a Geiger counter
- Beta radiation must be used, because:
  - Alpha particles would be absorbed by all the materials
  - Gamma radiation would pass through undetected through the materials
- The Geiger counter controls the pressure of the rollers to maintain the correct thickness
- A source with a long half-life must be chosen so that it does not need to be replaced often



The pressure of the rollers can be adjusted to control the thickness of the aluminium foil depending on the amount of beta radiation detected

Worked Example

Below are listed four radioactive sources, together with the type of radiation they emit

A	Americium-241	Alpha (α)
B	Strontium-90	Beta Minus (β^-)
C	Cobalt-60	Beta Minus (β^-) & Gamma (γ)
D	Fluorine-18	Beta Plus (β^+)

Which isotope is suitable for the purpose of:

a) Sterilising hospital equipment sealed inside plastic bags?

b) Discharging static electricity that has built up in the manufacture of polythene?

c) Monitoring the thickness of a thin metal being produced in a factory?

d) A smoke detector?

a) **ANSWER: C**

- Alpha and low energy beta radiation would most likely be absorbed by the bag
- Therefore, gamma radiation, or very high energy beta particles, would be needed to penetrate the bag
- This would be best suited to **Cobalt-60**

b) **ANSWER: D**

- Static electricity is an imbalance of electric charges on the surface of the polythene and is generally composed of negatively charged electrons
- In order to get rid of the static charge, it will need to be neutralised
- Beta-plus particles, or positrons, are the antimatter counterpart of the electron, and hence, are oppositely charged
- When the positrons are directed at the surface of the polythene, the electrons will be attracted to them and become neutralised as the particles annihilate as they collide
- Therefore, the beta-plus emitter, **Fluorine-18**, would be best suited to this job

c) **ANSWER: B**

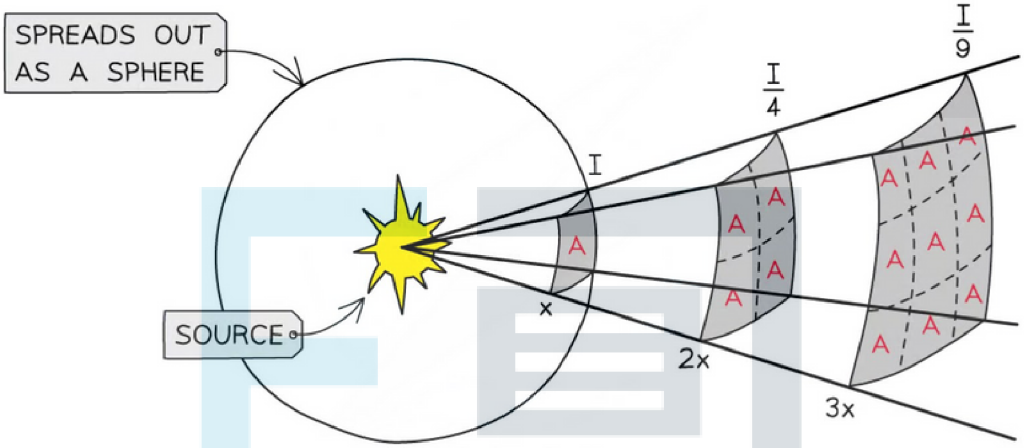
- Alpha particles would **not** be suitable for measuring the thickness of metal as they can be stopped by a **thin sheet of paper**
- Gamma rays are the most penetrating of the radiations and hence would **not** be suitable where thickness monitoring is up to a few millimetres as they would **all pass through**
- Beta particles are ideally suited as they have enough energy to pass through thin sheets of metal and any changes in thickness would be easily detected
- Therefore, the beta-minus emitter **Strontium-90** would be the most suitable isotope

d) **ANSWER: A**

- Since smoke detectors are present inside homes and other buildings, they must **pose no hazard** to residents
- This means the smoke detector must contain a **very small amount** of the radioactive material
- Also, the radiation should not be too penetrating and should only be able to travel **a few centimetres**
- Therefore, an alpha source should be selected – this means **Americium-241** would be the most suitable isotope

Inverse-Square Law of Gamma Radiation

- As an electromagnetic wave, gamma radiation shares many of the same wave properties as light
- Light sources which are further away appear fainter because the light they emit is spread out over a greater area than a light source which is closer by
- The moment the light leaves the source, it begins to spread out uniformly as a sphere, according to an **inverse square law**



When an EM wave spreads out, the area over which it spreads is proportional to the radius squared

- This applies to gamma radiation too, and can be calculated using the equation:

$$I = \frac{k}{x^2}$$

- Where:
  - I = intensity of the gamma radiation (W m^{-2})
  - k = constant of proportionality
  - x = the distance from the source (m)

- Since k is a constant, this equation can be written for radiation at two different points as follows:

$$\frac{I_1}{I_2} = \left(\frac{x_2}{x_1}\right)^2$$

- Where:
  - I_1 = intensity of the gamma radiation at x_1 (W m^{-2})
  - I_2 = intensity of the gamma radiation at x_2 (W m^{-2})
  - x_1 = the initial distance from the source (m)
  - x_2 = the subsequent distance from the source (m)

Worked Example

A source of gamma radiation is placed at a distance of 0.2 m away from a small radiation detector. The detector records a corrected count rate of 200 Bq from the gamma source. Calculate the count rate that would be recorded when the detector is moved a distance of 0.5 m away from the source.

Step 1: List the known quantities

Initial count rate, I_1 = 200 Bq

Initial distance, x_1 = 0.2 m

Final count rate = I_2

Final distance, x_2 = 0.5 m

Step 2: Write down the inverse square law equation

$$I \propto \frac{1}{x^2}$$

$$\frac{I_2}{I_1} = \left(\frac{x_1}{x_2}\right)^2$$

Step 3: Rearrange and calculate the count rate at 0.5 m

$$I_2 = 200 \times \left(\frac{0.2}{0.5}\right)^2 = 32 \text{ Bq}$$

Exam Tip

As you can see from the worked example, the inverse square law applies to other quantities such as the activity, or count rate, of the gamma radiation as well as the intensity. However, you must remember that the inverse square law **only** applies to gamma radiation and not alpha or beta radiation. This is because gamma radiation is not absorbed by matter easily, whereas alpha and beta are absorbed quickly before they can spread out.

8.1.5 Background Radiation

Background Radiation

- Background radiation describes the low level of radiation present in the surroundings at all times
- There are two types of sources of background radiation:
  - Natural sources
  - Man-made sources

Natural Sources

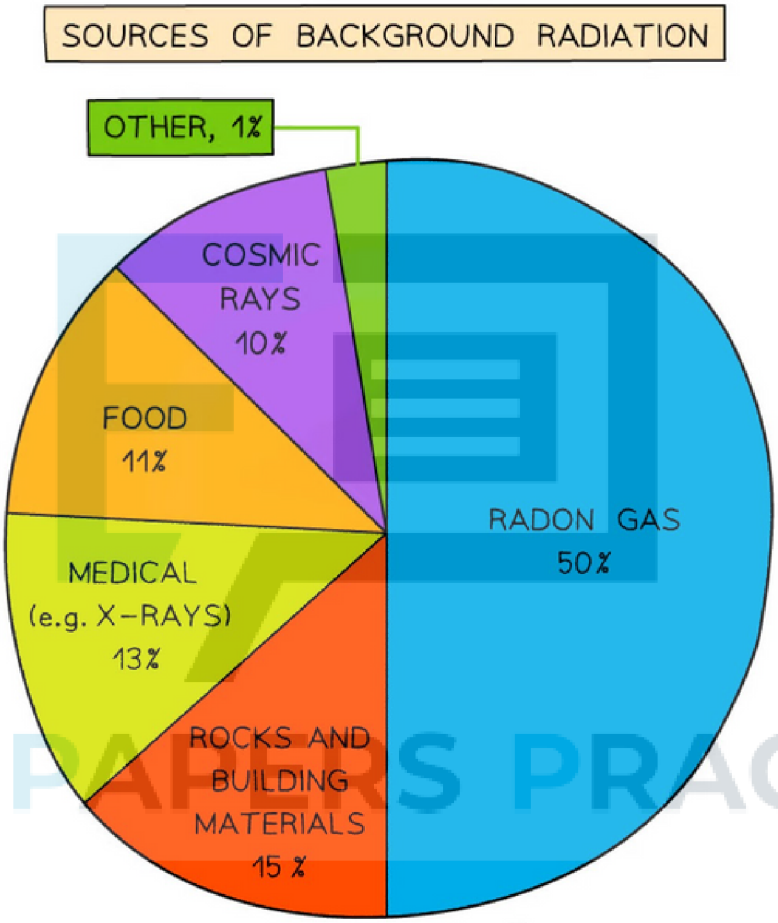
- **Radon gas from rocks and soil**
  - Heavy radioactive elements, such as uranium and thorium, occur naturally in rocks in the ground
  - Uranium decays into radon gas, which is an alpha emitter
  - This is particularly dangerous if inhaled into the lungs in large quantities
- **Cosmic rays from space**
  - The sun emits an enormous number of protons every second
  - Some of these enter the Earth's atmosphere at high speeds
  - When they collide with molecules in the air, this leads to the production of gamma radiation
  - Other sources of cosmic rays are supernovae and other high energy cosmic events
- **Carbon-14 in biological material**
  - All organic matter contains a tiny amount of carbon-14
  - Living plants and animals constantly replace the supply of carbon in their systems hence the amount of carbon-14 in the system stays almost constant
- **Radioactive material in food and drink**
  - Naturally occurring radioactive elements can get into food and water since they are in contact with rocks and soil containing these elements
  - Some foods contain higher amounts such as potassium-40 in bananas
  - However, the amount of radioactive material is minuscule and is not a cause for concern

Man-Made Sources

- **Medical sources**
  - In medicine, radiation is utilised all the time
  - Uses include X-rays, CT scans, radioactive tracers, and radiation therapy
- **Nuclear waste**
  - While nuclear waste itself does not contribute much to background radiation, it can be dangerous for the people handling it
- **Nuclear fallout from nuclear weapons**
  - Fallout is the residue radioactive material that is thrown into the air after a nuclear explosion, such as the bomb that exploded at Hiroshima

    - While the amount of fallout in the environment is presently very low, it would increase significantly in areas where nuclear weapons are tested

- **Nuclear accidents**
    - Accidents such as that in Chernobyl contributed a large dose of radiation into the environment
    - While these accidents are now extremely rare, they can be catastrophic and render areas devastated for centuries



In the UK, radon gas is by far the largest proportion of background radiation, whereas radiation due to nuclear waste and fallout accounts for less than 1%

Corrected Count Rate

- Background radiation must be accounted for when taking readings in a laboratory
- This can be done by taking readings with no radioactive source present and then subtracting this from readings with the source present
    - This is known as the **corrected count rate**

8.1.6 Radiation Safety

Safe Handling of Radioactive Sources

- It is very well known that radioactive sources are dangerous if handled improperly
- When choosing a source to work with, the following characteristics are preferred:
    - Short-lived isotopes are preferred to long-lived ones
    - The smaller the amount of radioactive material, the better

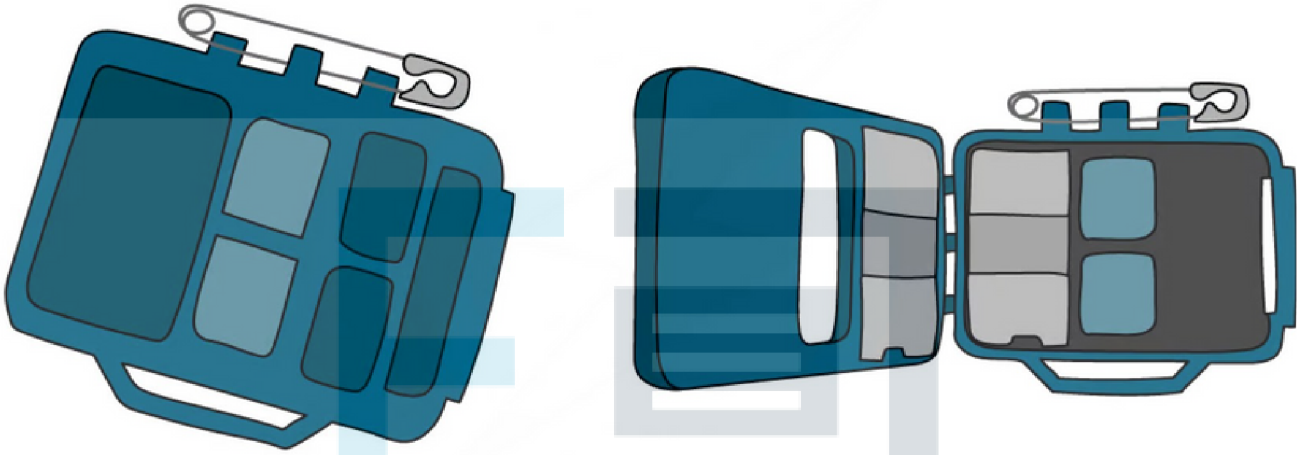
- The risk associated with radioactive materials depends on the **amount** and **type** of radiation
    - For example, alpha radiation is more ionising than gamma radiation but does not penetrate as far

- The biggest risks when working with radioactive sources are **exposure** and **contamination**
    - Contamination happens when a piece of radioactive material is transferred onto a person, or a personal item, where it can then decay and cause damage

- The radiation hazard warning safety symbol is used to warn about hazardous materials, locations or objects

- Precautions must be taken to reduce the risk of harm when using radioactive sources. These include:

- Keeping radioactive sources shielded when not in use, for example in a lead-lined bo
- Wearing protective clothing to prevent the body from becoming contaminated
- Keeping personal items outside of the room to prevent these from becoming contaminated
- Limiting exposure time so less time is spent with radioactive materials
- Handling radioactive materials with long tongs to increase the distance from them
- Monitoring the exposure of workers, such as radiographers, using detector badges



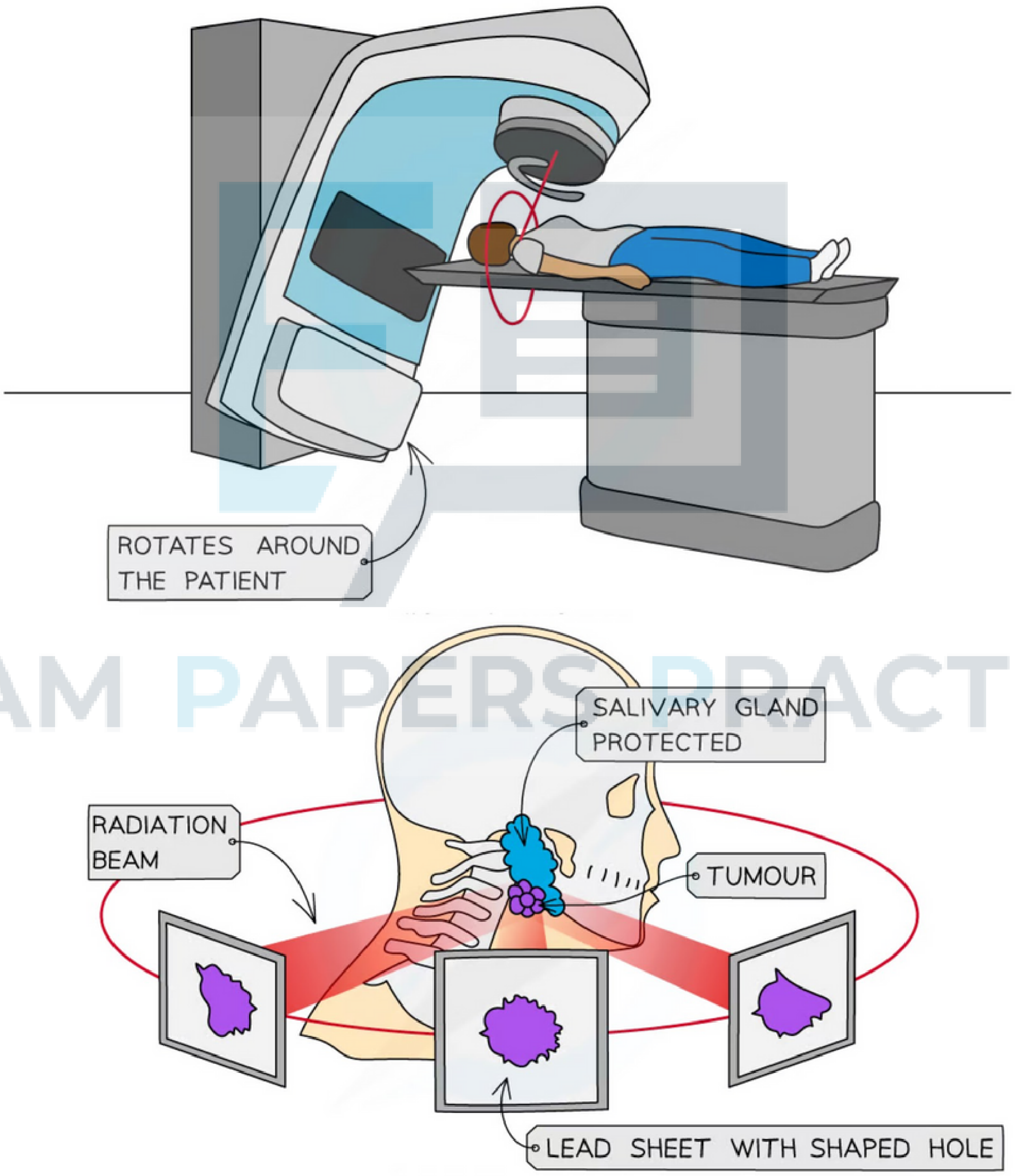
A badge containing photographic film can be used to monitor a person's exposure to radiation

Radiation in Medicine

- Radioactive materials can cause a huge amount of damage to the human body, however, under careful management, they can be of huge benefit in medicine

Radiation Therapy

- Gamma radiation can be used to destroy cancerous tumours
    - The gamma rays are concentrated on the tumour to protect the surrounding tissue
- Less penetrating beta radiation can be used to treat skin cancer by direct application to the affected area



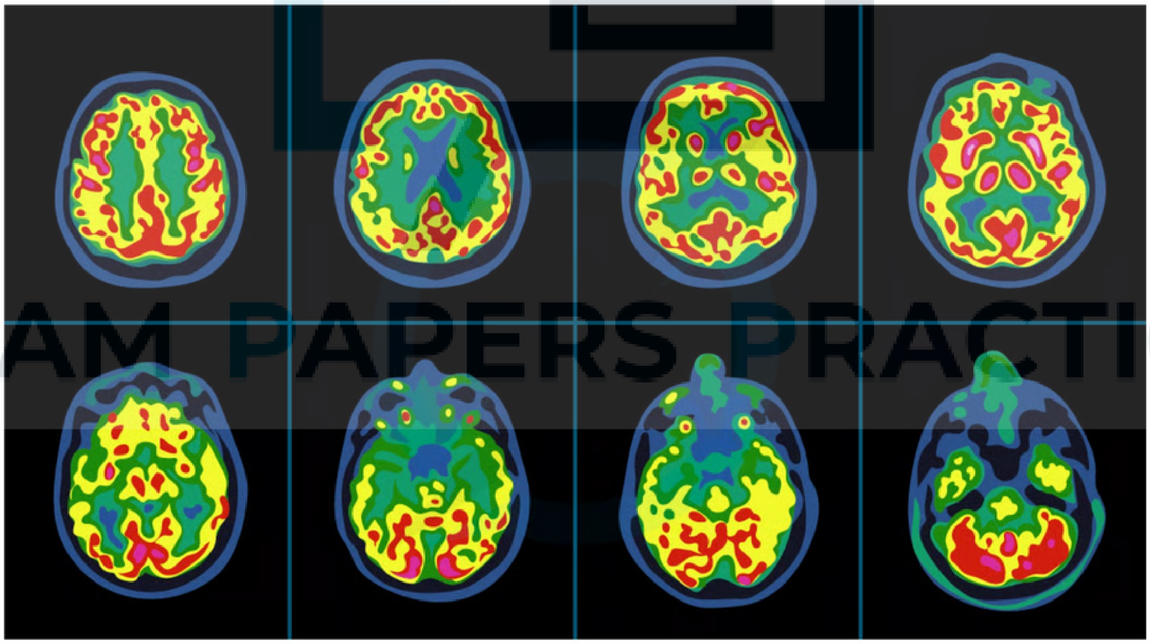
A radiotherapy machine. Powerful radiation is directed at the tumour and lead sheets can be used to prevent healthy tissue from being damaged

- Precautions for the **patient**:
  - The patient should be protected with lead to cover parts of the body not to be exposed to radiation
  - The exact dose should be calculated carefully
  - The dose should be directed very accurately at the cancerous tissue to minimise damage to healthy tissue

- Precautions for the **radiographer**:
  - The radiographer should handle the source remotely with tongs or a machine
  - The radiographer should be protected by a screen
  - The radiographer should be a long way from the source while the dose is given
  - The source should be immediately stored in its lead case once the dose is given

Radioactive Tracers

- Radioisotopes can be used as 'tracers' to monitor the processes occurring in different parts of the body
- Radioactive tracers with a short half-life are preferred because:
  - Initially, the activity is very high, so only a small sample needed
  - The shorter the half-life, the faster the isotope decays
  - Isotopes with a shorter half-life pose a much lower risk to the patient
  - The medical test doesn't last long so a half-life of a few hours is enough



A radioactive tracer must be injected into the patient in order to take PET scan images of brain activity

- One example is **Iodine-131**
  - This isotope is known to be specifically taken up by the thyroid gland making it useful for monitoring and treating thyroid conditions
  - It emits beta particles which means it will stay concentrated on the thyroid area and nowhere else in the body

  - It has a short half-life of 8 days meaning it will not be around too long to cause prolonged exposure

- Another isotope commonly used as a tracer is **Technetium-99m**
  - It is a gamma emitter with an energy of about 140 keV which is ideal for detection
  - It has a half-life of 6 hours so it is ideal for use as a tracer, but will not remain active for too long and can be tolerated by the body
  - Gamma radiation is ideal as it is the most penetrating so it can be detected outside the body
  - Also, gamma is the weakest ioniser and causes minimal damage
  - As well as this, technetium-99m may be prepared easily at the hospital when required making it a cost-effective treatment

Sterilising Medical Equipment

- Gamma radiation is widely used to sterilise medical equipment
- Gamma is most suited to this because:
  - It is the most **penetrating** out of all the types of radiation
  - It is penetrating enough to irradiate **all sides** of the instruments
  - Instruments can be sterilised without removing the **packaging**

- The general public might be worried that using gamma radiation in this way might cause the equipment itself to become radioactive, however, this is not the case because:
  - In order for a substance to become radioactive, the **nuclei** have to be affected
  - Ionising radiation only affects the **outer electrons** and not the nucleus
  - The radioactive material is kept securely sealed away from the packaged equipment so there is **no chance of contamination**

8.1.7 Required Practical: Inverse Square-Law for Gamma Radiation

Required Practical: Inverse Square-Law for Gamma Radiation

Aim of the Experiment

The aim of this experiment is to verify the inverse square law for gamma radiation of a known gamma-emitting source

Variables

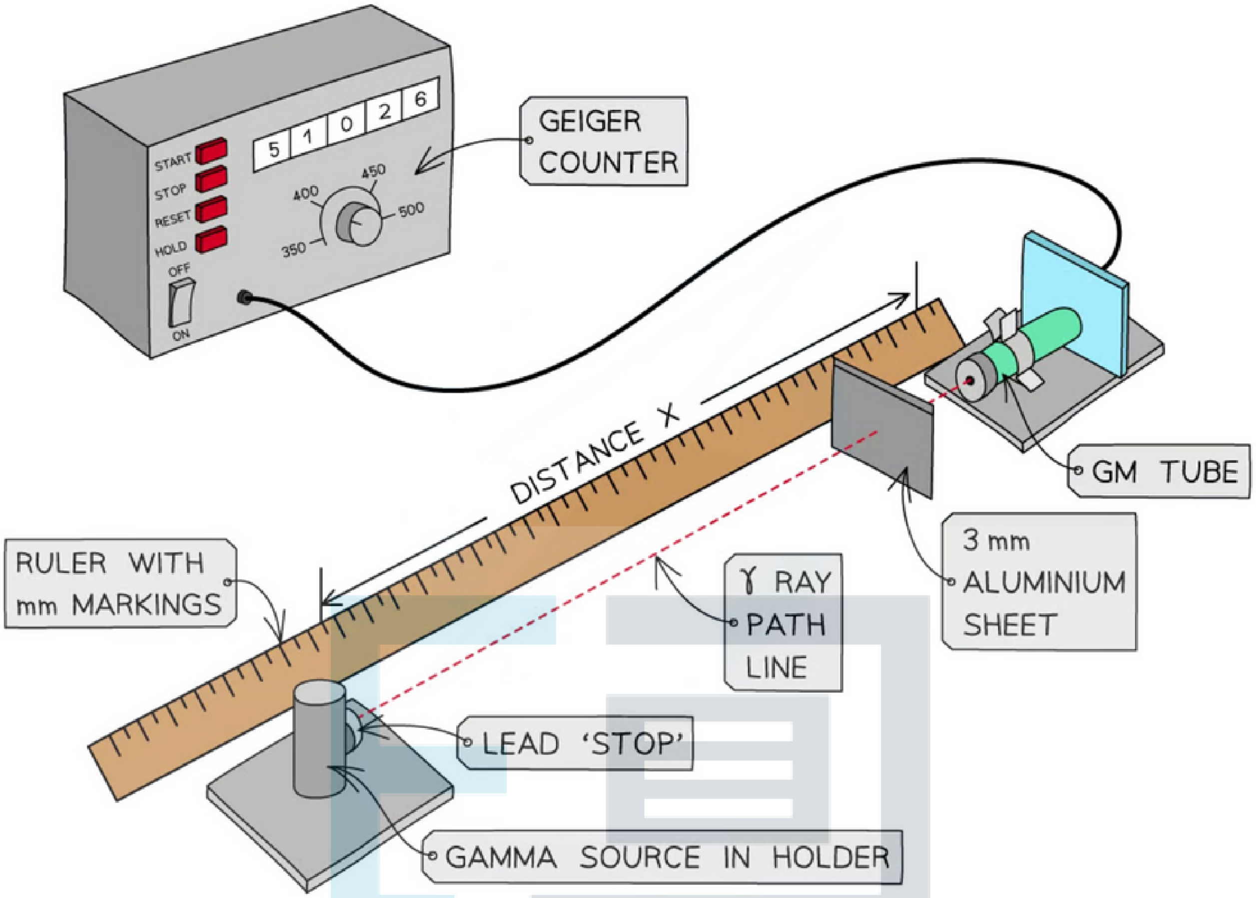
- Independent variable = the distance between the source and detector, x (m)
- Dependent variable = the count rate / activity of the source, C
- Control variables
  - The time interval of each measurement
  - The same thickness of aluminium foil
  - The same gamma source

Equipment List

Apparatus	Purpose
Source such as Radium-222	To provide a source of gamma radiation
Secure holder for the source	To keep the radioactive source firmly in place and positioned to limit exposure
Long tongs	To handle the radioactive source at a distance
Gloves	To limit radioactive contamination on hands
Lab coat	To limit radioactive contamination on clothing
Safety goggles	To protect eyes from radioactive exposure
Metre ruler	To measure the distance between the source and the detector
Geiger-Muller tube & counter	To measure the count rate of the gamma source
Thin sheet of aluminium	To limit the amount of alpha and beta radiation reaching the detector
Stopwatch timer	To measure the same time interval of count rate for each reading

- Resolution of equipment:
  - Metre ruler = 1 mm
  - Stopwatch = 0.01 s

Method



Set up for inverse-square law investigation

1. Measure the background radiation using a Geiger Muller tube without the gamma source in the room, take several readings and find an average
2. Next, put the gamma source at a set starting distance (e.g. 5 cm) from the GM tube and measure the number of counts in 60 seconds
3. Record 3 measurements for each distance and take an average
4. Repeat this for several distances going up in 5 cm intervals

- A suitable table of results might look like this:

DISTANCE BETWEEN SOURCE AND DETECTOR

COUNT RATE PER MINUTE

x / cm	CPM 1st READING	CPM 2nd READING	CPM 3rd READING	CPM MEAN
5				
10				
15				
20				
25				
30				
35				
40				
45				
50				
55				
60				

Analysing the Results

- According to the inverse square law, the intensity, *I*, of the γ radiation from a point source depends on the distance, *x*, from the source

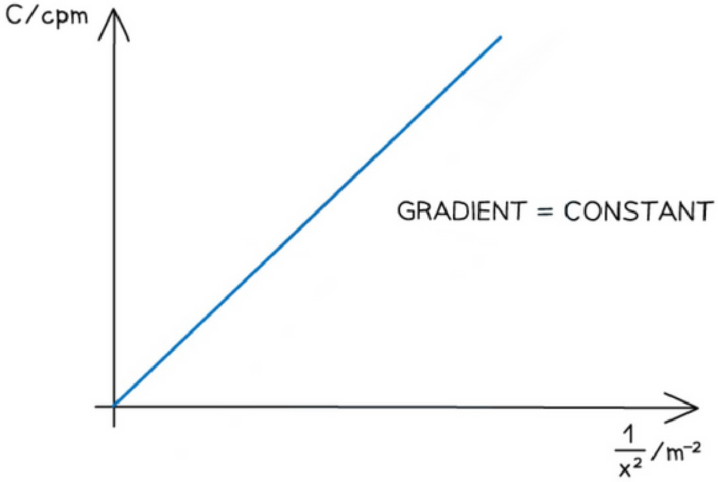
$$I \propto \frac{1}{x^2}$$

- Intensity is proportional to the corrected count rate, C, so

$$C = \frac{k}{x^2}$$

- Comparing this to the equation of a straight line, y = mx
  - y = C (counts min^{-1})
  - x = $1/x^2$ (m^{-2})
  - Gradient = constant, *k*

1. Square each of the distances and subtract the background radiation from each count rate reading
2. Plot a graph of the corrected count rate per minute against $1/x^2$
3. If it is a straight line graph through the origin, this shows they are directly proportional, and the inverse square relationship is confirmed



A straight-line graph verifies the inverse square relationship. The closer the points are to the line, the better the experiment has demonstrated the relationship

Evaluating the Experiment

Systematic errors:

- The Geiger counter may suffer from an issue called "dead time"
  - This is when multiple counts happen simultaneously within ~100 μs and the counter only registers one
  - This is a more common problem in older detectors, so using a more modern Geiger counter should reduce this problem
- The source may not be a pure gamma emitter
  - To prevent any alpha or beta radiation being measured, the Geiger-Muller tube should be shielded with a sheet of 2–3 mm aluminium

Random errors:

- Radioactive decay is **random**, so repeat readings are vital in this experiment
- Measure the count over the longest time span possible
  - A larger count helps reduce the statistical percentage uncertainty inherent in smaller readings
  - This is because the percentage error is proportional to the inverse-square root of the count

Safety Considerations

- For the gamma source:
  - Reduce the exposure time by keeping it in a lead-lined box when not in use
  - Handle with long tongs
  - Do not point the source at anyone and keep a large distance (as activity reduces by an inverse square law)
- Safety clothing such as a lab coat, gloves and goggles must be worn

Worked Example

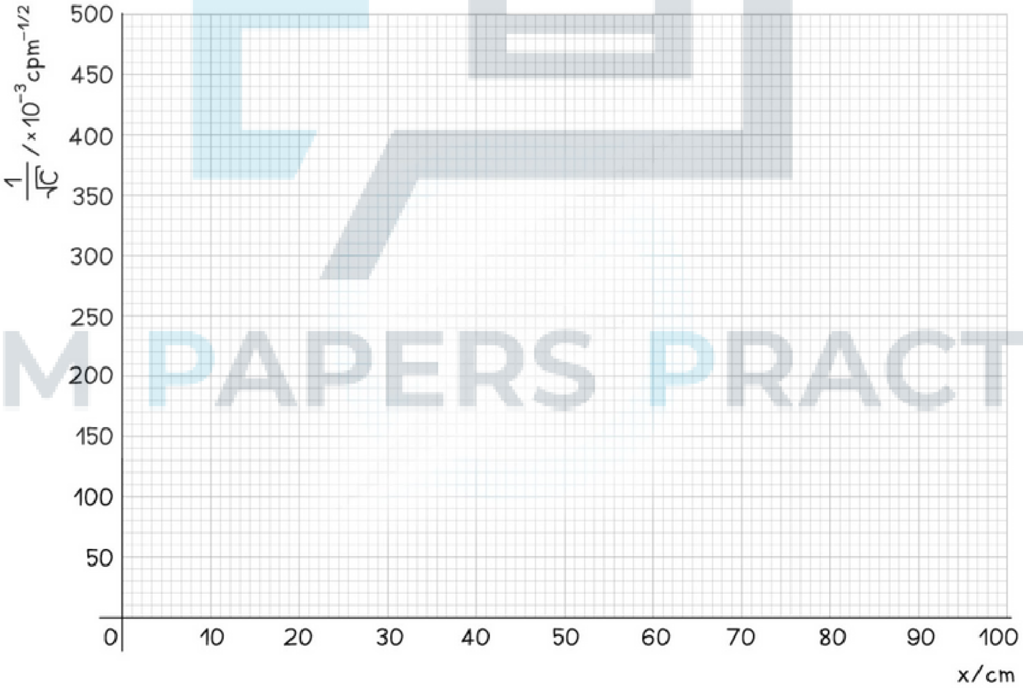
A student measures the background radiation count in a laboratory and obtains the following readings:

Count rate/ counts min^{-1}	69	68	70	71	69	72

The student is trying to verify the inverse square law of gamma radiation on a sample of Radium-226. He collects the following data:

Distance / cm		10	20	30	40	50	60	70	80	90
Count rate/ counts min^{-1}	1	586	202	123	100	89	87	79	78	76
	2	569	193	136	102	94	85	83	77	74
	3	591	199	122	104	90	80	81	79	78

Use this data to determine if the student's data follows an inverse square law. Determine the uncertainty in the gradient of the graph.



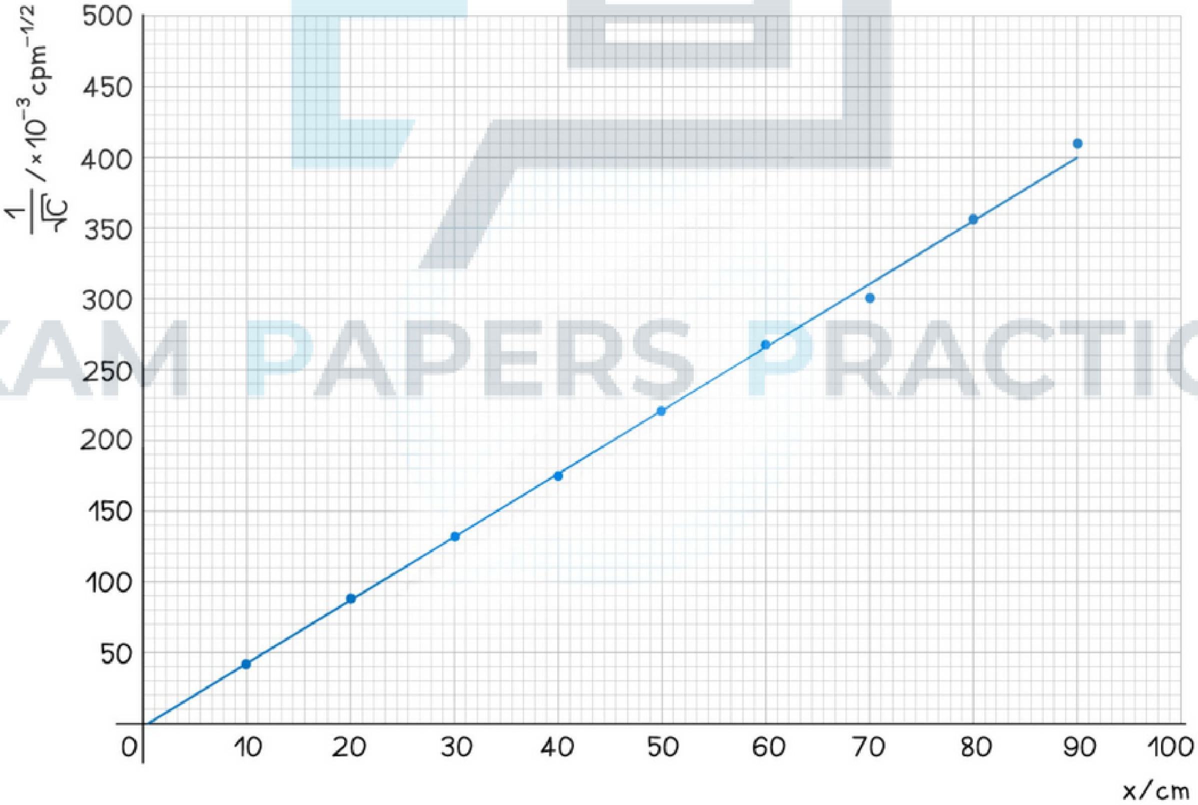
Step 1: Determine a mean value of background radiation

$$\text{Count rate} = \frac{69 + 68 + 70 + 71 + 69 + 72}{6} = 69.8 = 70$$

Step 2: Calculate C (corrected average count rate) and C$^{-1/2}$

Distance x / cm	10	20	30	40	50	60	70	80	90
Average count rate/ counts min^{-1}	582	198	127	102	91	84	81	78	76
Corrected average count rate C/ counts min^{-1}	512	128	57	32	21	14	11	8	6
$\frac{1}{\sqrt{C}}$ / $\text{cpm}^{-1/2}$	0.044	0.088	0.132	0.177	0.218	0.267	0.302	0.354	0.408

Step 3: Plot a graph of $C^{-1/2}$ against x and draw a line of best fit



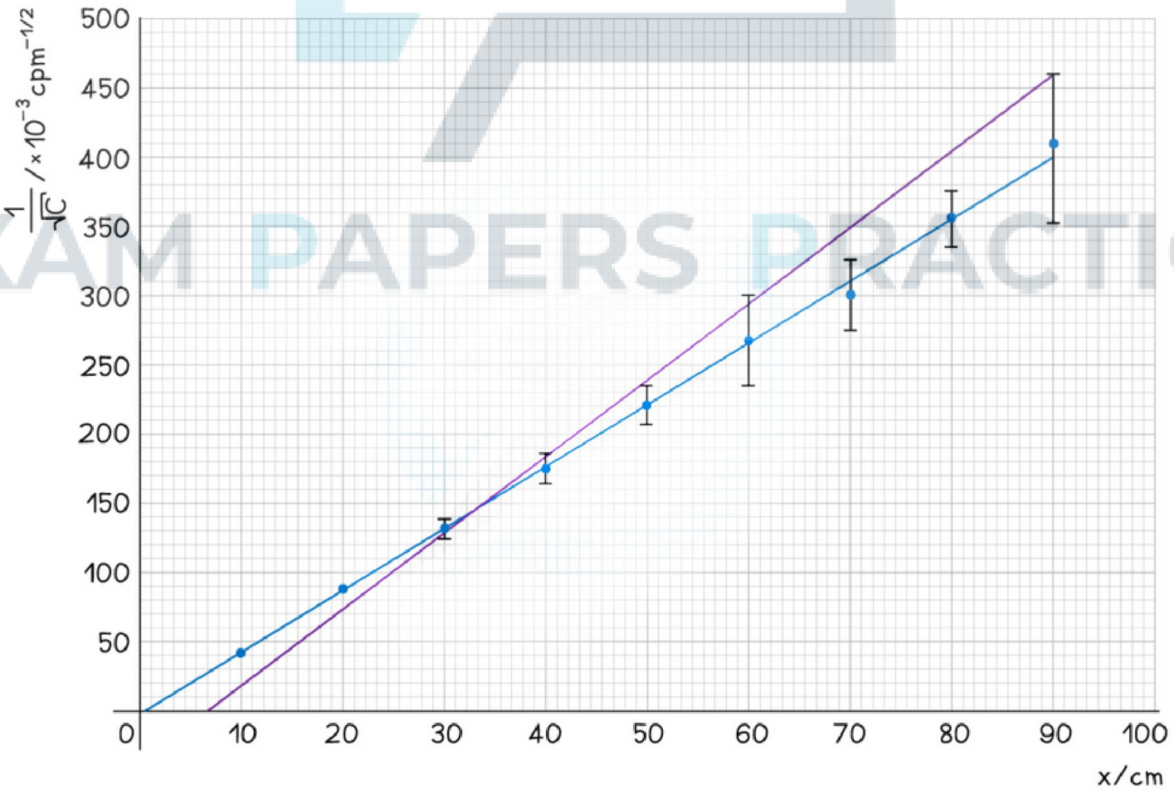
- The graph shows $C^{-1/2}$ is directly proportional to x, therefore, the data follows an inverse square law

Step 4: Determine the uncertainties in the readings

- Uncertainty in the count rate, $\Delta C = \frac{1}{2}$(range of repeat readings)
- Maximum value of C, $C_{max} = C + \Delta C$
- Error bars found from: $\Delta\left(\frac{1}{\sqrt{C}}\right) = \frac{1}{\sqrt{C_{max}}} - \frac{1}{\sqrt{C}}$

Distance x / cm	10	20	30	40	50	60	70	80	90
$\frac{1}{\sqrt{C}}$ / cpm$^{-1/2}$	0.044	0.088	0.132	0.177	0.218	0.267	0.302	0.354	0.408
ΔC/cpm	11	4.5	7	2	2.5	3.5	2	1	2
C_{max}/cpm	523	133	64	34	24	18	13	9	8
$\frac{1}{\sqrt{C_{max}}}$/cpm$^{-1/2}$	0.044	0.087	0.125	0.171	0.204	0.236	0.277	0.333	0.354
$\Delta\left(\frac{1}{\sqrt{C}}\right)$/cpm$^{-1/2}$	0	0.001	0.007	0.006	0.014	0.031	0.025	0.021	0.054

Step 5: Plot the error bars and draw a line of worst fit



Step 6: Calculate the uncertainty in the gradient

$$\text{Best gradient} = \frac{\Delta y}{\Delta x} = \frac{400 - 0}{90 - 0.5} = 4.47$$

$$\text{Worst gradient} = \frac{\Delta y}{\Delta x} = \frac{462 - 0}{90 - 7} = 5.57$$

$$\text{Percentage uncertainty} = \frac{\text{worst gradient} - \text{best gradient}}{\text{best gradient}} \times 100\%$$

$$\text{Percentage uncertainty} = \frac{5.57 - 4.47}{4.47} \times 100\% = 24.6\ \%$$