IGCSE Physics CIE

YOUR NOTES
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5. Nuclear Physics

CONTENTS

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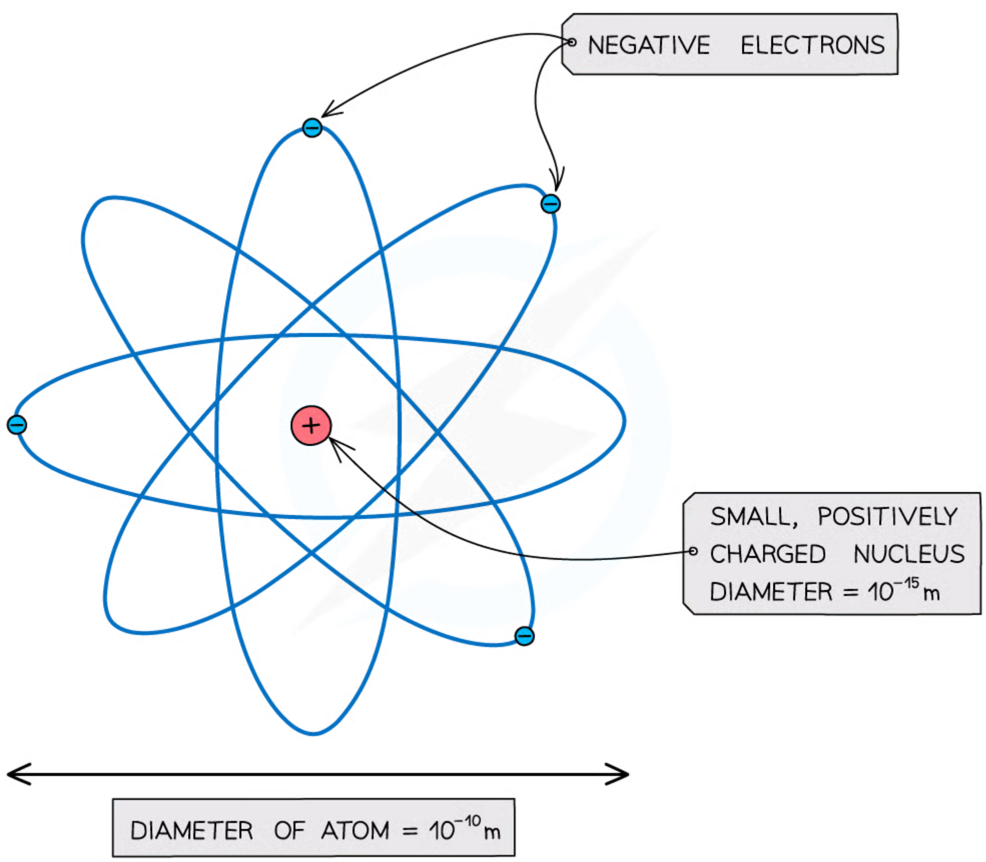
5.1 The Nuclear Model of the Atom

5.1.1 The Atom

Atomic Structure

- Atoms are the building blocks of **all matter**
- They are incredibly small, with a radius of only 1×10^{-10} m
  - This means that about one hundred million atoms could fit side by side across your thumbnail
- Atoms have a tiny, dense **nucleus** at their centre, with **electrons** orbiting around the nucleus
- The radius of the nucleus is over 10,000 times smaller than the whole atom, but it contains almost **all of the mass** of the atom
- They consist of small dense **positively** charged nuclei, surrounded by **negatively** charged electrons



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

(Note: the atom is around 100,000 times larger than the nucleus!)

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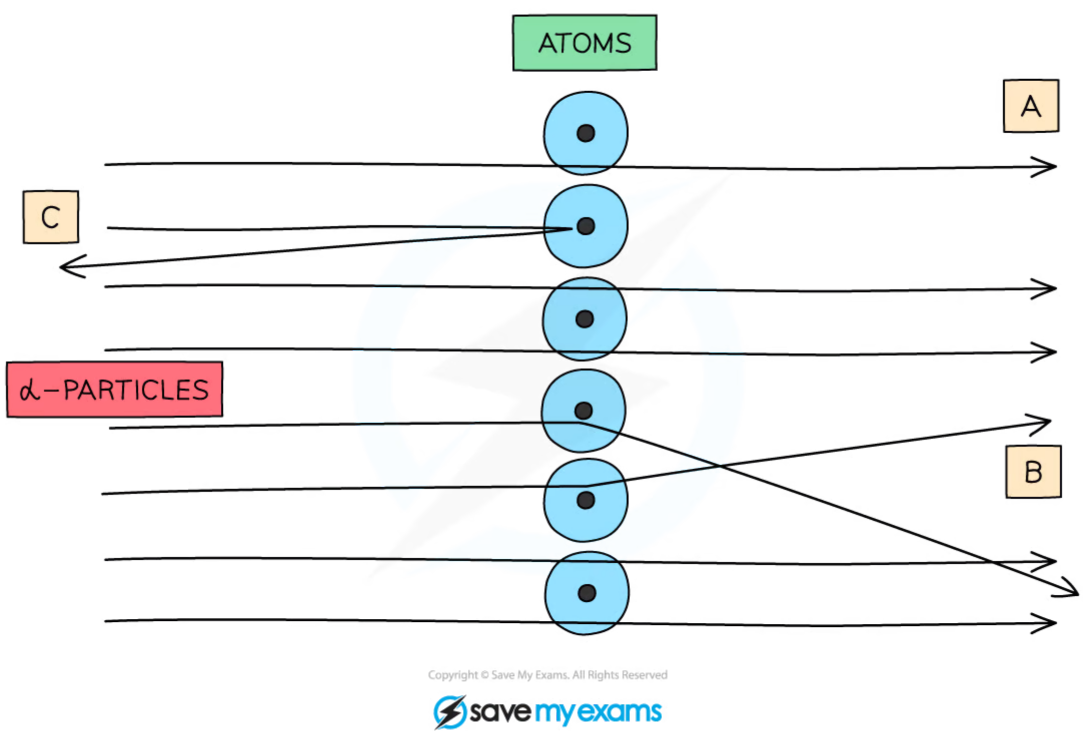
Rutherford's Experiment

EXTENDED

- In 1909 a group of scientists were investigating the Plum Pudding model
  - Physicist, **Ernest Rutherford** was instructing two of his students, Hans Geiger and Ernest Marsden to carry out the experiment
- This involved the scattering of alpha (α) particles by a sheet of thin metal supports the nuclear model of the atom
- A beam of **alpha particles** (He^{2+} ions) were directed at a thin gold foil
- They expected the alpha particles to travel through the gold foil, and maybe change direction a small amount
- Instead, they discovered that :
  - Most of the alpha particles **passed straight through** the foil
  - Some of the alpha particles **changed direction** but continued through the foil
  - A few of the alpha particles **bounced back** off the gold foil

- The bouncing back could not be explained by the Plum Pudding model, so a new model had to be created
  - This was the first evidence of the structure of the atom



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

- When α-particles are fired at thin pieces of gold foil:
  - **The majority of them go straight through (A)**

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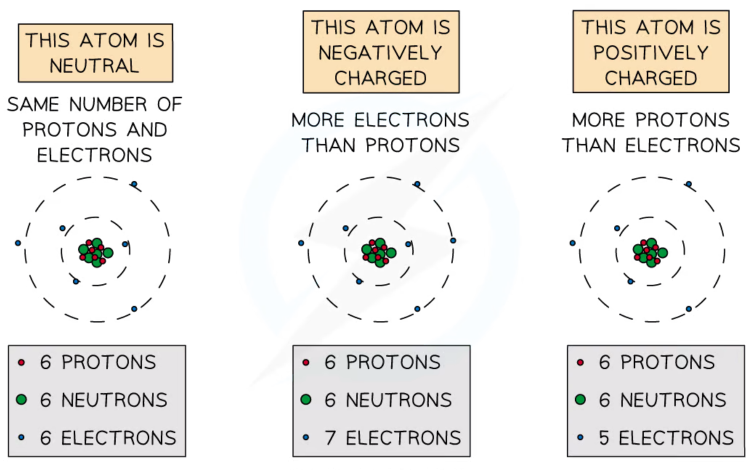
This happens because the atom is mainly empty space

- **Some are deflected through small angles (B)**
  This happens because the positive α-particles are repelled by the positive nucleus which contains most of its mass
- **A very small number are deflected straight back (C)**
  This is because the nucleus is extremely small

Atoms & Ions

- An ion is an **electrically charged** atom or group of atoms formed by the **loss** or **gain** of **electrons**
  - An atom will lose or gain electrons to become more stable
- A stable atom is normally electrically neutral
  - This means it has the same number of protons (positive charge) and electrons (negative charge)
- Positive ions are therefore formed when atoms **lose** electrons
  - There will be more protons than electrons
- Negative ions are therefore formed when atoms **gain** electrons
  - There will be more electrons than protons



The difference between positive and negative ions

Exam Tip

You may hear the term 'net charge'. This just means the 'overall' charge of the atom. If an atom has 5 protons, 5 neutrons and 6 electrons, it has a **net** negative charge because it's a negative ion (more electrons than protons).

Remember which way around the charges are by **p**roton being **p**ositive.

5.1.2 The Nucleus

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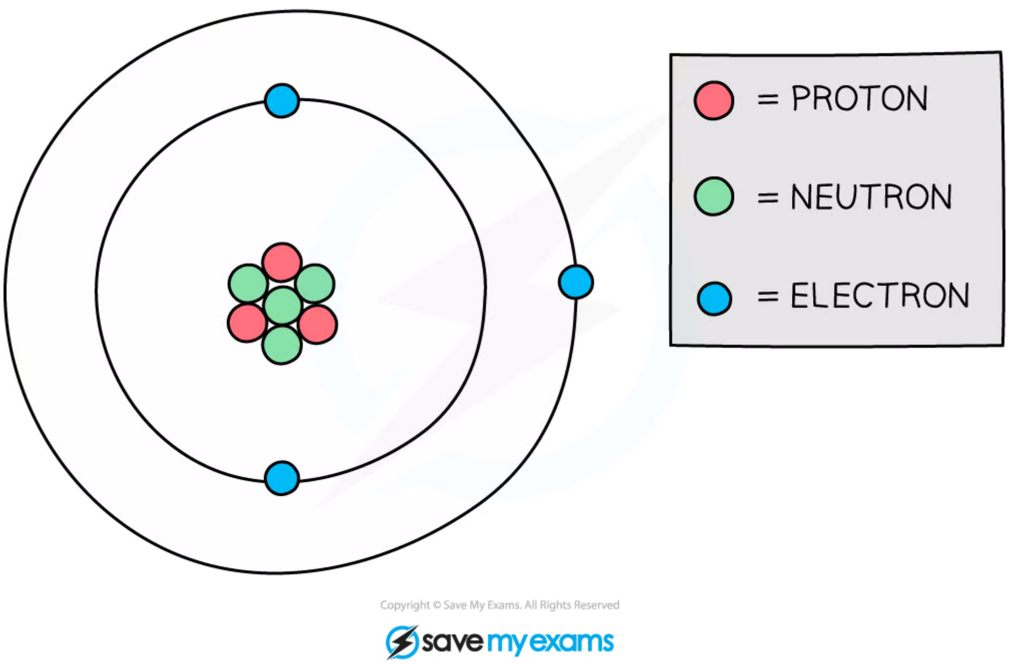
Composition of the Nucleus

- The structure of the atom is made up of a:
  - **Positively** charged nucleus at the centre (made up protons and neutrons)
  - **Negatively** charged electrons in orbit around the nucleus



Protons and neutrons are found in the nucleus of an atom

- Protons have a positive charge, whilst neutrons have no charge
  - This is why the nucleus is overall positive

Exam Tip

Be careful with your terminology:

- Atom = nucleus (proton and neutron) **and** electrons
- Nucleus = protons and neutrons at the centre of the atom

Describing the Nucleus

Define the terms proton number (atomic number) Z and nucleon number (mass number) A and be able to calculate the number of neutrons in a nucleus

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Proton Number, Z

- The number of protons in an atom is called its proton number (it can also be called the atomic number)
  - Elements in the periodic table are ordered by their atomic number
  - Therefore, the number of protons determines which element an atom is
- The atomic number of a particular element is always the same
- For example:
  - Hydrogen has an atomic number of 1. It always has just one proton
  - Sodium has an atomic number of 11. It has 11 protons
  - Uranium has an atomic number of 92. It has 92 protons
- The atomic number is also equal to the number of electrons in an atom
  - This is because atoms have the same number of electrons and protons in order to have no overall charge

Nucleon Number, A

- The total number of particles in the nucleus of an atom is called its **nucleon number** (or **mass** number)
- The mass number is the number of protons **and** neutrons in the atom
- The number of neutrons can be found by **subtracting** the **atomic** number from the **mass** number

Number of Neutrons = Nucleon Number – Proton Number

- For example, if a sodium atom has a mass number of 23 and an atomic number of 11, then the number of neutrons would be 23 – 11 = 12

Exam Tip

You may have noticed that the number of electrons is not part of the mass number. This is because electrons have a **tiny** mass compared to neutrons and protons. We say their mass is negligible when compared to the particles in the nucleus.

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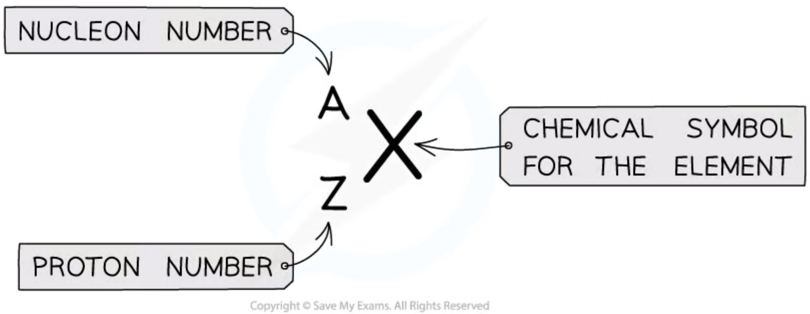
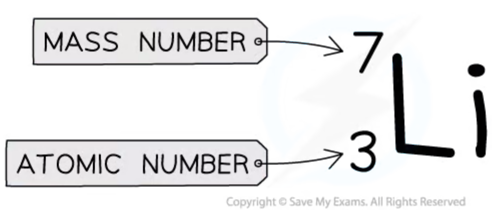
Nuclide Notation

- A nuclide is a group of atoms containing the same number of protons and neutrons
  - For example, 5 atoms of oxygen are all the same nuclide but are 5 separate atoms
- Atomic symbols are written in a specific notation called **nuclide** or **ZXA notation**



Atomic symbols in AZX Notation describe the constituents of nuclei

- The top number A represents the **nucleon** number or the **mass** number
  - **Nucleon number (A)** = total number of **protons and neutrons** in the nucleus
- The lower number Z represents the **proton** or **atomic** number
  - **Proton number (Z)** = total number of **protons** in the nucleus
- Note: In Chemistry, the nucleon number is referred to as the mass number and the proton number as the atomic number. The periodic table is ordered by atomic number
- An example of an atomic symbol is:



Atomic symbols, like the one above, describe the constituents of nuclei

- When given an atomic symbol, you can figure out the total number of protons, neutrons and electrons in the atom:
  - **Protons:** The number of protons is equal to the proton number
  - **Electrons**: Atoms are neutral, and so in a neutral atom the number of negative electrons must be equal to the number of positive protons
  - **Neutrons**: The number of neutrons can be found by subtracting the proton number from the nucleon number
- The term **nucleon** is used to mean a particle in the nucleus – ie. either a proton or a neutron
- The term **nuclide** is used to refer to a nucleus with a specific combination of protons and neutrons

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Worked Example

The element symbol for gold is Au. How many protons, neutrons and electrons are in the gold atom?

$$^{197}_{79}\text{Au}$$

	Protons	Neutrons	Electrons
A	79	79	79
B	197	79	118
C	118	118	79
D	79	118	79

ANSWER: D

Step 1: Determine the atomic and mass number

- The gold atom has an atomic number of 79 (lower number) and a mass number of 197 (top number)

Step 2: Determine the number of protons

- The **atomic** number is equal to the number of **protons**
- The atom has 79 protons

Step 3: Calculate the number of neutrons

- The mass number is equal to the number of protons and neutrons
- The number of neutrons is equal to the mass number minus the atomic number

$$197 - 79 = 118$$

- The atom has 118 neutrons

Step 4: Determine the number of electrons

- An atom has the **same** number of **protons and electrons**
- The atom has 79 electrons

Isotopes

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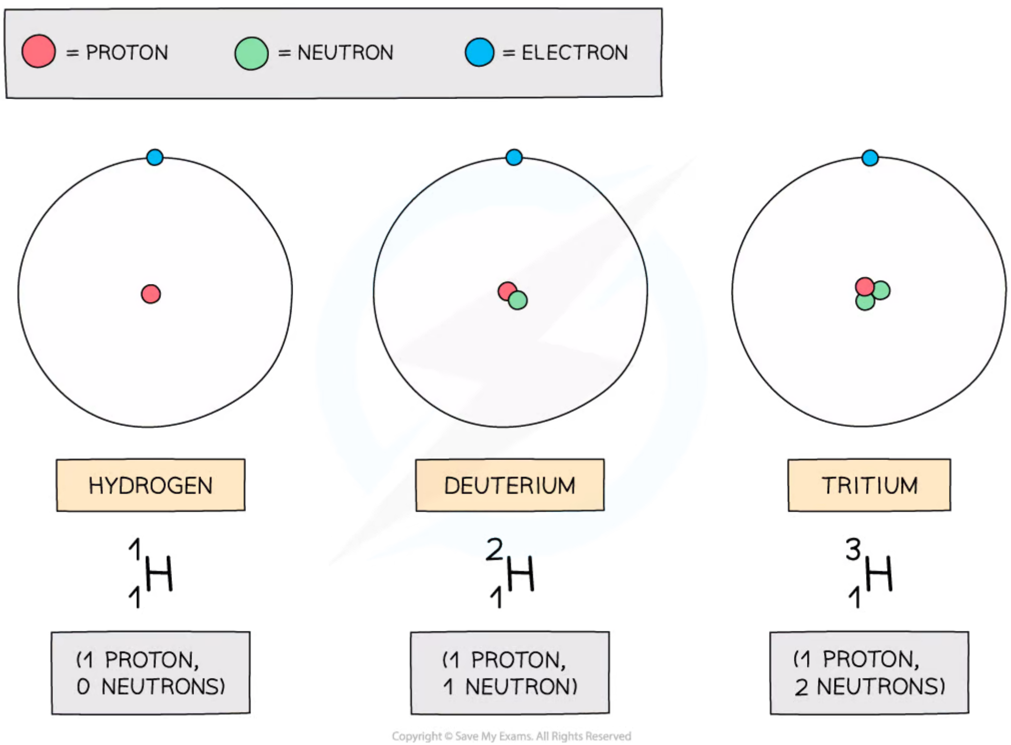
- Although the number of protons in a particular element is always the same, the number of **neutrons** can be different
- **Isotopes** are atoms of the same element that have an equal number of protons but a **different** number of **neutrons**
  - This means that each element can have more than one isotope
- Isotopes tend to be more **unstable** due to their imbalance of protons and neutrons
  - This means they're more likely to decay
- In the diagram below are three isotopes of Hydrogen:



Hydrogen has three isotopes, each with a different number of neutrons

- Isotopes occur naturally, but some are more rare than others
- For example, about 2 in every 10,000 Hydrogen atoms is Deuterium
  - Tritium is even more rare (about 1 in every billion billion hydrogen atoms)

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Worked Example

Which of the following elements are isotopes of each other?

A	${}^{35}_{17}\text{Cl}$ and ${}^{35}_{18}\text{Cl}$
B	${}^{238}_{92}\text{U}$ and ${}^{235}_{92}\text{U}$
C	${}^{12}_{6}C$ and ${}^{14}_{8}\text{C}$
D	${}^{16}_{8}\text{O}$ and ${}^{14}_{7}\text{N}$

Answer: **B**

- In nuclide notion, the top number is the **nucleon** number (number of protons and neutrons) and the bottom number is the **proton** number (number of protons)
- Isotopes are two of the same elements
  - This eliminates option **D** since one is oxygen (O) and the other nitrogen (N)
- Which have the same number of protons
  - This eliminates option **C** and **A**
  - Their proton numbers are different for the same element
- But a different number of neutrons
  - Therefore, the correct answer is **B**

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Relative Charge

- The different particles that make up atoms have different properties
- Relative **mass** is a way of comparing particles. It is measured in **atomic mass units** (amu)
  - A relative mass of 1 is equal to mass of 1.67×10^{-27} kg
- **Charge** can be positive or negative
  - Relative charge is, again, used to compare particles
- The fundamental charge is equal to the **size** of the charge on a proton and an electron, however the electron's charge is negative
- The properties of each of the particles are shown in the table below:

Table of Relative Charge & Mass

PARTICLE	RELATIVE CHARGE	RELATIVE MASS
PROTON	+1	1
NEUTRON	0	1
ELECTRON	−1	1/2000 (NEGLIGIBLE)

- If have a particle has 0 relative charge, this means it is **neutral**

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Nuclear Charge

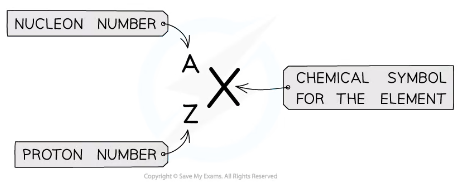
- Nuclear charge is normally stated as the relative charge of the nucleus
  - The term 'relative' refers to the charge of the particle divided by the charge of the proton
- The proton number is the number of protons in a nucleus
- Since nuclei are made up of only protons and neutrons, the proton number determines the **relative charge** on a nucleus

Worked Example

What is the relative charge of the Chromium nucleus $^{52}_{24}\text{Cr}$?

Step 1: Determine the number of protons

- The number of protons is the proton number
- This is the bottom number in the AZX notation



  - This Chromium nucleus has 24 protons and neutrons

Step 2: State the relative mass of 1 proton

- 1 proton has a relative charge of +1

Step 3: Multiple relative charge of 1 proton by the number of protons

- This nucleus of Chromium therefore has a relative charge of +24

Exam Tip

Charge can be either positive (+) or negative (–). Therefore, remember to include the sign when writing the relative charge!

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Nuclear Mass

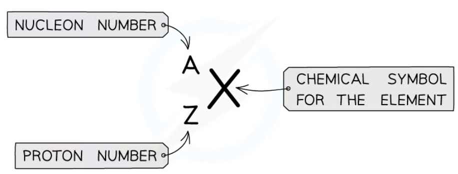
- Nuclear mass is stated as the relative mass of the nucleus
  - The term 'relative' refers to the mass of the particle divided by the mass of the proton
- The mass number is the total number of protons and neutrons in the nucleus
- The nucleon number (mass number) determines the **relative mass** of a nucleus

Worked Example

What is the relative mass of the Chromium nucleus $^{52}_{24}\mathrm{Cr}$?

Step 1: Determine the number of protons and neutrons

- The number of protons and neutrons is the mass (nucleon) number
- This is the top number in the AZX notation



  - This Chromium nucleus has 52 protons and neutrons

Step 2: State the relative mass of 1 proton and neutron

- 1 proton has a relative mass of 1
- 1 neutron has a relative mass of 1

Step 3: Multiple relative charge of 1 proton and neutron by number of protons and neutrons

- This nucleus of Chromium therefore has a relative mass of 52

Exam Tip

The relative mass of a nucleus only includes the protons and neutrons. However, this is pretty much the relative mass of the whole atom because electrons have negligible (very little) mass in comparison to the proton and neutron.

Fission & Fusion

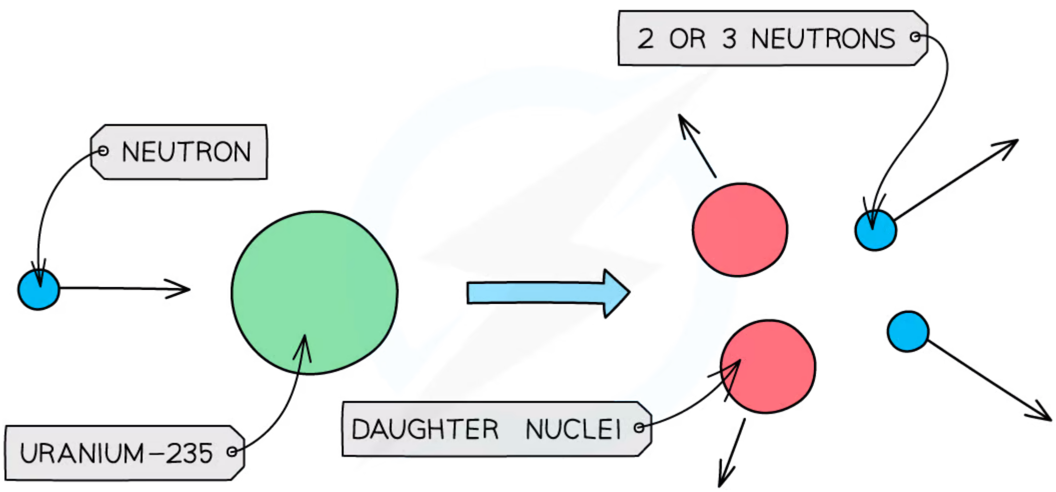
Nuclear Fission

- There is a lot of energy stored within the nucleus of an atom
  - This energy can be released in a nuclear reaction such as **fission**

- Nuclear fission is defined as:

  The splitting of a large, unstable nucleus into two smaller nuclei

- Isotopes of **uranium** and **plutonium** both undergo fission and are used as fuels in nuclear power stations
- During fission, when a neutron collides with an unstable nucleus, the nucleus splits into **two smaller nuclei** (called daughter nuclei) as well as **two or three neutrons**
  - Gamma rays are also emitted



Large nuclei can decay by fission to produce smaller nuclei and neutrons with a lot of kinetic energy

- The products of fission move away very **quickly**
  - Energy transferred is from **nuclear potential energy** to kinetic energy
- The mass of the products (daughter nuclei and neutrons) is **less** than the mass of the original nucleus
  - This is because the remaining mass has been converted into **energy** which is released during the fission process

- The processes involved in nuclear fission can be shown in different ways as diagrams
- These diagrams show how the reaction happens in a way that is easy to understand

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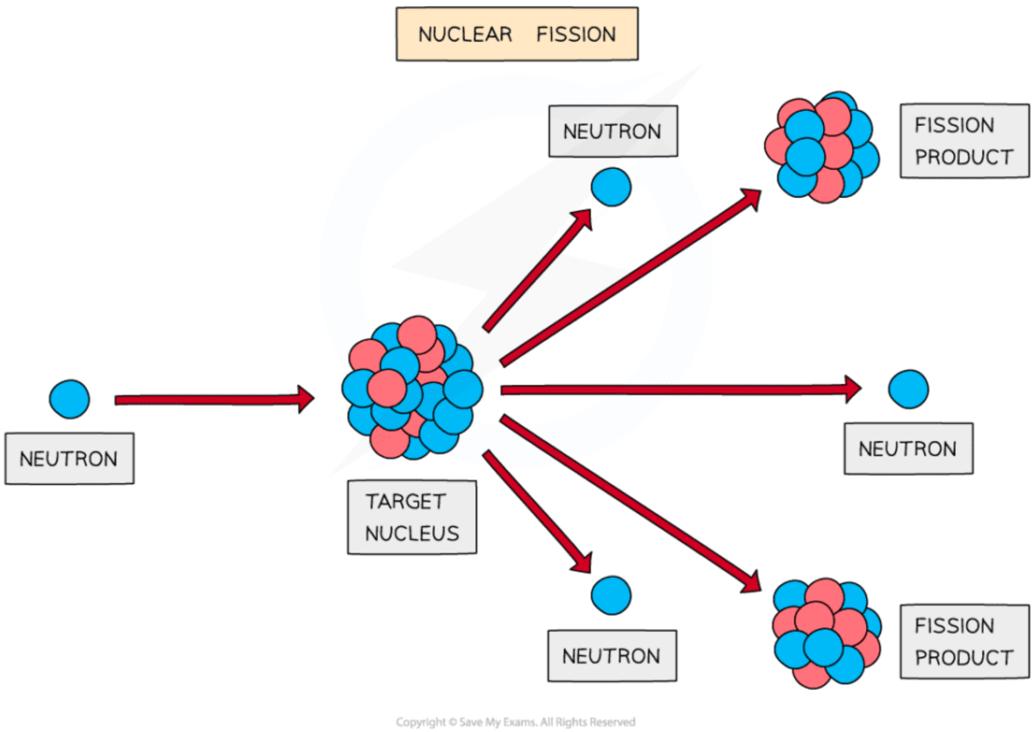


A neutron is fired into the target nucleus, causing it to split

- The diagram above is useful because it shows clearly the different parts of the fission reaction
- An example of a nuclide equation for fission is:

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{92}_{36}\text{Kr} + ^{141}_{56}\text{Ba} + 3\,^{1}_{0}\text{n} + \text{energy}$$

- Where:
    - $^{235}_{92}\text{U}$ is an unstable isotope of Uranium
    - $^{1}_{0}\text{n}$ is a neutron
    - $^{92}_{36}\text{Kr}$ us an unstable isotope of Krypton
    - $^{141}_{56}\text{Ba}$ is an unstable isotope of Barium
- The above equation represents a fission reaction in which a Uranium nucleus is hit with a neutron and splits into two smaller nuclei – a Krypton nucleus and a Barium nucleus, releasing three neutrons in the process
    - The sum of top (nucleon) numbers on the left-hand side equals the sum of top number on the right-hand side:

$$\mathbf{235 + 1 = 92 + 141 + (3 \times 1)}$$

    - The same is true for the lower (proton) numbers:

$$\mathbf{92 + 0 = 36 + 56 + (2 \times 0)}$$

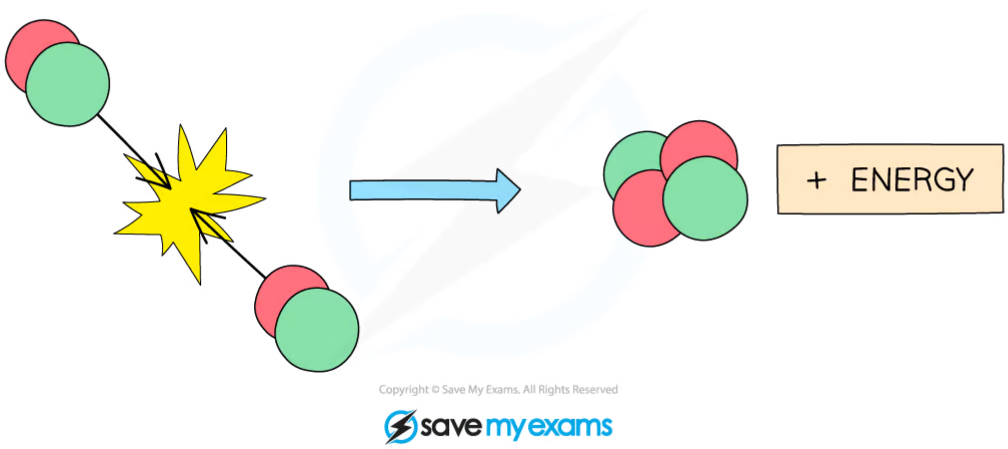
Nuclear Fusion

YOUR NOTES

- Small nuclei can react to release energy in a process called **nuclear fusion**
- Nuclear fusion is defined as:

When two light nuclei join to form a heavier nucleus

- This process requires extremely **high temperatures** to maintain
  - This is why nuclear fusion has proven very hard to reproduce on Earth
- Stars use nuclear fusion to produce energy
- In most stars, hydrogen atoms are fused together to form helium and produce lots of energy



Two hydrogen nuclei are fusing to form a helium nuclei

- The energy produced during nuclear fusion comes from a very small amount of the particle's mass being **converted** into energy
- Albert Einstein described the mass-energy equivalence with his famous equation:

$$E = m \times c^2$$

- Where:
  - E = energy released from fusion in Joules (J)
  - m = mass converted into energy in kilograms (kg)
  - c = the speed of light in metres per second (m/s)
- Therefore, the mass of the product (fused nucleus) is **less** than the mass of the two original nuclei
  - This is because the remaining mass has been converted into **energy** which is released when the nuclei fuse
- The amount of energy released during nuclear fusion is huge:
  - The energy from 1 kg of hydrogen that undergoes fusion is equivalent to the energy from burning about 10 million kilograms of coal
- An example of a nuclide equation for fusion is:

$$^{2}_{1}H + ^{1}_{1}H \rightarrow ^{3}_{2}\text{He} + \text{energy}$$

- Where:

- $^{2}_{1}H$ is deuterium (isotope of hydrogen with 1 proton and 1 neutron)
- $^{1}_{1}H$ is hydrogen (with one proton)
- $^{3}_{2}He$ is an isotope with helium (with two protons and one neutron)

YOUR NOTES

Worked Example

A nuclide equation for nuclear fission is stated as:

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{96}_{37}Rb + ^{137}_{55}Cs + N^{1}_{0}n$$

Calculate the number of neutrons, *N* emitted in this reaction.

Step 1: Calculate the nucleon number on the left side of the equation

$$235 + 1 = 236$$

Step 2: Calculate the nucleon number on the right side of the equation

$$96 + 138 + N = 233 + N$$

Step 3: Equate the nucleon number for both sides of the equation

$$236 = 233 + N$$

Step 4: Rearrange for the number of neutrons, N

$$N = 236 - 233 = 3$$

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5.2 Radioactivity

5.2.1 Background Radiation

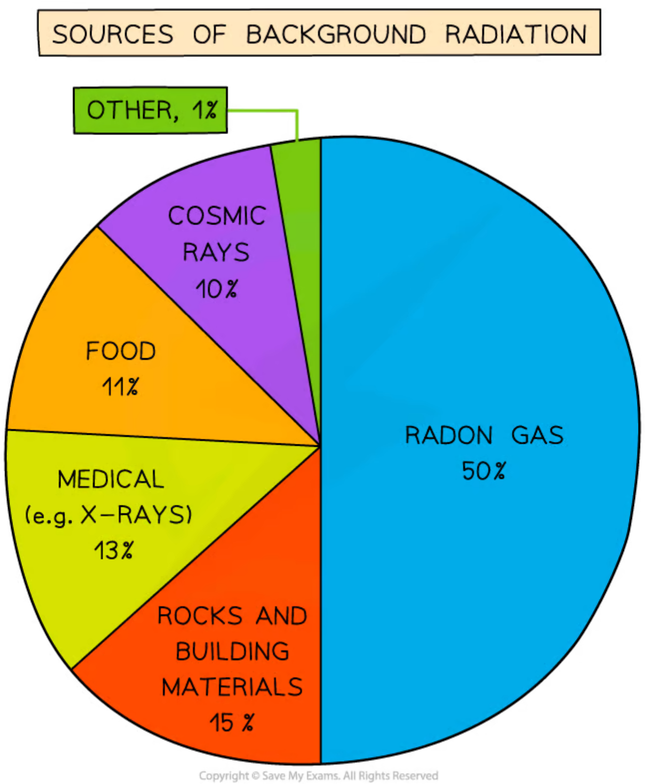
Background Radiation

- It is important to remember that radiation is a natural phenomenon
- Radioactive elements have **always** existed on Earth and in outer space
- However, human activity has added to the amount of radiation that humans are exposed to on Earth

- Background radiation is defined as:

The radiation that exists around us all the time

- There are two types of background radiation:
  - Natural sources
  - Man-made sources



Background radiation is the radiation that is present all around in the environment. Radon gas is given off from some types of rock

- Every second of the day there is some radiation emanating from **natural sources** such as:
  - Rocks
  - Cosmic rays from space
  - Foods

- Although most background radiation is natural, a small amount of it comes from artificial sources, such as **medical procedures** (including X-rays)
- Levels of background radiation can vary significantly from place to place

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Sources of Background Radiation

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- Background radiation can come from natural sources on Earth or space and man-made sources

Natural Sources

- **Radon gas (in the air)**
  - Airborne radon comes from the ground
  - This is from the natural decay of uranium in rocks and soil
  - The gas is tasteless, colourless and oderless but it not generally a health issue
- **Rocks and Buildings**
  - 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
  - Natural radioactivity can be found in building materials, including decorative rocks, stone and brick
- **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

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- 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

Exam Tip

The sources that make the most significant contribution are the natural sources:

- Radon gas
- Rocks and buildings
- Food and drink
- Cosmic rays

Make sure you remember these for your exam!

Detecting Radiation

YOUR NOTES

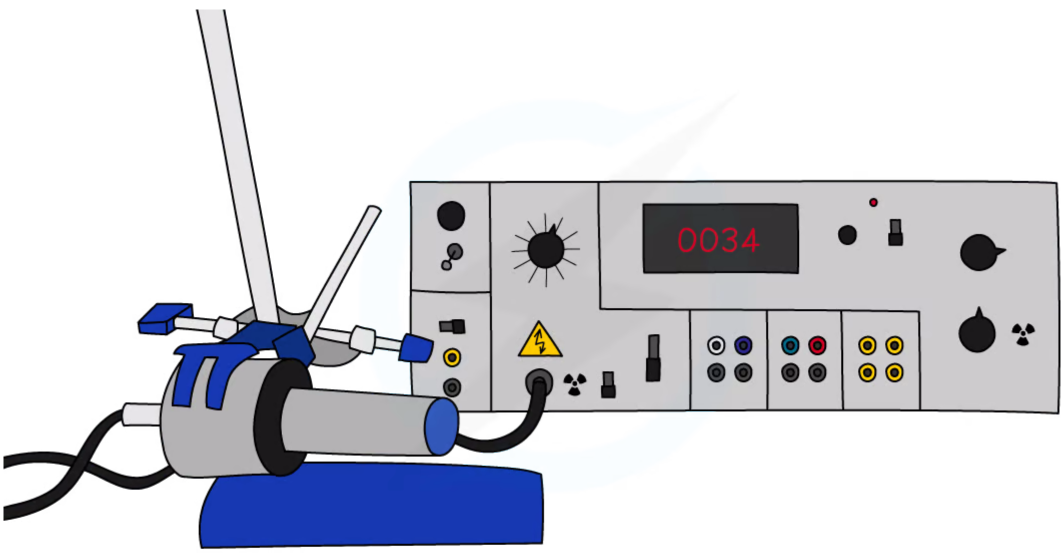
- It is important to regulate the exposure of humans to radiation
  - The amount of radiation received by a person is called the **dose**
- Ionising nuclear radiation is measured using a **detector** connected to a **counter**

Count Rate

- Count rate is the **number** of decays per second recorded by a detector and recorded by the **counter**
  - It is measured in **counts/s** or **counts/min**
- The count rate decreases the further the detector is from the source
  - This is because the radiation becomes more spread out the further away it is from the source

Geiger-Müller tube

- The Geiger-Müller tube is the most common device used to measure and detect radiation
- Each time it absorbs radiation, it transmits an electrical pulse to a counting machine
  - This makes a clicking sound or displays the **count rate**
- The greater the frequency of clicks, or the higher the count rate, the more radiation the Geiger-Müller tube is absorbing
  - Therefore, it matters how close the tube is to the radiation source
  - The further away from the source, the lower the count rate detected



A Geiger-Müller tube (or Geiger counter) is a common type of radiation detector

Examples of other radiation detectors include:

- **Photographic film** (often used in badges)
- **Ionisation chambers**
- **Scintillation counters**

- **Spark counters**

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Worked Example

A Geiger-Müller tube is used to detect radiation in a particular location. If it counts 16,000 decays in 1 hour, what is the count rate?

Step 1: Identify the different variables

- The number of decays is 16 000
- The time is 1 hour

Step 2: Determine the time period in seconds

- 1 hour is equal to 60 minutes, and 1 minute is equal to 60 seconds

$$\text{Time period} = 1 \times 60 \times 60 = 3600 \text{ seconds}$$

Step 3: Divide the total counts by the time period in seconds

$$\text{Counts} \div \text{Time period} = 16\,000 \div 3600 = 4.5$$

- Therefore, there are **4.5 decays per second**

Exam Tip

If asked to name a device for detecting radiation, the Geiger-Müller tube is a good example to give. You can also refer to it as a GM tube, a GM detector, GM counter, Geiger counter etc. (The examiners will allow some level of misspelling, providing it is readable). Don't, however, refer to it as a 'radiation detector' as this is too vague and may simply restate what was asked for in the question.

Accounting for Background Radiation

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EXTENDED

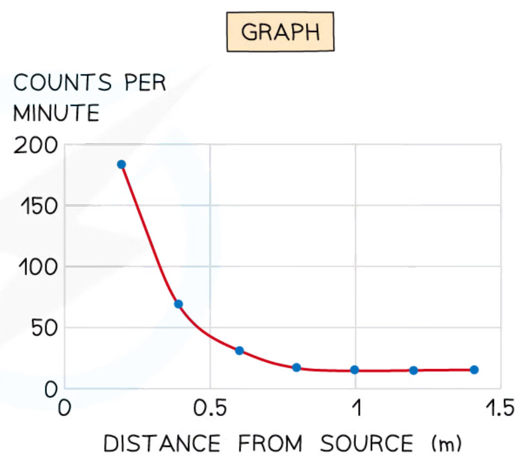
- Background radiation must be accounted for when taking readings in a laboratory
- This can be done by taking readings with no radioactive source present and then subtracting this from readings with the source present
  - This is known as the **corrected count rate**

Worked Example

A student is using a Geiger-counter to measure the counts per minute at different distances from a source of radiation. Their results and a graph of the results are shown here.

RESULTS TABLE

Distance from source (m)	Counts per minute
0.2	180
0.4	67
0.6	29
0.8	17
1.0	15
1.2	15
1.4	15



Determine the background radiation count.

Step 1: Determine the point at which the source radiation stops being detected

- The background radiation is the amount of radiation received all the time
- When the source is moved back far enough it is all absorbed by the air before reaching the Geiger-counter
- Results after 1 metre do not change
- Therefore, the amount after 1 metre is only due to background radiation

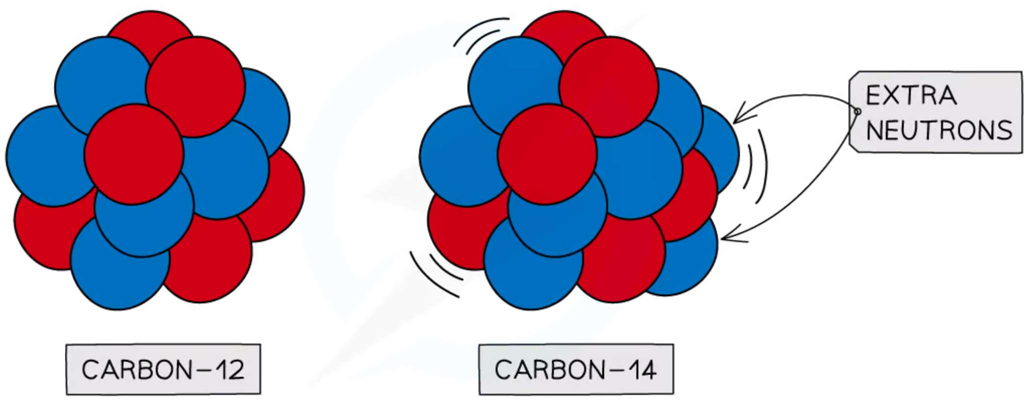
Step 2: State the background radiation count

- The background radiation count is **15 counts per minute**

YOUR NOTES

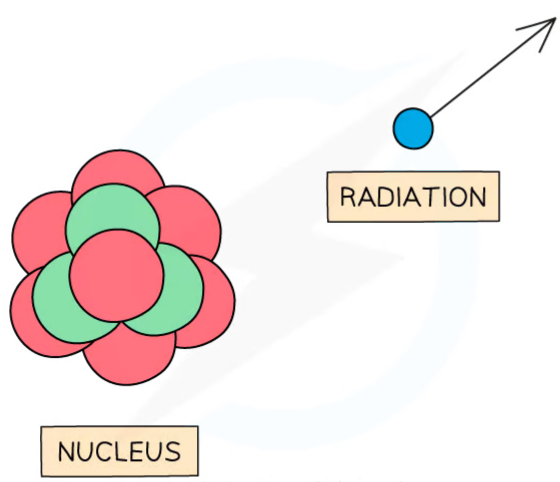
Radioactive Decay

- Some atomic nuclei are **unstable**
- This is because of an imbalance in the forces within the nucleus
  - Forces exist between the particles in the nucleus
  - This is commonly due to the nucleus have too many protons or neutrons
- Carbon-14 is an isotope of carbon which is **unstable**
  - It has two extra neutrons compared to stable carbon-12



Carbon-12 is stable, whereas carbon-14 is unstable. This is because carbon-14 has two extra neutrons

- Some isotopes are unstable because of their large size or because they have too many or too few neutrons
- Unstable nuclei can **emit radiation** to become more stable
  - Radiation can be in the form of a high energy particle or wave



Unstable nuclei decay by emitting high energy particles or waves

YOUR NOTES
⬇

- As the radiation moves away from the nucleus, it takes some energy with it
  - This reduces the overall energy of the nucleus
  - This makes the nucleus more **stable**
- The process of emitting radiation is called **radioactive decay**
- Radioactive decay is a **random** process
  - This means it is not possible to know exactly when a particular nucleus will decay
- It cannot be predicted when a particular unstable nucleus will decay
- This is because radioactive decay is a **random** process, this means that:
  - There is an **equal probability** of any nucleus decaying
  - It cannot be known **which particular nucleus will decay next**
  - It cannot be known **at what time a particular nucleus will decay**
  - The rate of decay is **unaffected** by the surrounding conditions
  - It is only possible to estimate the **probability** of a nuclei decaying in a given time period
- Therefore, the emission of radiation is:
  - Spontaneous
  - Random in direction

Worked Example

Which of the following statements is **not** true?

A Isotopes can be unstable because they have too many or too few neutrons

B The process of emitting particles or waves of energy from an unstable nucleus is called radioactive decay

C Scientists can predict when a nucleus will decay

D Radiation refers to the particles or waves emitted from a decaying nucleus

ANSWER: C

- Answer A is **true.** The number of neutrons in a nucleus determines the stability
- Answer B is **true.** This is a suitable description of radioactive decay
- Answer D is **true.** Radiation is about emissions. It is different to radioactive particles
- Answer C is **not true**
- Radioactive decay is a random process
- It is not possible to predict precisely when a particular nucleus will decay

Exam Tip

The terms **unstable**, **random** and **decay** have very particular meanings in this topic. Remember to use them correctly when answering questions!

YOUR NOTES
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Types of Radioactive Decay

- When an unstable nucleus decays, it emits radiation called **nuclear radiation**
- There are different types of radiation that can be emitted:
  - **Alpha (α)** particles
  - **Beta (β⁻)** particles
  - **Gamma (γ)** radiation
- These changes are **spontaneous** and **random**

Alpha Particles

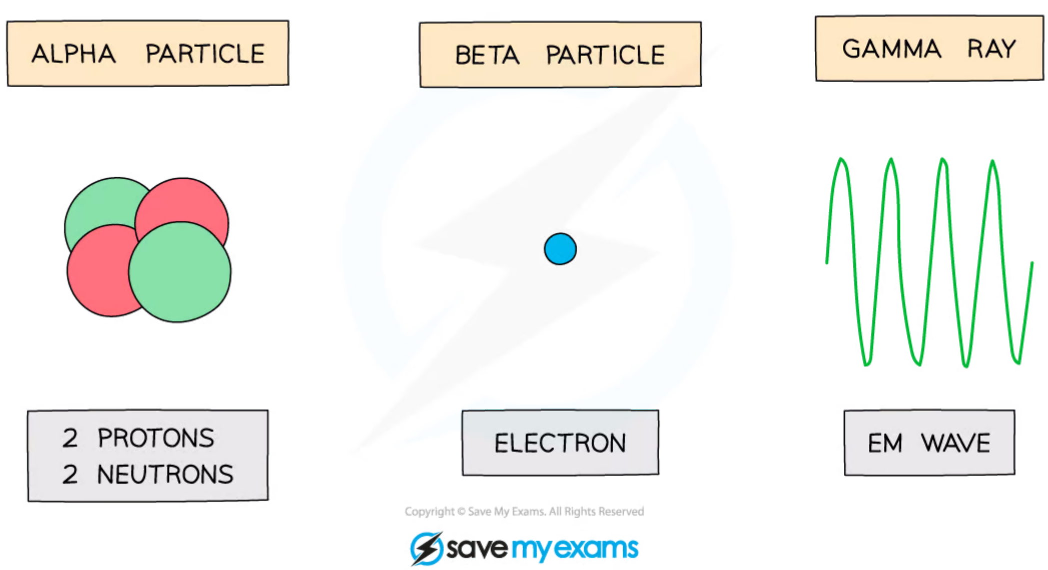
- The symbol for alpha is **α**
- An alpha particle is the same as a helium nucleus
  - This is because they consist of two neutrons and two protons
- Alpha particles have a charge of +2
  - This means they can be affected by an electric field

Beta Particles

- The symbol for beta is β^-
- Beta particles are fast-moving electrons
- They are produced in nuclei when a neutron changes into a proton and an electron
- Beta particles have a charge of -1
  - This means they can be affected by an electric field

Gamma Rays

- The symbol for gamma is **γ**
- Gamma rays are electromagnetic waves
- They have the highest energy of the different types of electromagnetic waves
- Gamma rays have no charge



Alpha particles, beta particles and gamma waves can be emitted from unstable nuclei

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Alpha, Beta & Gamma Emission

- α, β and γ radiation can be identified by the emission from a nucleus by recalling their:
  - Nature (what type of particle or radiation they are)
  - Their relative ionising effects (how easily they ionise other atoms)
  - Their relative penetrating abilities (how far can they travel before they are stopped completely)

- The properties of Alpha, Beta and Gamma are given in this table, and then described in more detail below

Different Properties of Nuclear Radiation

Particle	What is it	Charge	Range in air	Penetration	Ionisation
Alpha (α)	2 protons + 2 neutrons	+2	Few cm	Stopped by paper	High
Beta (β^-)	Electron	−1	Few 10s of cm	Stopped by few mm Aluminium	Medium
Gamma (γ)	Electromagnetic wave	0	Infinite	Reduced by few mm Lead	Low

- The trend down the table shows:
  - The range increases
  - Penetrating power increases
  - Ionisation decreases

Penetrating Power

- Alpha, beta and gamma have different properties
- They **penetrate** materials in different ways
  - This means they are stopped by different materials

YOUR NOTES
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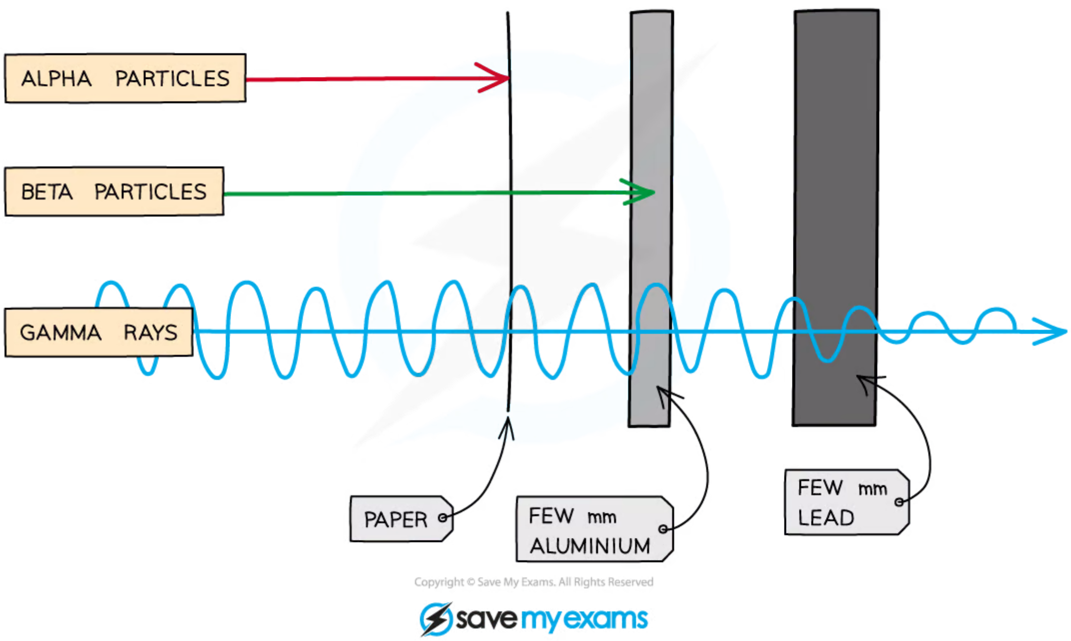

Alpha, beta and gamma are different in how they penetrate materials. Alpha is the least penetrating, and gamma is the most penetrating

- Alpha is stopped by **paper**, whereas beta and gamma pass through it
- Beta is stopped by a few millimetres of aluminium
    - Gamma can pass through **aluminium**
- Gamma rays are only partially stopped by thick **lead**

YOUR NOTES
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Worked Example

A student has an unknown radioactive source. They are trying to work which type of radiation is being given off:

A Alpha particles

B Beta particles

C Gamma rays

D Neutrons

They measure the count-rate, using a Geiger-Muller tube, when the source is placed behind different material. Their results are shown in the table below:

	No material Between Source and Detector	Paper Between Source and Detector	5 mm Aluminium Between Source and Detector	5 mm Lead Between Source and Detector
Count-rate	4320	4218	256	34

Which type of radiation is being given off by the source?

ANSWER: B

- The answer is **not A** because the radiation passed through the paper almost unchanged
  - This means it is **not** alpha
- The answer is **not C or D** because the aluminium decreased the count-rate significantly
  - This means it is **not** gamma (gamma penetrates aluminium)
  - This also means it is **not** neutrons (neutrons penetrate aluminium, however you do not need to know this for your GCSE)
- Therefore, the source must be **Beta** particles

Exam Tip

Remembering the type of particle, penetration and ionising power for alpha, beta and gamma radiation is very important for your exam! Often the exam question will give some clues and you will have to choose which type of radiation it could be based off these.

YOUR NOTES
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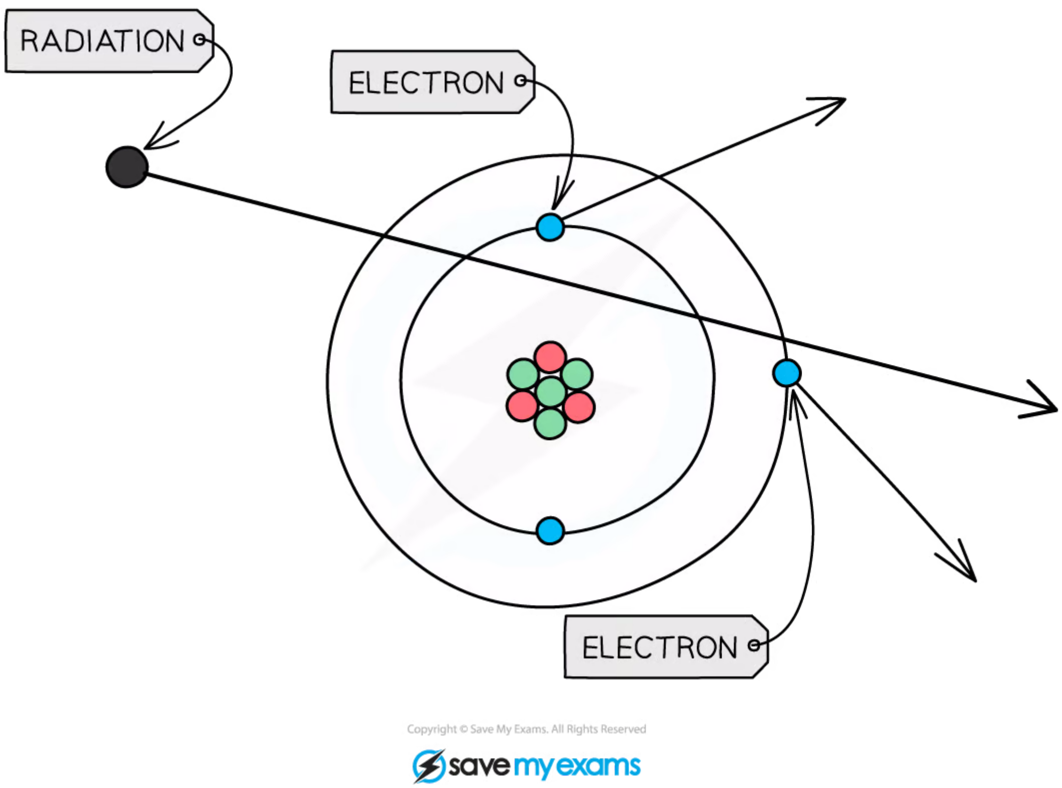
Ionising Effect of Radiation

EXTENDED

- Ionisation is the process of which an atom becomes negative or positive by gaining or losing electrons
- All nuclear radiation is capable of **ionising** atoms that it hits
  - When an atom is ionised, the number of electrons it has **changes**
- This is mostly done by knocking out an electron so the atom loses a negative charge and is left overall **positive**



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

- **Alpha** is by far the most ionising form of radiation
  - Alpha particles leave a dense trail of ions behind them, affecting virtually every atom they meet
  - Because of this they quickly lose their energy and so have a short range
  - Their short range makes them relatively harmless if handled carefully, but they have the potential to be extremely dangerous if the alpha emitter enters the body
- **Beta** particles are moderately ionising

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⬇

- The particles create a less dense trail of ions than alpha, and consequently have a longer range
- They tend to be more dangerous than alpha because they are able to travel further and penetrate the skin, and yet are still ionising enough to cause significant damage

- **Gamma** is the least ionising form of radiation (although it is still dangerous)
  - Because Gamma rays don't produce as many ions as alpha or beta, they are more penetrating and have a greater range
  - This can make them hazardous in large amounts

- The ionising effects depend on the **kinetic energy** and **charge** of the type of radiation

- The **greater** the **charge** of the radiation, the **more** ionising it is
  - This means alpha radiation is the most ionising as it has a charge of +2
  - A beta particle has a charge of –1 so is moderately ionising
  - This means gamma radiation is the least ionising as it has a charge of 0 (no charge)

- The **higher** the **kinetic energy** of the radiation, the **more** ionising it is
  - This means alpha particle is still the most ionising because it has the greatest mass
  - However, a beta particle is very light (it is an electron) but travels at high speeds, therefore, it has a lot of kinetic energy and is still moderately ionising
  - Gamma radiation has virtually no mass so is weakly ionising

Exam Tip

Remembering the properties of alpha, beta and gamma radiation really helps with deducing how much ionising power they have. E.g. An alpha particle is a helium nucleus which contains two protons and two neutrons. It therefore has a charge of +2 since each proton has a charge of +1 and a neutron has no charge.

Kinetic energy is defined by the equation $\frac{1}{2}mv^2$ therefore it depends on the mass m of the particle and its velocity v.

Deflection in Electric & Magnetic Fields

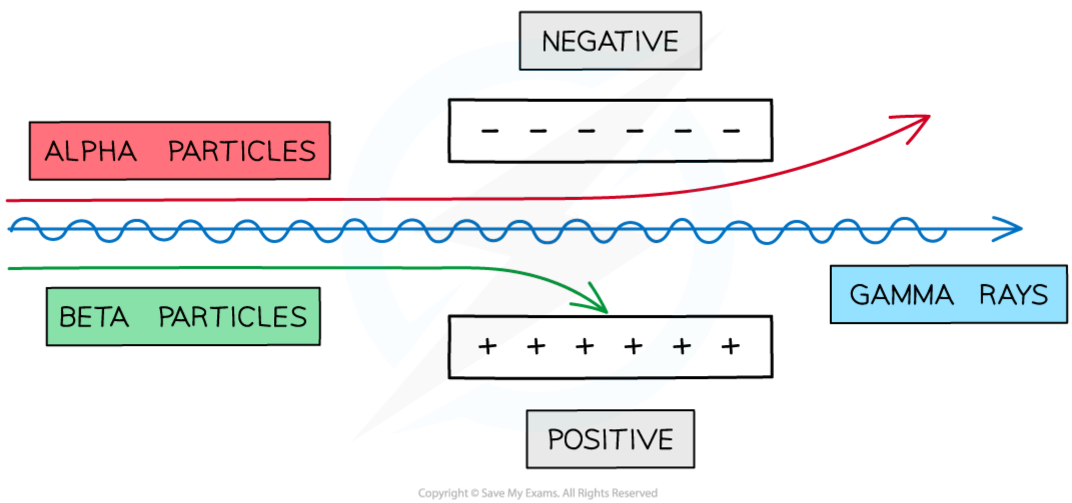
YOUR NOTES

EXTENDED

- A particle is deflected in an electric field if it has **charge**
- A particle is deflected in a magnetic field if it has **charge** and is **moving** perpendicular to it
  - Therefore, since gamma (γ) particles have no charge, they are **not** deflected by either electric or magnetic fields
  - Only alpha (α) and beta (β) particles are

Electric Fields

- Alpha particles have a **charge of +2** (charge of a helium nucleus)
- Beta particles have a **charge of –1** (charge of an electron)
- Therefore, between an electric field created between a negatively charged and positively charged plate
  - Alpha particles are deflected towards the **negative** plate
  - Beta particles are deflected towards the **positive** plate
  - Gamma radiation is not deflected and travels straight through between the plates



Alpha and Beta particles can be deflected by electric fields

- Alpha particles are **heavier** than beta particles
  - Therefore, beta particles are deflected more in the electric field and alpha is deflected less

Magnetic Fields

- Similarly, alpha and beta particles are deflected by magnetic fields whilst they are moving
- They are deflected in **opposite** directions due to their opposite charges

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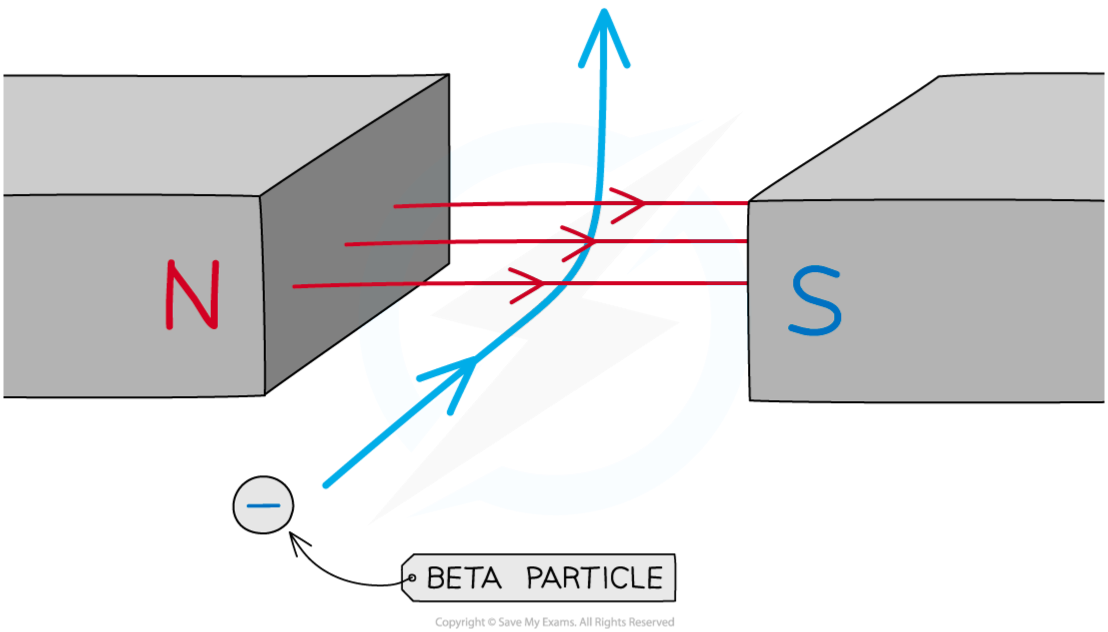


Alpha and Beta particles can also be deflected by magnetic fields

Exam Tip

It is important to note that because of their opposite charges, alpha and beta particles will deflect in **opposite** directions. You do not need to know which direction alpha and beta particles are deflected in a magnetic field (this is covered at A-level) but you should know that they are deflected, whilst gamma is not because they are charged and they deflect in opposite directions.

5.2.4 Radioactive Decay

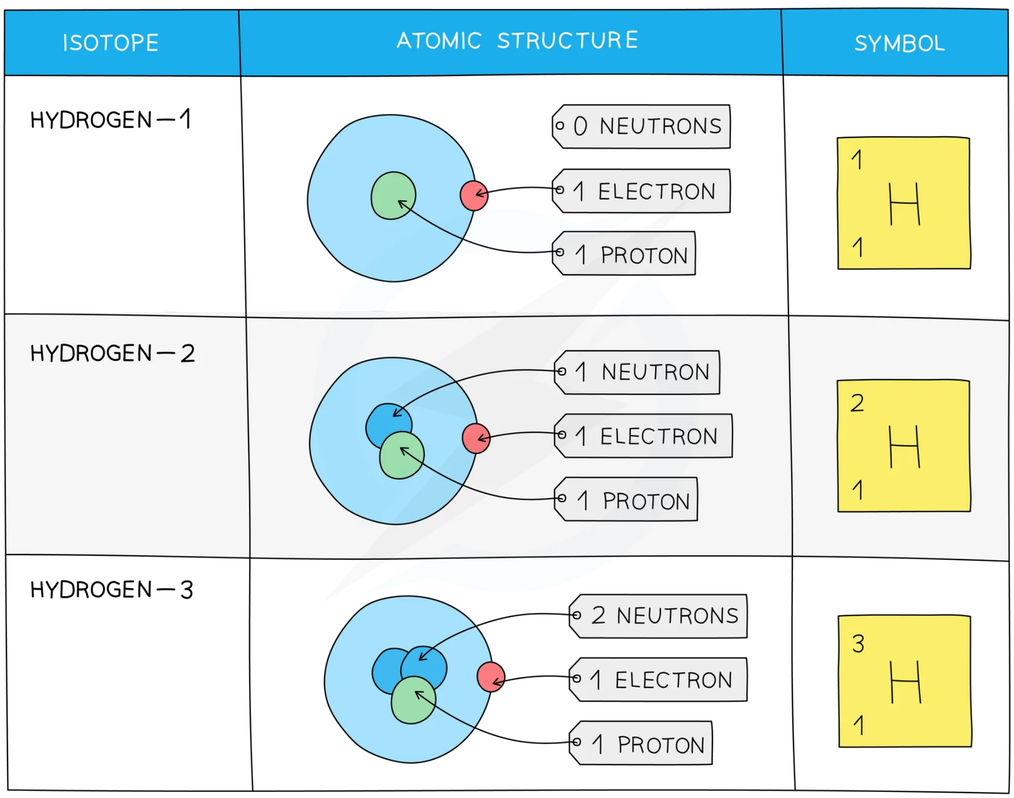
YOUR NOTES

Effect of Nuclear Size on Decay

EXTENDED

- The most stable nuclei have roughly the same number of protons to neutrons
  - If there were too many protons, then the repulsive force caused by them all having the same positive charge which cause the nucleus to repel when it becomes very large
- Therefore, if a nucleus has an imbalance of protons or neutrons, it is more likely to decay into small nuclei until it gets to a stable nucleus with roughly the same number of each
- Therefore, Isotopes of an element may be radioactive due to:
  - An excess of neutrons in the nucleus
  - The nucleus being too heavy
- An example of these are the isotope of hydrogen-1

Hydrogen Isotopes

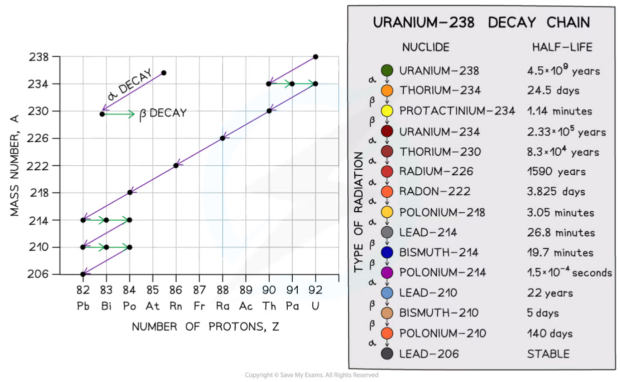


- H-1 is the stable nucleus of hydrogen
  - H-2 (deuterium) adds on one more neutron
  - H-3 (tritium) adds on another neutron, making 2 neutrons to 1 proton. This is much more unstable than H-1 or H-2
- If an nucleus is too **heavy**, this means it has too many protons and neutrons
  - The forces in the nucleus will be weaker in keeping the protons and neutrons together

YOUR NOTES

- This can also cause the nucleus to decay
- An example of this is Uranium-238 which is used in nuclear fission
  - This nucleus has 238 protons and neutrons
- The decay of Uranium-238 gradually reduces the mass number of the element which it decays into
  - This is done through alpha (α) or beta (β) decay

Uranium-238 Decay Chain

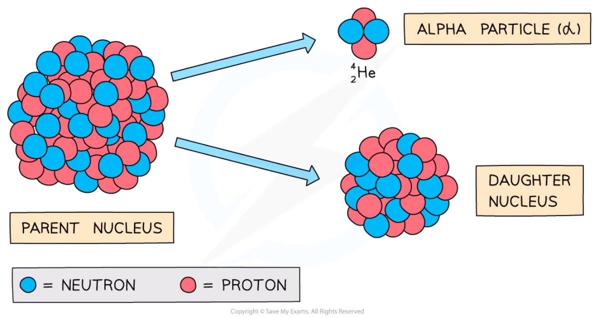


> **Exam Tip**
>
> The notation of C-12 for example, means the element 'Carbon' with the **mass** (or nucleon) number of 12.

YOUR NOTES

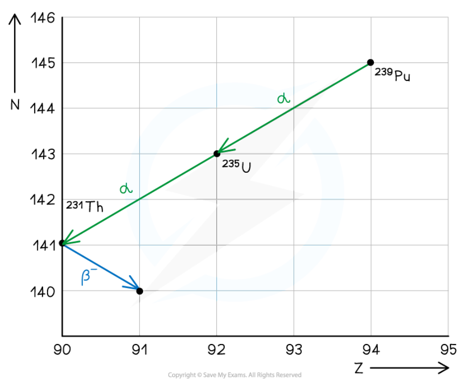
Change to a New Element

- During α-decay or β-decay, the nucleus changes to a **different element**
- The initial nucleus is often called the **parent nucleus**
- The nucleus of the new element is often called the **daughter** nucleus



Alpha decay creating change a parent nucleus to a daughter nucleus of a new element

- The daughter nucleus is a new element because it has a **different** proton and/or nucleon number to the original parent nucleus
- This can be seen on a graph of N (neutron number) against Z (proton number)



Graph of N against Z for the decay of Pu-239

- When Pu-239 decays by alpha to U-235, it loses 2 protons and 2 neutrons
  - U (Uranium) is a completely different element to Pu (Plutonium)

Reducing Neutron Number

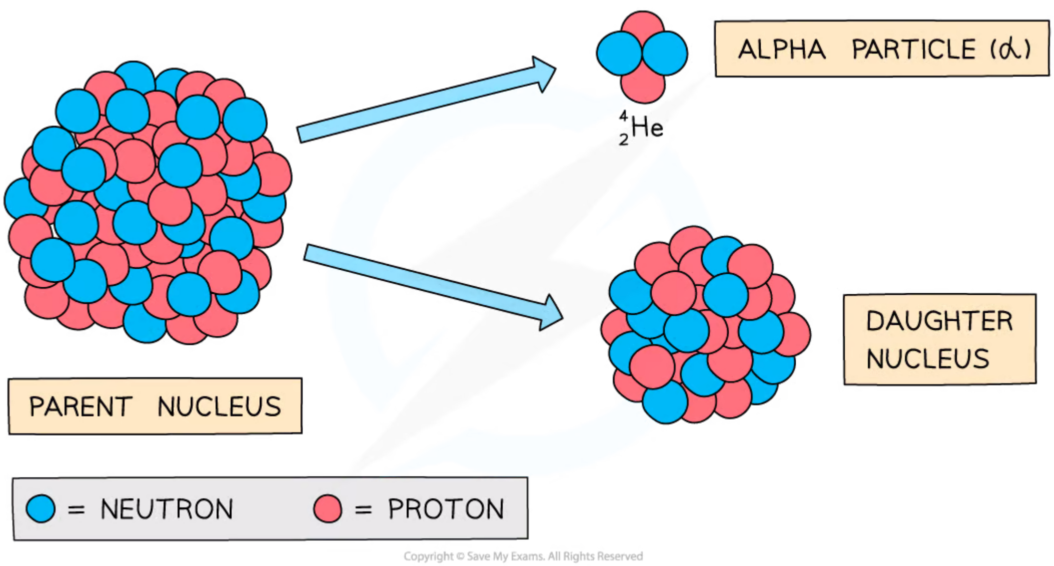
YOUR NOTES

EXTENDED

- A nucleus decays to increase its stability by reducing the number of excess neutrons
  - This is done by alpha or beta decay
- If the nucleus has too much energy, this is given off in the form of radiation
  - This is often gamma radiation

Alpha Decay

- During alpha decay an alpha particle is emitted from an unstable nucleus
- A completely **new element** is formed in the process



Alpha decay usually happens in large unstable nuclei, causing the overall mass and charge of the nucleus to decrease

- An alpha particle is a **helium nucleus**
  - It is made of 2 protons and 2 neutrons
- When the alpha particle is emitted from the unstable nucleus, the mass number and atomic number of the nucleus changes
  - The mass number **decreases** by 4
  - The atomic number **decreases** by 2
- The charge on the nucleus also decreases by 2
  - This is because protons have a charge of +1 each

Beta Decay

- During **beta** decay, a **neutron** changes into a **proton** and an **electron**
  - The electron is **emitted** and the proton **remains** in the nuclei
- A completely new element is formed because the **atomic number** changes

YOUR NOTES
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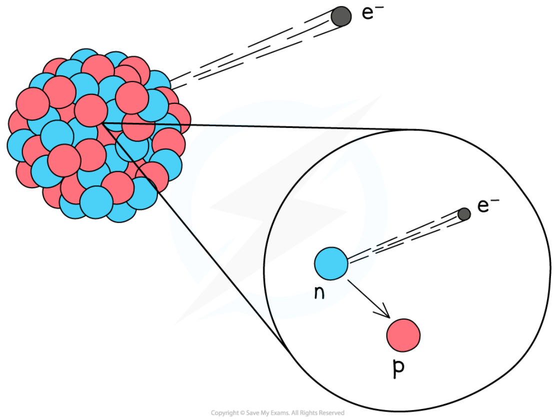
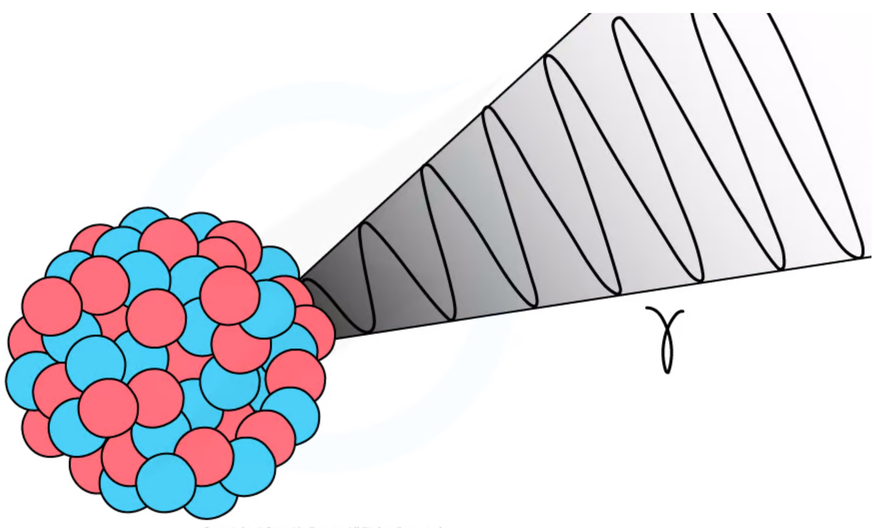


Beta decay often happens in unstable nuclei that have too many neutrons. The mass number stays the same, but the atomic number increases by one

- A beta particle is a high-speed **electron**
- It has a mass number of 0
  - This is because the electron has a negligible mass, compared to neutrons and protons
- Therefore, the **mass number** of the decaying nuclei **remains the same**
- Electrons have an atomic number of -1
  - This means that the new nuclei will **increase its atomic number by 1** in order to maintain the overall atomic number before and after the decay
- The following equation shows carbon-14 undergoing beta decay
  - It forms nitrogen-14 and a beta particle
  - Beta particles are written as an electron in this equation

Gamma Decay

- During gamma decay, a gamma ray is emitted from an unstable nucleus
- The process that makes the nucleus less energetic but does not change its structure



YOUR NOTES
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Gamma decay does not affect the mass number or the atomic number of the radioactive nucleus, but it does reduce the energy of the nucleus

- The gamma ray that is emitted has a lot of energy, but no mass or charge

Exam Tip

There is a second form of beta decay during which a proton changes into a neutron. This is called beta-plus decay - you might come across it while revising, but you don't need to know about it for your exam. Only use the information here for your iGCSE.

It is easy to forget that an alpha particle **is** a helium nucleus, or that a beta particle is an electron. Look out for either wording!

Decay Equations

YOUR NOTES

EXTENDED

- Radioactive decay events can be shown using a **decay equation**
- A decay equation is similar to a chemical reaction equation
  - The particles present before the decay are shown **before** the arrow
  - The particles produced in the decay are shown **after** the arrow
- During decay equations the sum of the mass and atomic numbers **before** the reaction must be the same as the sum of the mass and atomic numbers **after** the reaction
- The following decay equation shows Polonium-212 undergoing alpha decay
  - It forms Lead-208 and an alpha particle
  - An alpha particle can also be written as a helium nucleus (Symbol He)

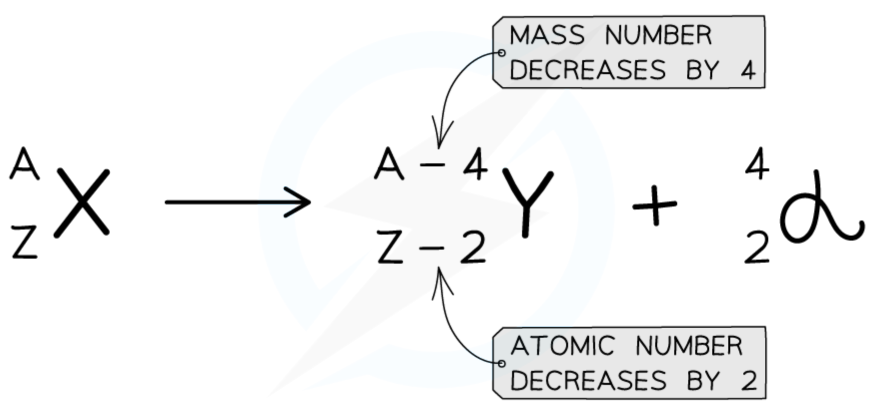
$$^{A}_{Z}X \rightarrow \, ^{A-4}_{Z-2}Y + \, ^{4}_{2}\alpha$$

$$\text{e.g.} \quad ^{212}_{84}Po \rightarrow \, ^{208}_{82}Pb + \, ^{4}_{2}\alpha$$

The polonium nucleus emits an alpha particle, causing its mass and charge to decrease. This means it changes into a new element

Alpha Decay Equation

- When the alpha particle is emitted from the unstable nucleus, the mass number and atomic number of the nucleus changes
  - The mass number **decreases** by 4
  - The atomic number **decreases** by 2



Alpha decay equation

Beta Decay Equation

- During **beta** decay, a **neutron** changes into a **proton** and an **electron**
  - The electron is **emitted** and the proton **remains** in the nuclei

YOUR NOTES
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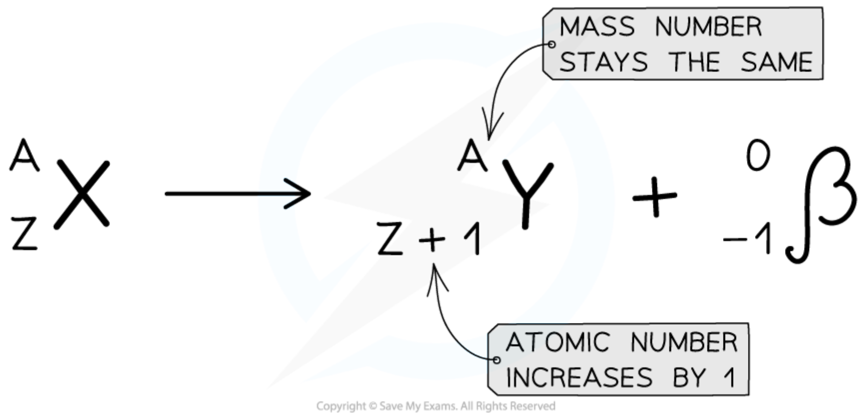
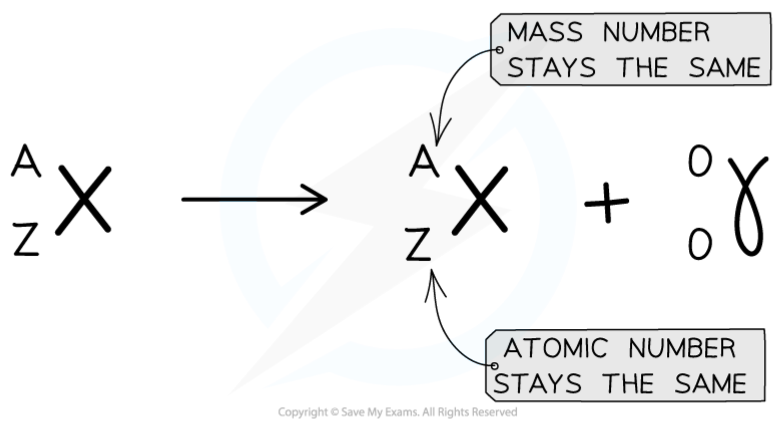


Beta decay equation

Gamma Decay

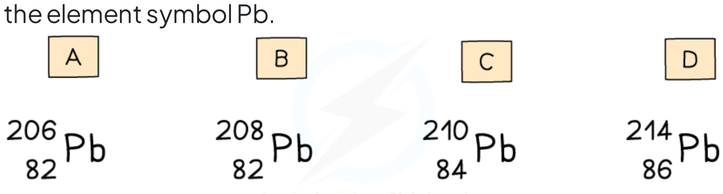
- The gamma ray that is emitted has a lot of energy, but no mass or charge
- Here is an example of Uranium-238 undergoing gamma decay
    - Notice that the mass number and atomic number of the unstable nuclei remains the same during the decay



Gamma decay equation

Worked Example

A nucleus with 84 protons and 126 neutrons undergoes alpha decay. It forms lead, which has the element symbol Pb.



Which of the isotopes of lead pictured is the correct one formed during the decay?

ANSWER: A

Step 1: Calculate the mass number of the original nucleus

- The mass number is equal to the number of protons plus the number of neutrons
- The original nucleus has 84 protons and 126 neutrons

$$84 + 126 = 210$$

- The mass number of the original nucleus is 210

Step 2: Calculate the new atomic number

- The alpha particle emitted is made of two protons and two neutrons
- Protons have an atomic number of 1, and neutrons have an atomic number of 0
- Removing two protons and two neutrons will reduce the atomic number by 2

$$84 - 2 = 82$$

- The new nucleus has an atomic number of **82**

Step 3: Calculate the new mass number

- Protons and neutrons both have a mass number of 1
- Removing two protons and two neutrons will reduce the mass number by 4

$$210 - 4 = 206$$

- The new nucleus has a mass number of **206**

Worked Example

A nucleus with 11 protons and 13 neutrons undergoes beta decay. It forms magnesium, which has the element symbol Mg.

A	B	C	D
${}^{20}_{9}\text{Mg}$	${}^{24}_{10}\text{Mg}$	${}^{23}_{11}\text{Mg}$	${}^{24}_{12}\text{Mg}$

Which is the correct isotope of magnesium formed during the decay?

ANSWER: D

Step 1: Calculate the mass number of the original nucleus

- The mass number is equal to the number of protons plus the number of neutrons
- The original nucleus has 11 protons and 13 neutrons

$$11 + 13 = 24$$

- The mass number of the original nucleus is 24

Step 2: Calculate the new atomic number

- During beta decay a neutron changes into a proton and an electron
- The electron is emitted as a beta particle

YOUR NOTES
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- The neutron has an atomic number of 0 and the proton has an atomic number of 1
- So the atomic number increases by 1

$$11 + 1 = 12$$

- The new nucleus has an atomic number of 12

Step 3: Calculate the new mass number

- Protons and neutrons both have a mass number of 1
- Changing a neutron to a proton will not affect the mass number
- The new nucleus has a mass number of 24 (the same as before)

Exam Tip

You are not expected to know the names of the elements produced during radioactive decays, but you do need to be able to calculate the mass and atomic numbers by making sure they are balanced on either side of the reaction.

5.2.5 Half-Life

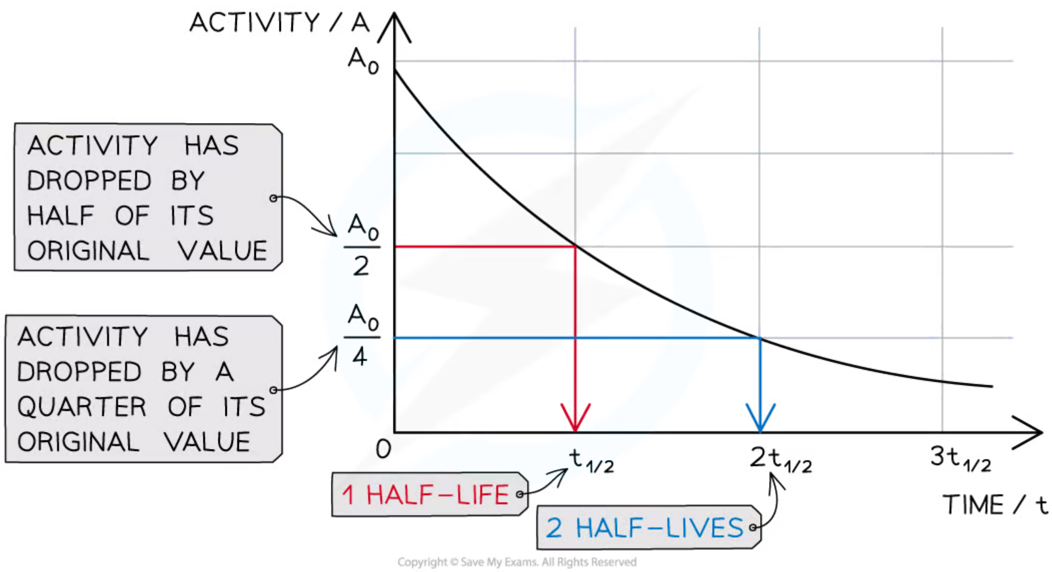
YOUR NOTES

Half-Life Basics

- It is impossible to know when a particular unstable nucleus will decay
- But the **rate** at which the activity of a sample decreases can be known
  - This is known as the **half-life**
- Half-life is defined as:

The time taken for half the nuclei of that isotope in any sample to decay

- In other words, the time it takes for the activity of a sample to fall to half its original level
- Different isotopes have different half-lives and half-lives can vary from a fraction of a second to billions of years in length
- Half-life can be determined from an activity-time graph



The graph shows how the activity of a radioactive sample changes over time. Each time the original activity halves, another half-life has passed

- The time it takes for the activity of the sample to decrease from 100 % to 50 % is the half-life
  - It is the same length of time as it would take to decrease from 50 % activity to 25 % activity
  - The half-life is **constant** for a particular isotope
- Half-life can also be represented on a table
  - As the number of half life increases, the proportion of the isotope remaining **halves**

Table For Number of Half Lives to Proportion of Isotope

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NUMBER OF HALF–LIVES	PROPORTION OF ISOTOPE REMAINING
0	1
1	1/2
2	1/4
3	1/8
4	1/16
...	...

YOUR NOTES
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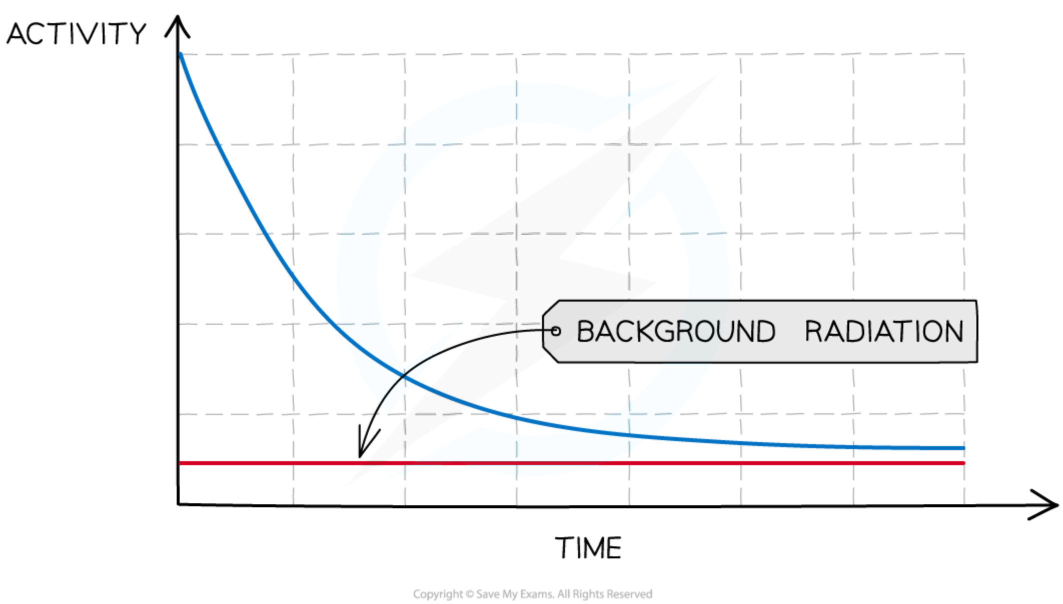
Half-Life Graphs

- To calculate the half-life of a sample from a graph:
  - Check the original activity (where the line crosses the y-axies), A_0
  - Halve this value and look for this activity
  - Go across from the halved value (on the y-axis) to the best fit curve, and then straight down to the x-axis
  - The point where you reach the x-axis should be the half-life
- The time taken for the activity to decrease to half its original value is the **half-life**

Background Radiation

- Background radiation is radiation that is always present in the environment around us
- As a consequence, whenever an experiment involving radiation is carried out, some of the radiation that is detected will be background radiation
- When carrying out experiments to measure half-life, the presence of background radiation must be taken into account



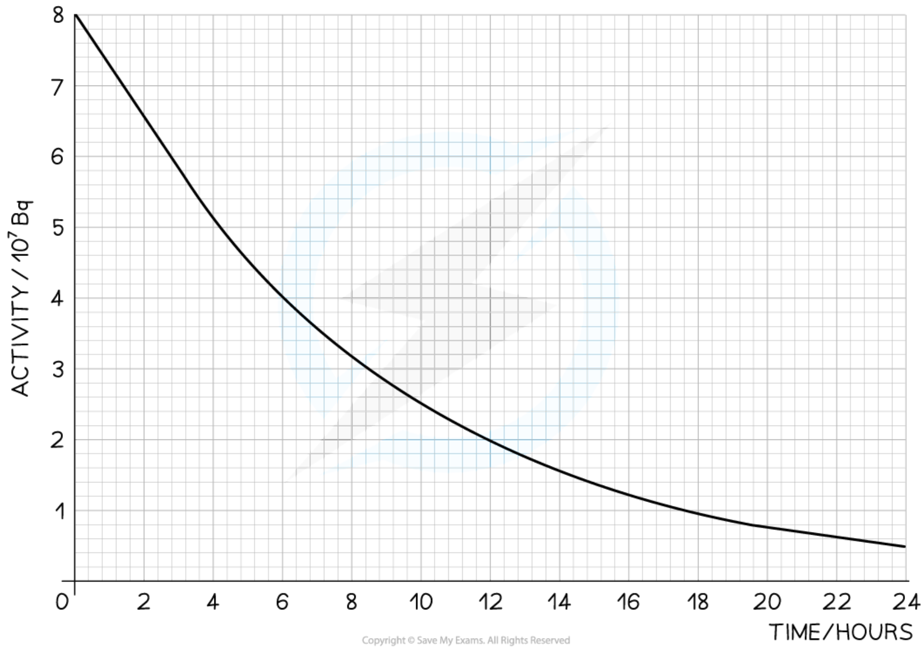
When measuring radioactive emissions, some of the detected radiation will be background

- To do this you must:
  - Start by measuring background radiation (with no sources present) – this is called your **background count**
  - Then carry out your experiment
  - Subtract the background count from each of your readings, in order to give a **corrected count**
  - The corrected count is your best estimate of the radiation emitted from the source, and should be used to measure its half-life

YOUR NOTES

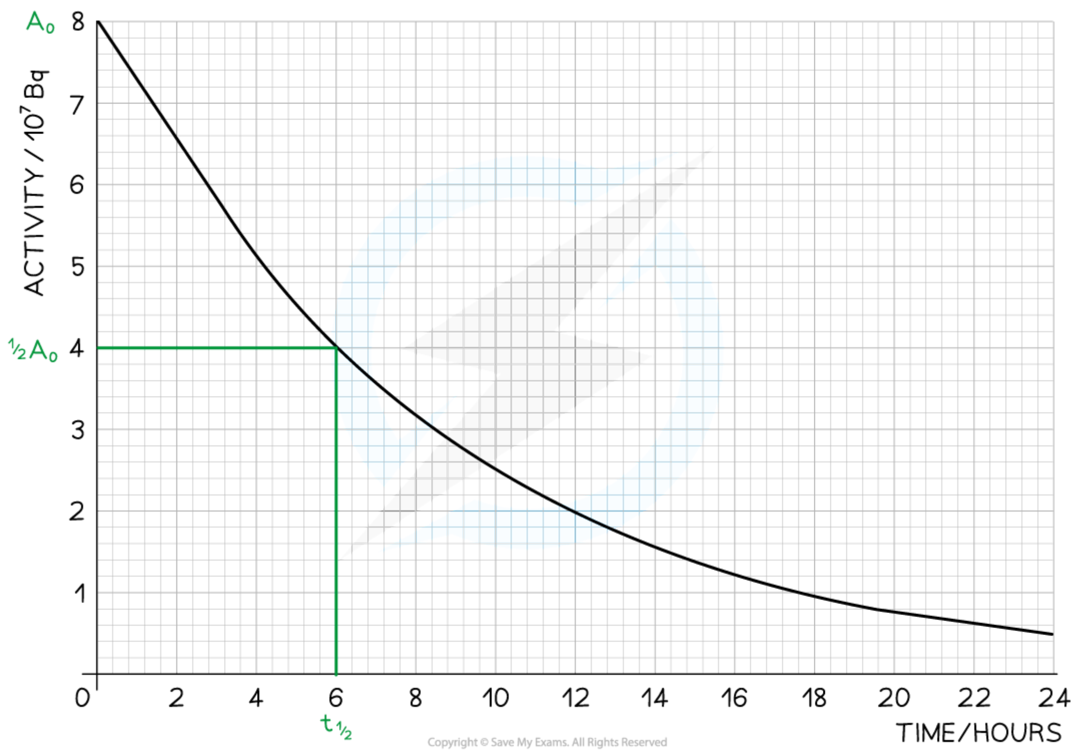
Worked Example

The radioisotope technetium is used extensively in medicine. The graph below shows how the activity of a sample varies with time.



Determine the half-life of this material.

Step 1: Draw lines on the graph to determine the time it takes for technetium to drop to half of its original activity



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Step 2: Read the half-life from the graph

- In the diagram above the initial activity, A_0, is 8×10^7 Bq
- The time taken to decrease to 4×10^7 Bq, or ½ A_0, is 6 hours
- The time taken to decrease to 2×10^7 Bq is 6 **more** hours
- The time taken to decrease to 1×10^7 Bq is 6 **more** hours
- Therefore, the half-life of this isotope is **6 hours**

Worked Example

A particular radioactive sample contains 2 million un-decayed atoms. After a year, there is only 500 000 atoms left un-decayed. What is the half-life of this material?

Step 1: Calculate how many times the number of un-decayed atoms has halved

- There were 2 000 000 atoms to start with
- **1 000 000** atoms would remain after **1 half-life**
- **500 000** atoms would remain after **2 half-lives**
- Therefore, the sample has undergone 2 half-lives

Step 2: Divide the time period by the number of half-lives

- The time period is a year
- The number of half-lives is 2
- 1 year divided by 2 is half a year or 6 months
- Therefore, the half-life is **6 months**

Exam Tip

When looking for the corresponding time for the activity, it is good practice to draw a line on the graph with your ruler like is done in the mark scheme of the worked example. This ensures you're reading the most accurate value possible.

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5.2.6 Uses of Radiation

YOUR NOTES

Uses of Radiation

- Radiation is used in a number of different ways:
    1. Medical procedures including diagnosis and treatment of cancer
    2. Sterilising food (irradiating food to kill bacteria)
    3. Sterilising medical equipment (using gamma rays)
    4. Determining the age of ancient artefacts
    5. Checking the thickness of materials
    6. Smoke detectors (alarms)
- The properties of the different types of radiation determine which one is used in a particular application

Smoke Detectors

- Alpha particles are used in smoke detectors
- The alpha radiation will normally **ionise** the air within the detector, creating a current
- The alpha emitter is blocked when smoke enters the detector
- The alarm is triggered by a microchip when the sensor no longer detects alpha

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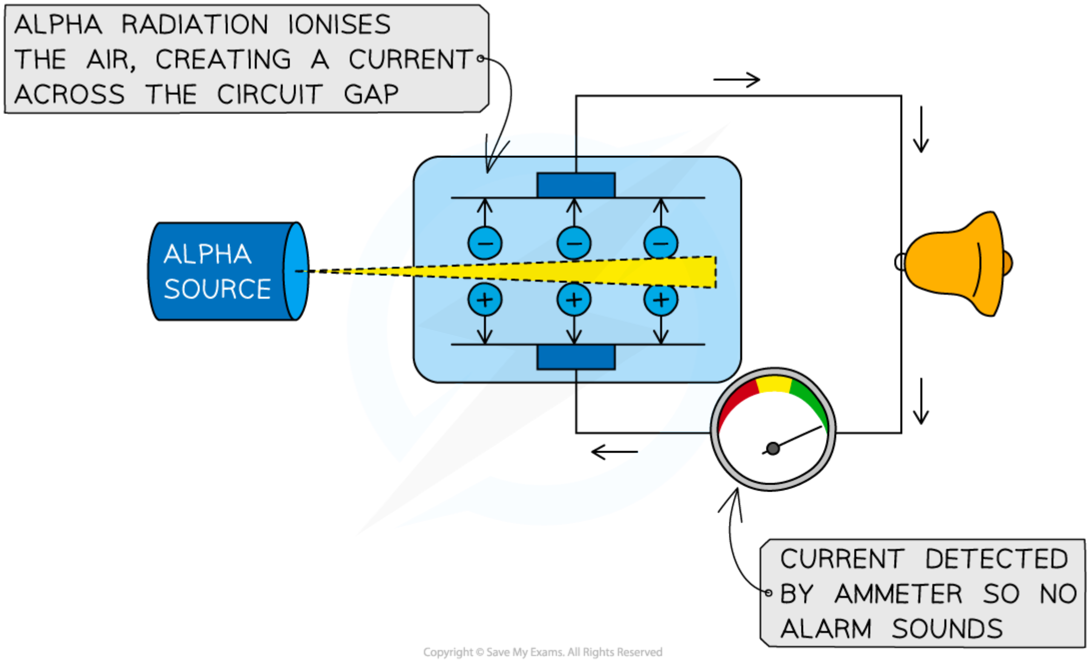

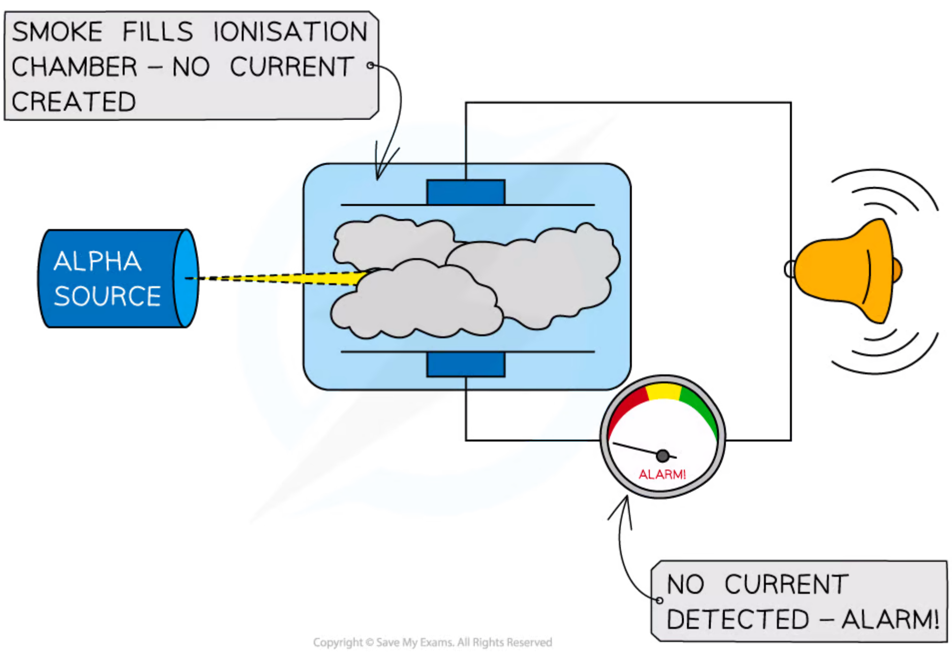

In the diagram on the right, alpha particles are stopped by the smoke, preventing the flow of current and triggering the alarm

Measuring the Thickness of Materials

- Radiation can be used for tracing and gauging thickness
  - Mostly commonly this is **beta** particles
- As a material moves above a **beta** source, the particles that are able to penetrate it can be monitored using a detector

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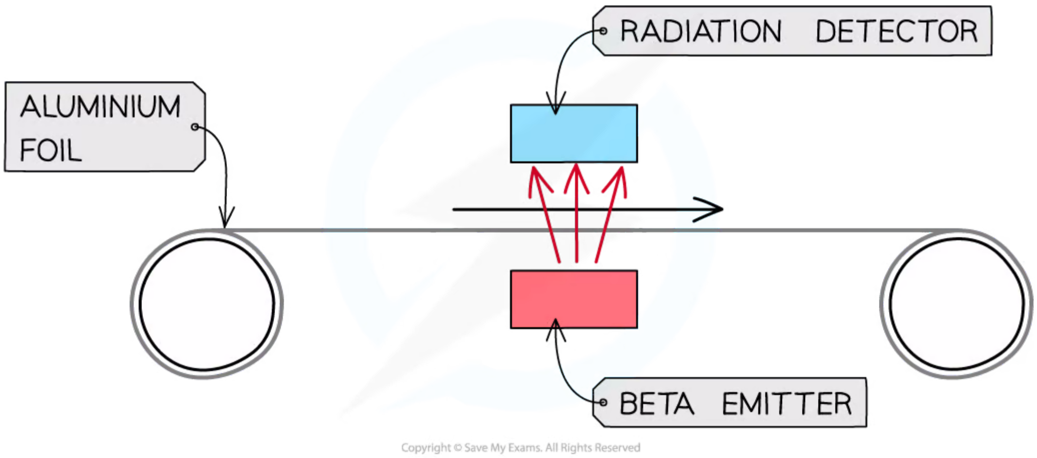
- If the material gets **thicker, more** particles will be absorbed, meaning that **less** will get through
  - If the material gets **thinner** the **opposite** happens
- This allows the machine to make **adjustments** to keep the thickness of the material **constant**



Beta particles can be used to measure the thickness of thin materials such as paper, cardboard or aluminium foil

- Beta radiation is used because it will be **partially absorbed** by the material
  - If **alpha** particles were used **all of them would be absorbed** and none would get through
  - If **gamma** were used almost **all of it would get through** and the detector would not be able to sense any difference if the thickness were to change

Diagnosis and Treatment of Cancer

- **Radiotherapy** is the name given to the treatment of cancer using radiation (Chemotherapy is treatment using chemicals)
- Although radiation can cause cancer, it is also highly effective at **treating** it
- Radiation can kill living cells. Some cells, such as bacteria and cancer cells, are more susceptible to radiation than others
- Beams of gamma rays are directed at the cancerous tumour
  - Gamma rays are used because they are **able to penetrate the body**, reaching the tumour
  - The beams are moved around to minimise harm to healthy tissue whilst still being aimed at the tumour
- A **tracer** is a radioactive isotope that can be used to track the movement of substances, like blood, around the body
  - A PET scan can detect the emissions from a tracer to diagnose cancer and determine the location of a tumour

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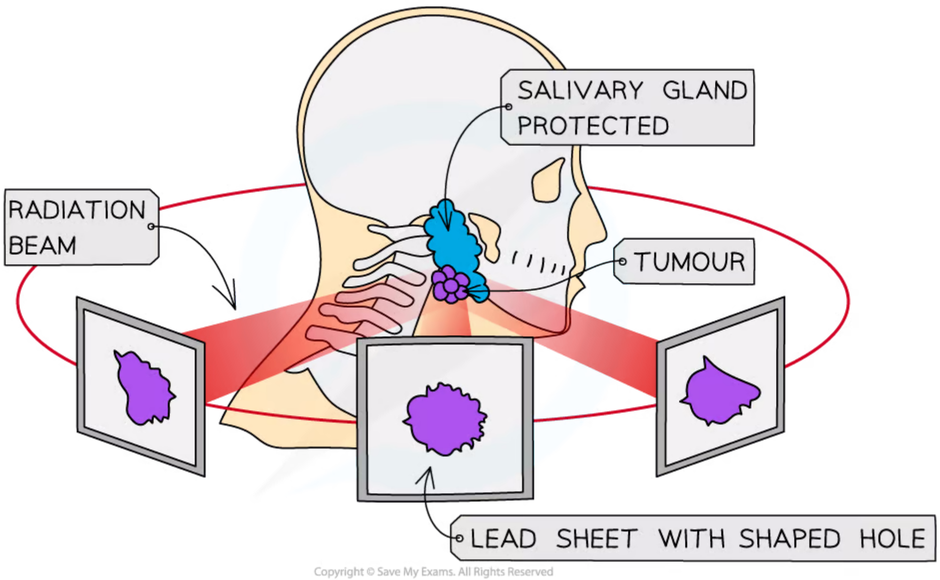

Radiation therapy to remove a tumour

Sterilising Food and 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**

- Food can be irradiated in order to **kill any microorganisms** that are present on it
- This makes the food last longer, and reduces the risk of food-borne infections

Food that has been irradiated carries this symbol, called the Radura. Different countries allow different foods to be irradiated

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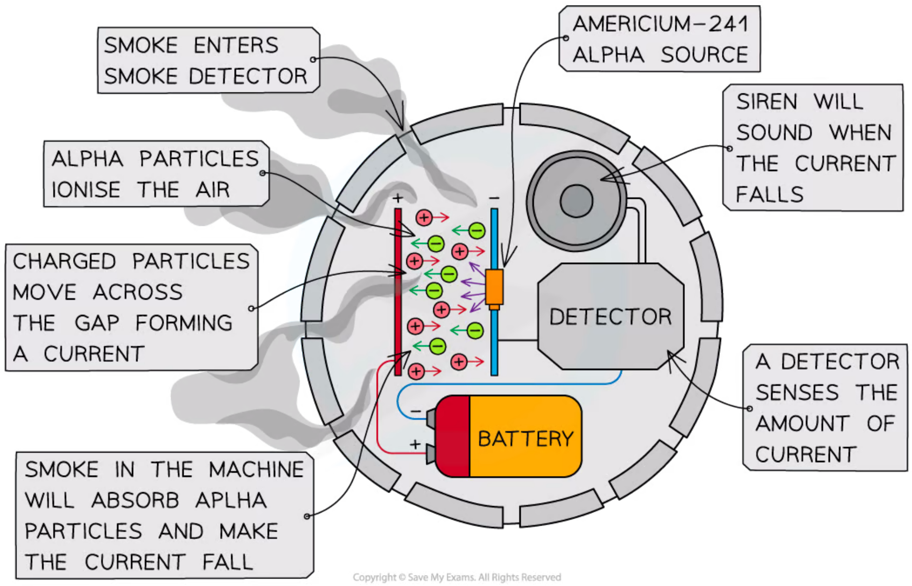
Worked Example

Use the diagram to explain why is alpha radiation used in smoke detectors, and not beta or gamma radiation.



- Consider the different properties of alpha, beta and gamma:
  - **Alpha** is the most **weakly** penetrating and **strongest** ioniser
  - **Beta** and **gamma** have **stronger** penetrating power and **weaker** ionising power
- If beta or gamma radiation were used in this situation then they would pass straight through the smoke and the alarm would not go off
- Therefore, since alpha is **absorbed** by smoke, and beta and gamma are not, this makes it **most suitable** for use in a smoke detector

Exam Tip

If you are presented with an unfamiliar situation in your exam don't panic! Just apply your understanding of the properties of alpha, beta and gamma radiation. Mainly think about the range (how far it can travel) and ionising power of the radiation to help understand which radiation is used in which situation.

5.2.7 Dangers of Radiation

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Dangers of Radioactivity

- Ionising radiation can damage human cells and tissues at high doses:
- This could be in terms of:
    1. Cell death
    2. Tissue damage
    3. Mutations
    4. Cancer

- As a result, its use needs to be kept to a minimum
- However, the benefits of using radiation in medicine can out way the potential risks
    - The risks posed by the radiation are smaller than the risks associated with leaving the condition untreated

- For example, if a person has a cancerous tumour that is likely to kill them, then it is **less** of a risk to use radiotherapy than to leave the tumour

Tissue Damage

- Radiation is effectively used to destroy cancerous tumour cells
- However, it can cause damage to healthy tissue if it is not properly targeted
- This is mostly from high-energy radiation such as gamma rays and X-rays

Mutations

- If the atoms that make up a DNA strand are ionised then the DNA strand can be damaged
- If the DNA is damaged then the cell may die, or the DNA may be **mutated** when it reforms
- If a mutated cell is able to replicate itself then a **tumour** may form
    - This is an example of **cancer**, which is a significant danger of radiation exposure

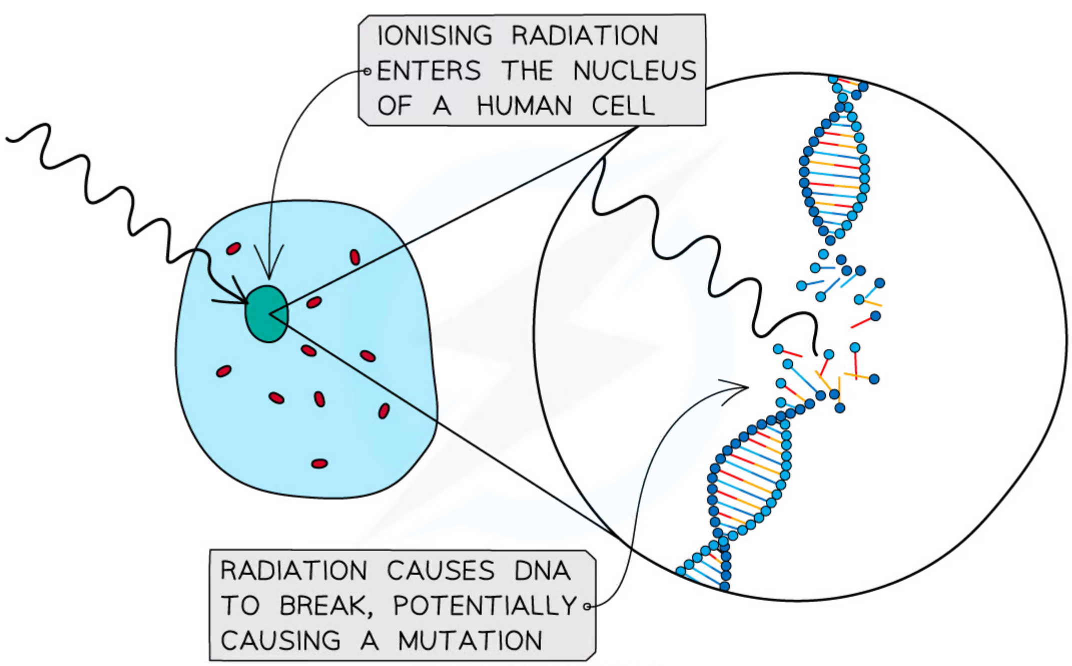

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Diagram showing the damage caused to DNA by ionising radiation. Sometimes the cell is able to successfully repair the DNA, but incorrect repairs can cause a mutation

- Acute radiation exposure can have other serious symptoms:
  - It can cause skin **burns**, similar to severe sunburn
  - Radiation can **reduce** the amount of **white blood cells** in the body, making a person more susceptible to infections by lowering their immune system
- Because of this, it is very important to handle radioactive sources carefully

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Safe Storage

- The risks associated with handling radioactive sources can be minimised by following a few simple procedures:
  - Store the sources in lead-lined boxes and keep at a distance from people
  - Minimise the amount of time you handle sources for and return them to their boxes as soon as you have finished using them
  - During use, keep yourself (and other people) as far from the sources as feasible. When handling the sources do so at arm's length, using a pair of tongs

Radioactivity warning sign

- When using tongs, gloves and safety specs are usually unnecessary when handling radioactive materials, unless there is a risk of the material leaking on to things

Disposing of Radioactive Waste

- If an isotope has a long half-life then a sample of it will decay slowly
  - Although it may not emit a lot of radiation, it will **remain radioactive for a very long time**
- Sources with long half-life values present a risk of contamination for a much longer time
- Radioactive waste with a long half-life is buried underground to prevent it from being released into the environment

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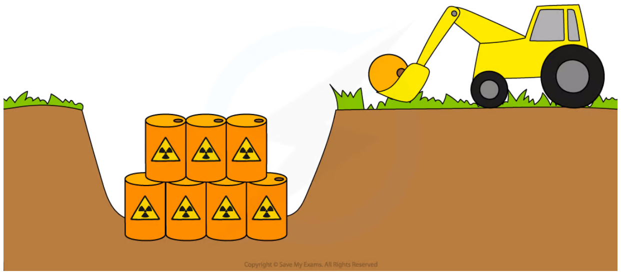

Radioactive waste with long half lifes are buried deep underground

Worked Example

A student plans to use a gamma source to conduct an experiment. List four things that the student should do in order to minimise the risk to themselves when using the source.

Any four from:

- Keep the source in a lead lined container until the time it is needed
- Use tongs to move the source, rather than handling it directly
- The source should be kept at as far a distance from the student as possible during the experiment
- The time that the source is being used should be minimised
- After the experiment the student should wash their hands
- The date and the time that the radiation has been used for should be recorded

Safety Precautions

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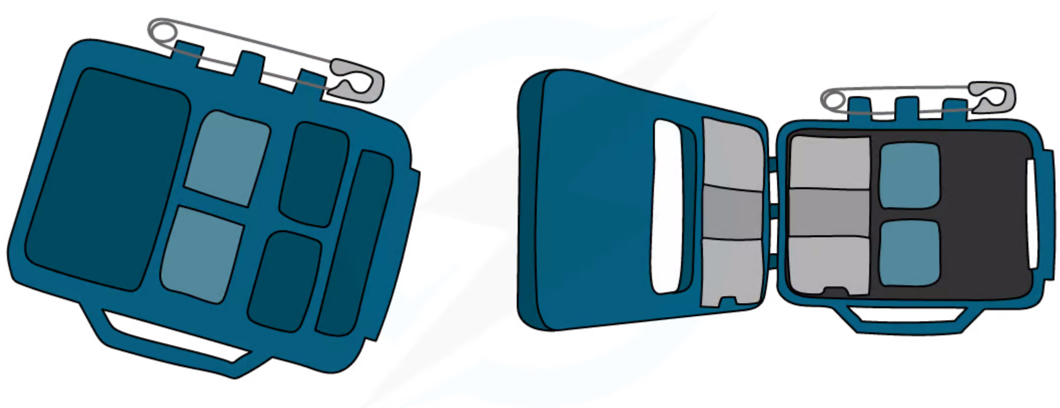
EXTENDED

- To mitigate the risks of radiation exposure, there are some safe practices that should be used:
  - Radioactive sources should be kept in a **shielded container** when not in use, for example, a lead-lined box
  - Radioactive materials should only be handled when wearing **gloves**, and with **tongs** to increase the distance from them
  - It may be appropriate to wear **protective clothing** to prevent the body becoming contaminated
  - The **time** that a radioactive source is being used for should be **limited**

Regulating Exposure

- Because of the harmful effects of radiation, it is important to **regulate** the exposure of humans to radiation
- The amount of radiation received by a person is called the dose and is measured in **sieverts** (Sv)
- One sievert is a very big dose of radiation
  - It would cause acute **radiation poisoning**

- People would normally receive about 3 mSv (0.003 Sv) in one year
- To protect against over-exposure, the dose received by different activities is measured
- A dosemeter measures the amount of radiation in particular areas and is often worn my radiographers, or anyone working with radiation



A dosemeter, or radiation badge, can be worn by a person working with radiation in order to keep track of the amount of radiation they are receiving

Differences in Exposure

- The amount of radiation that a person receives is affected by a person's **occupation, lifestyle** or **location**

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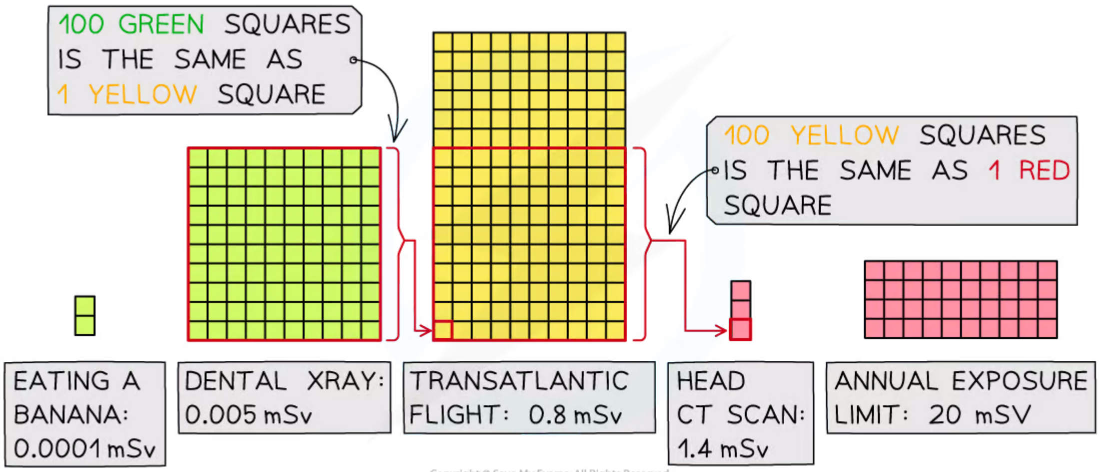
- Some areas around the world have higher **background radiation** because they are closer to sources of radiation
- People that work with nuclear radiation receive more radiation
  - The UK limit for nuclear industry employees is 20 mSv in one year
- The diagram below compares the dose received by some different activities



All living things emit a small amount of radiation: the amount of radiation within a banana is tiny, and not at all dangerous!