Edexcel GCSE Physics

Your notes

Radioactive Decay

Contents

Types of Radiation

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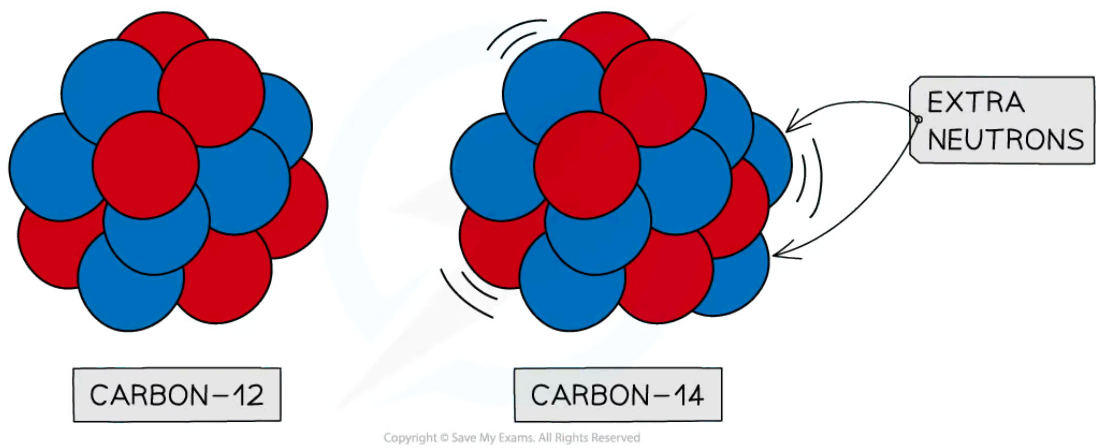
Types of Radiation

- 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
- Carbon-14 is an **isotope** of carbon which is unstable
  - It has two extra neutrons compared to stable carbon-12
- When an unstable nucleus decays it emits radiation, called **nuclear radiation**



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

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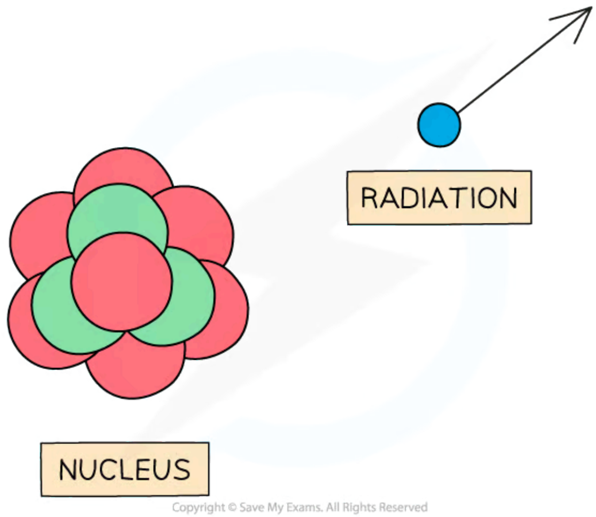

Unstable nuclei decay by emitting high energy particles or waves

- There are different types of radiation that can be emitted:
  - Alpha (α)
  - Beta-minus (β^-)
  - Beta-plus (β^+)
  - Gamma (γ)
  - Neutrons
- As the radiation moves away from the nucleus, it transfers energy away from the system
  - 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

Worked Example

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

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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

The Nature of Radiation

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

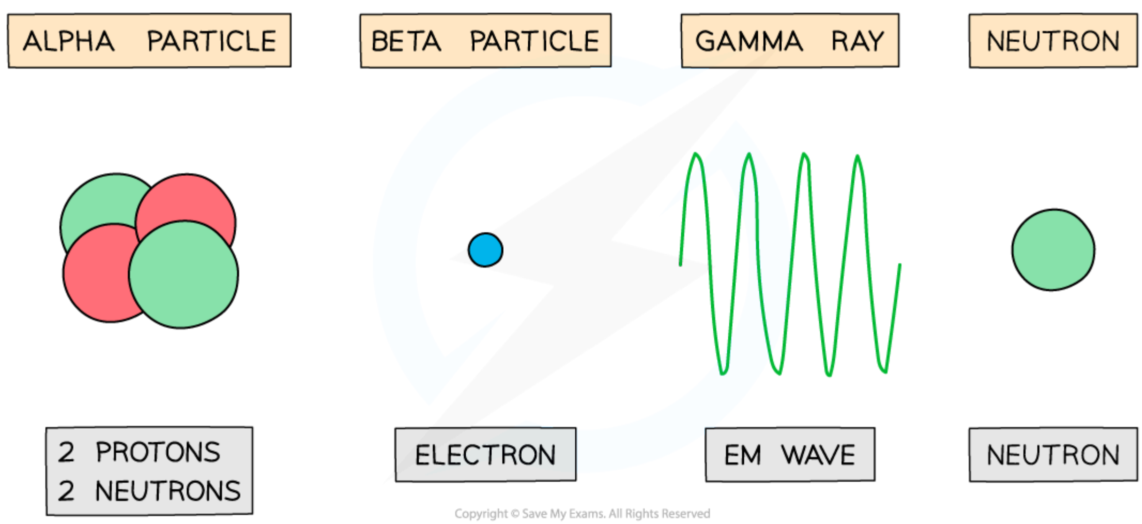
- The symbol for beta is β
- Beta particles are **fast-moving electrons emitted from the nucleus**
- Beta-plus particles are fast-moving **positrons** (positive version of electrons)
- They are produced in nuclei when a neutron changes into a proton and an electron
- Beta-minus particles have a charge of -1
- Beta-plus 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

Neutrons

- The symbol for a neutron is n
- Neutrons are one of the two particles found in the nucleus of atoms
- Neutrons are neutral, they have no charge



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

Examiner Tips and Tricks

Make sure to memorise the different types of radiation, as these are common exam questions. However, neutron radiation is less common and it is not required to know its properties for the exam

Ionising Radiation

- Ionisation is the process by which an atom loses an electron due to radiation

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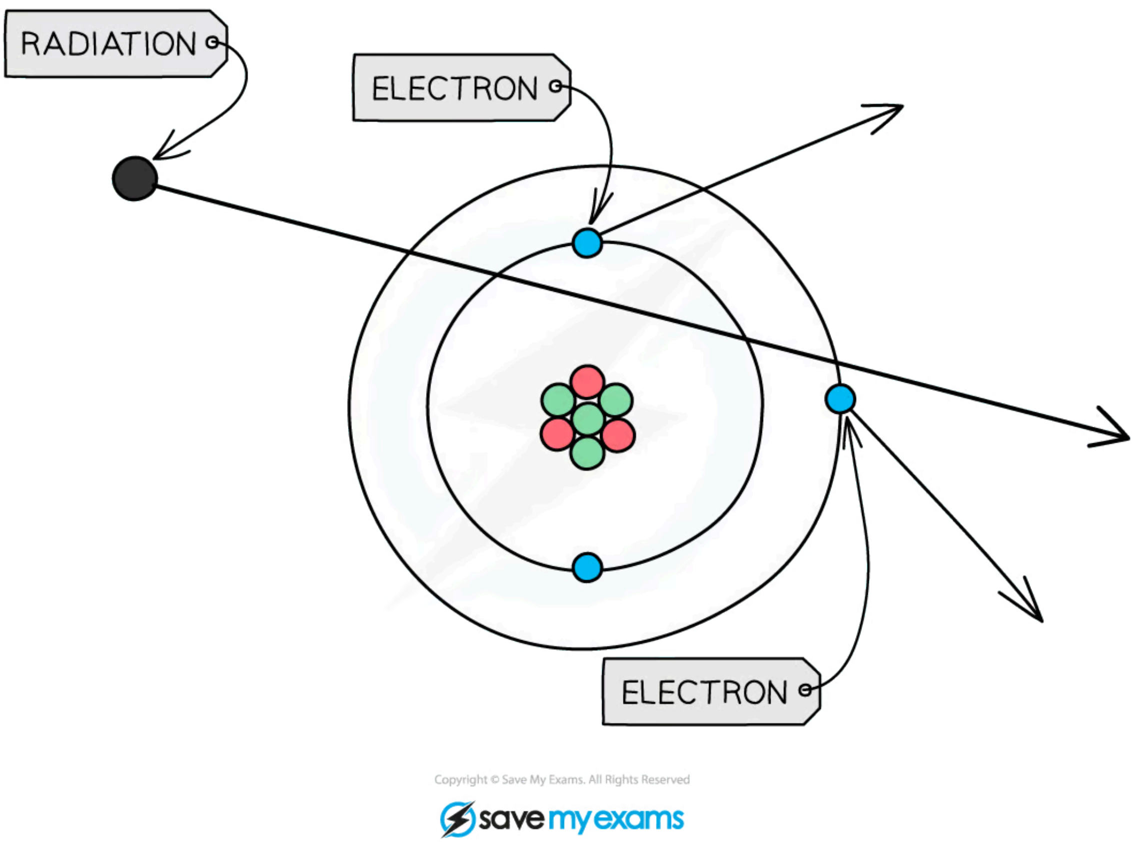
- All nuclear radiation is capable of **ionising** atoms that it hits
- When an atom is ionised, the number of electrons it has changes
  - This gives it a **non-zero** charge (the atom is left with a net positive charge)



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

- Alpha radiation is the **most** ionising form of nuclear radiation
  - This is because alpha particles have a charge of +2 and is the heaviest
- Gamma radiation is the **least** ionising form of nuclear radiation

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Properties of Radiation

Comparing Alpha, Beta & Gamma

- The properties of Alpha, Beta-plus, Beta-minus 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 minus (β^-)	Electron	−1	Few 10s of cm	Stopped by a few mm Aluminium	Medium
Beta plus (β^+)	Positron	+1	Few 10s of cm	Stopped by a few mm Aluminium	Medium
Gamma (γ)	Electromagnetic wave	0	Infinite	Reduced by a 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

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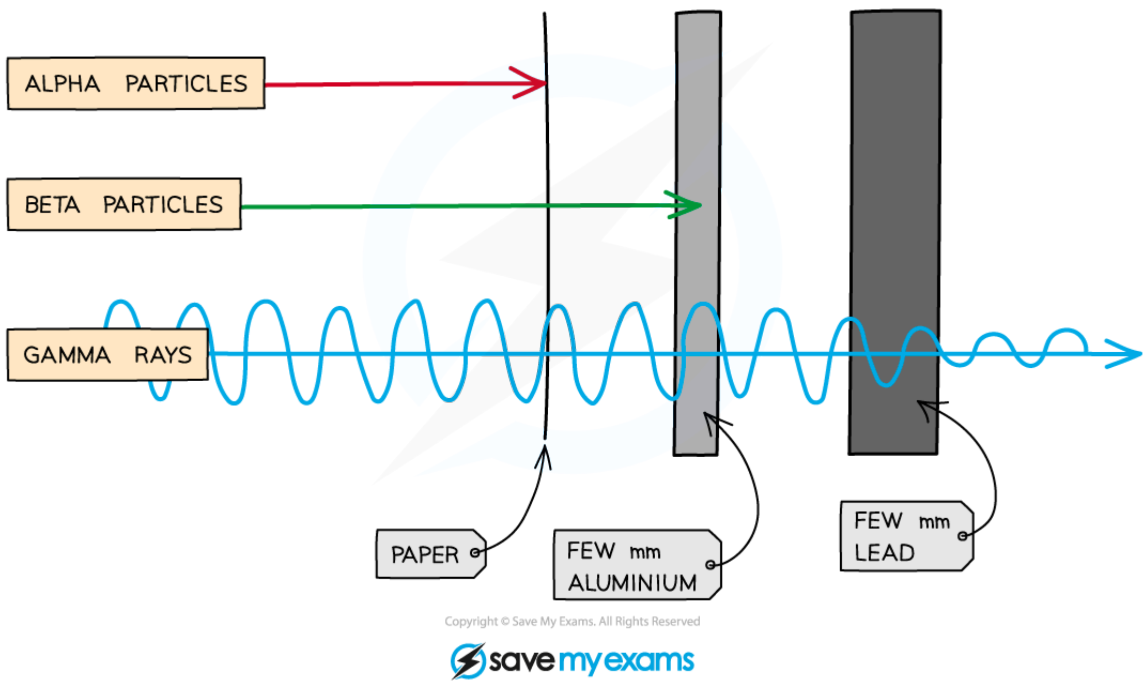

Alpha, beta and gamma are different in how they penetrate materials. Alpha is the least penetrating, and gamma is the most penetrating

- 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 can be **reduced** by several **metres of concrete** or several **centimetres of lead**
- The more ionising a form of radiation is, the sooner it will react with the air it is moving through
- **Strongly ionising** radiation has the **shortest range** in air
  - Alpha only travels a few centimetres in air
  - Beta has a range of a few tens of centimetres
  - Gamma is not absorbed by air and so has an infinite range, although it does become less intense with distance

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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

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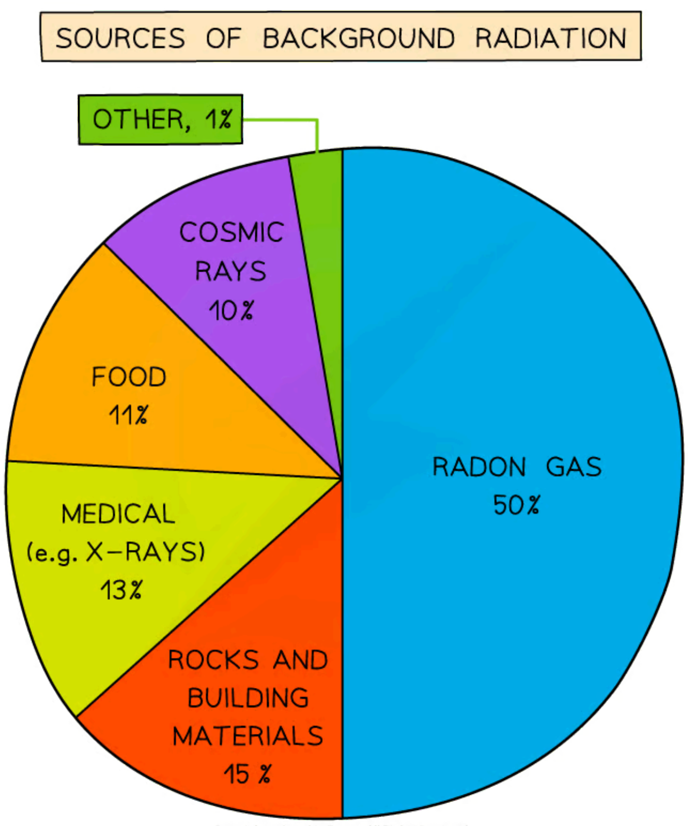
Background Radiation

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

Origins of Background Radiation

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

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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

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**

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.

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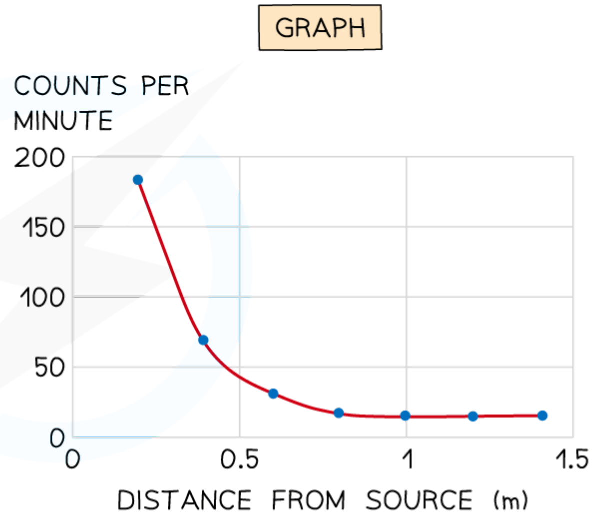
RESULTS TABLE

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.

Answer:

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**

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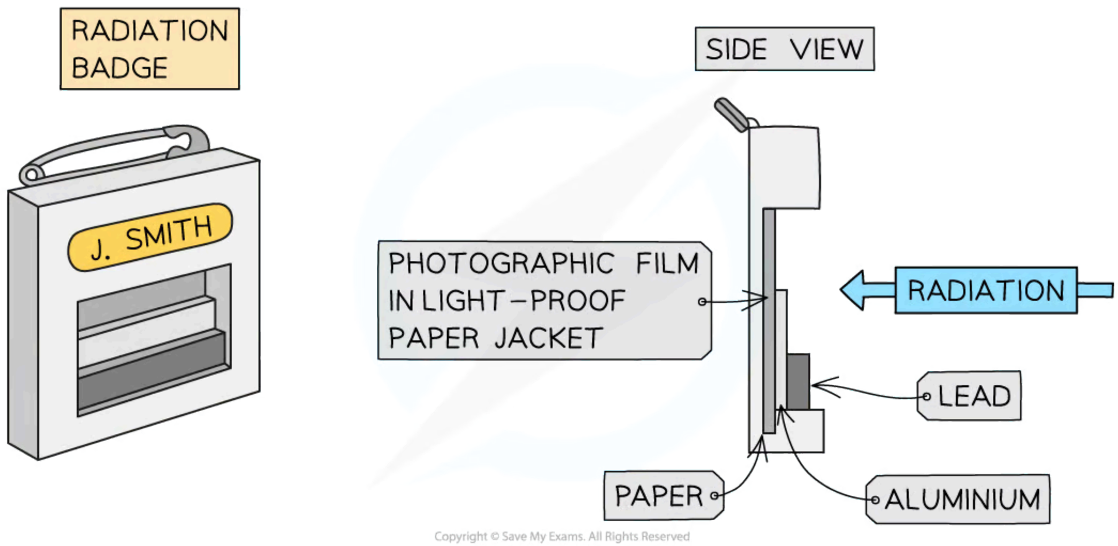
Detecting Radiation

Detecting 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
- Radiation can be measured and detected using a **photographic film** or a **Geiger–Müller tube**

Photographic Film

- Photographic films detect radiation by becoming darker when it absorbs radiation, just like it does when it absorbs visible light
  - The more radiation the film absorbs, the darker it is when it is developed
- People who work with radiation, such as radiographers, wear film badges which are checked regularly to monitor the levels of radiation absorbed
- To get an accurate measure of the dose received, the badge contains different materials that the radiation must penetrate to reach the film
  - These materials may include aluminium, copper, paper, lead and plastic
- The diagram shows what a typical radiation badge looks like:



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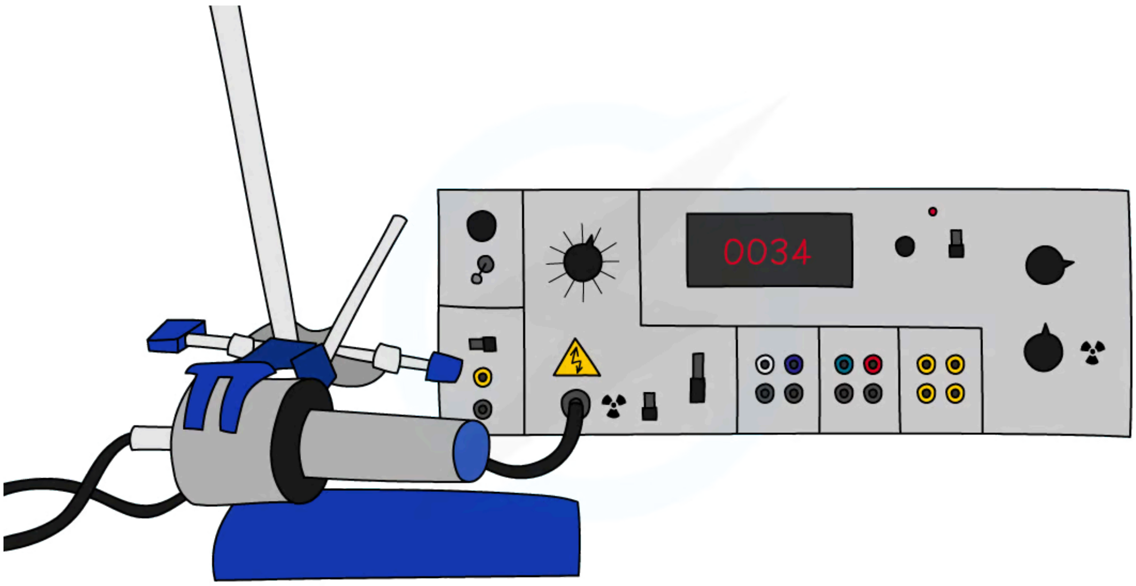
A badge containing photographic film can be used to monitor a person's exposure to radiation

- The badge shows the amount of different types of radiation that the radiographer has been exposed to
- Different areas of the film are exposed to different types of radiation
  - Alpha radiation is unlikely to be detected at all as it will be absorbed / stopped by the paper
  - Beta radiation is absorbed by the aluminium
  - Gamma (or X-rays) affect all areas of the film but the lead will reduce some of the gamma radiation

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

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Examiner Tips and Tricks

If asked to name a device for detecting radiation, the Geiger-Müller tube is a good example to giveYou 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.

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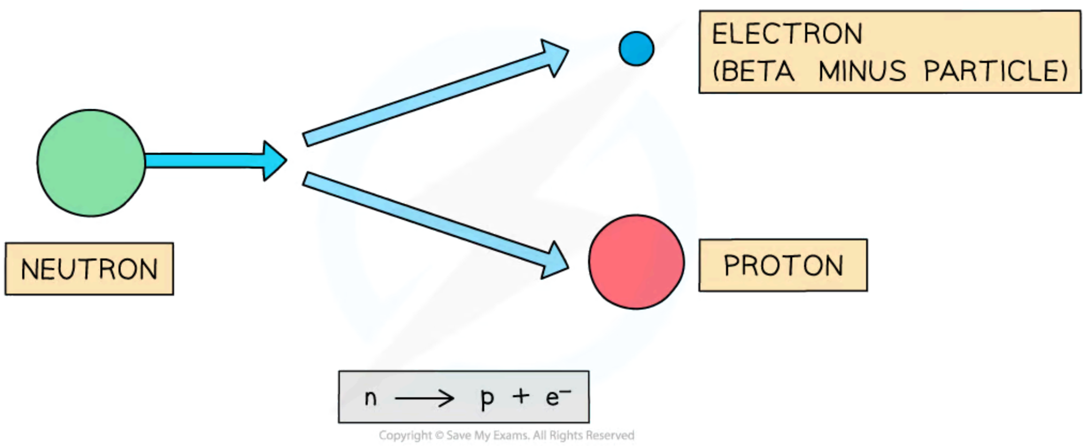
Beta Decay

Beta-Minus Decay

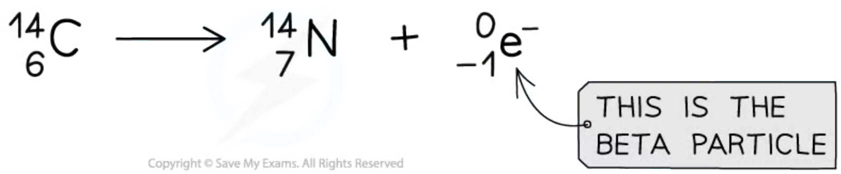
- **Beta (β^-) particles are high energy electrons** emitted from the nucleus
  - β^- particles are emitted by nuclei that have too many **neutrons**
- During **beta** decay, a **neutron** changes into a **proton** and an **electron**
  - The electron is **emitted** and the proton **remains** in the nucleus
- A completely new element is formed because the **atomic number** changes



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

- An electron has a mass number of 0
  - This is because electrons have 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 minus particle

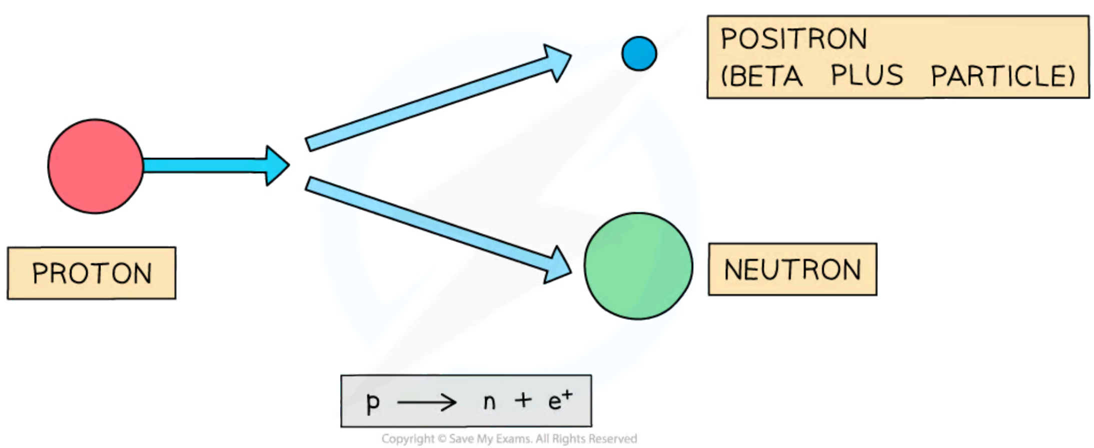
- Beta minus particles are written as an electron in this equation



The carbon nucleus emits a beta particle, causing its charge to increase. This means it changes into a new element

Beta-Plus Decay

- **Beta (β^+) particles are high energy positrons** (anti-matter of electrons) also emitted from the nucleus
  - β^+ particles are emitted by nuclei that have too many **protons**
- During beta **plus** (β^+) decay a **proton** turns into a **neutron** emitting a **positron** (anti-electron)
  - The positron is **emitted** and the neutron **remains** in the nucleus
- A completely new element is formed because the **atomic number** changes



Beta-plus decay often happens in unstable nuclei that have too many protons. The mass number stays the same, but the atomic number decreases by one

- A positron has a mass number of 0
  - This is because the positrons have a negligible mass, just like the electron, compared to neutrons and protons
- Therefore, the **mass number** of the decaying nuclei **remains the same**

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- Positrons have an **atomic number** of +1
    - This means that the new nuclei will **decrease its atomic number by 1** in order to maintain the overall atomic number before and after the decay

Examiner Tips and Tricks

One way to remember which particle decays into which depends on the type of beta emission, think of beta '**p**lus' as the '**p**roton' that turns into the neutron

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Decay & Transformations

Nuclear Transformations

- During radioactive decay, the atomic (proton) number and mass (nucleon) number of the nuclei will change

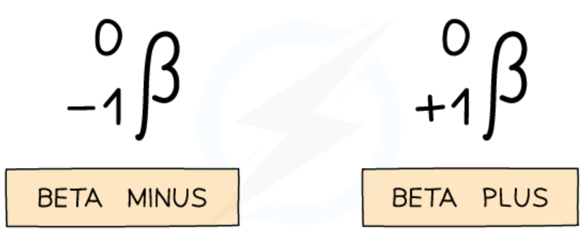
Alpha Emission

- An alpha particle consists of **2 protons and 2 neutrons** (same as a helium nucleus)
- It is emitted from large unstable nuclei

Nuclear notation for an alpha particle

- When an alpha particle is emitted from a nucleus:
  - The nucleus loses 2 protons
    - **The atomic (proton) number decreases by 2**
  - The nucleus loses 4 particles (nucleons) in total
    - **The mass (nucleon) number decreases by 4**

Beta emission



Nuclear notation for beta minus and beta plus particle

- Beta minus decay is when a **neutron** turns into a **proton** emitting an **electron**
- When a beta minus particle is emitted from a nucleus:
  - The number of protons in the nucleus increases by 1
    - **The atomic (proton) number increases by 1**
  - The total number of particles in the nucleus remains the same
    - **The mass (nucleon) number does not change**
- Beta plus decay is when a **proton** turns into a **neutron** emitting a **positron**
- When a beta plus particle is emitted from a nucleus:
  - The number of protons in the nucleus decreases by 1
    - **The atomic (proton) number decreases by 1**
  - The total number of particles in the nucleus remains the same
    - **The mass (nucleon) number does not change**

Gamma Emission

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

Nuclear notation for a gamma particle

- Gamma waves are emitted from a nucleus when the nucleus needs to lose some energy
- This usually occurs because the nucleus has excess **energy** following a previous decay
- Therefore, no protons or neutrons are lost from the nucleus in this process
  - **The atomic (proton) and mass (nucleon) numbers do not change**

Neutron Emission

- A small number of isotopes can decay by emitting neutrons
- When a nucleus emits a neutron:
  - The number of protons does not change

- **The atomic (proton) number does not change**
- The total number of particles (nucleons) in the nucleus decreases by 1
    - **The mass (nucleon) number decreases by 1**

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Worked Example

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

A $^{20}_{9}\text{Mg}$

B $^{24}_{10}\text{Mg}$

C $^{23}_{11}\text{Mg}$

D $^{24}_{12}\text{Mg}$

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

$$11 + 1 = 12$$

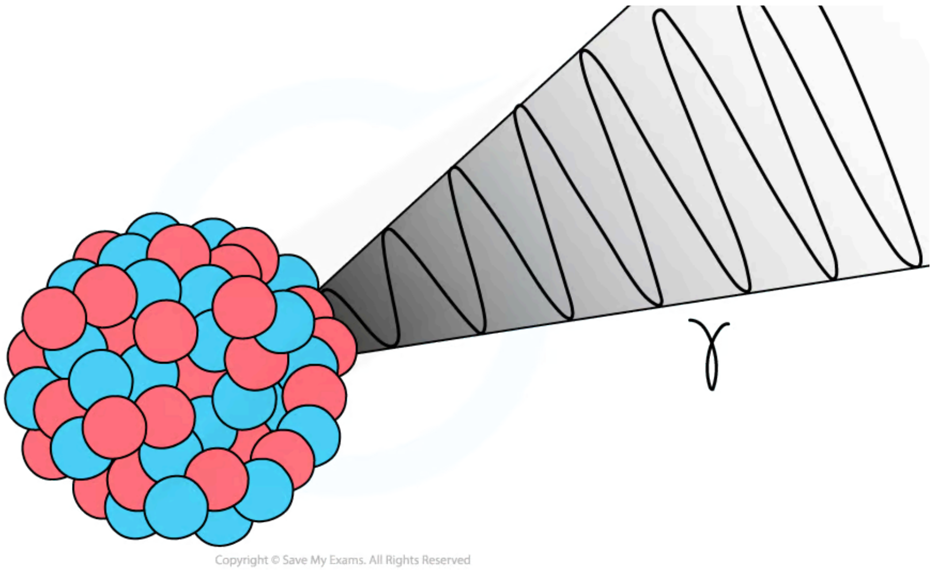
- The new nucleus has an atomic number of 12

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)

Gamma Emission

- Nuclei that have undergone radioactive decay often undergo nuclear rearrangement with a loss of **energy** as gamma radiation rather than a change in the atomic structure
- A gamma ray emitted has high energy but there is **no** change to the mass or charge of the initial atom
  - This is because gamma rays are electromagnetic radiation that have 0 atomic and mass number



Atom emitting high energy gamma radiation

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Nuclear Equations

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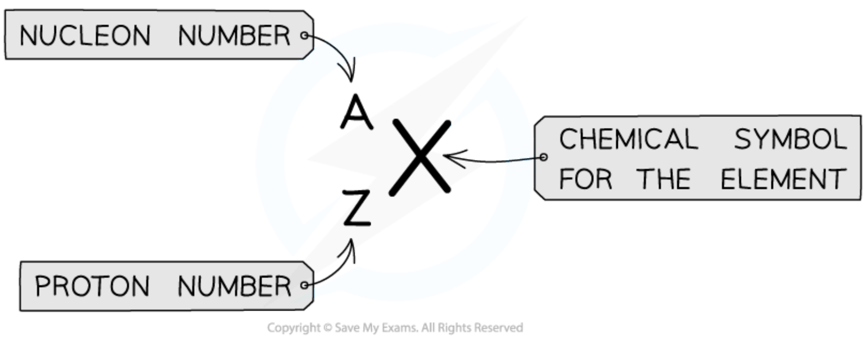
Nuclear Equations

Use given data to balance nuclear equations in terms of mass and charge

- Nuclear radioactive decay equations show the changes in mass and charge of the nuclei in the decay
- Each term will have the chemical symbol of the element or the type of radiation



Nuclear notation

- 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
- Nuclear equations, just like chemical equations, balance:
  - The **sum** of the nucleon (mass) numbers on the left of each equation should equal the sum on the right
  - The **sum** of the proton (atomic) numbers should also balance on the left and right
- The **parent** nucleus is the nucleus that decays
  - Subsequently, the **daughter** nucleus remaining **after** the decay

Alpha Decay Equation

- In nuclear equations representing alpha decay:

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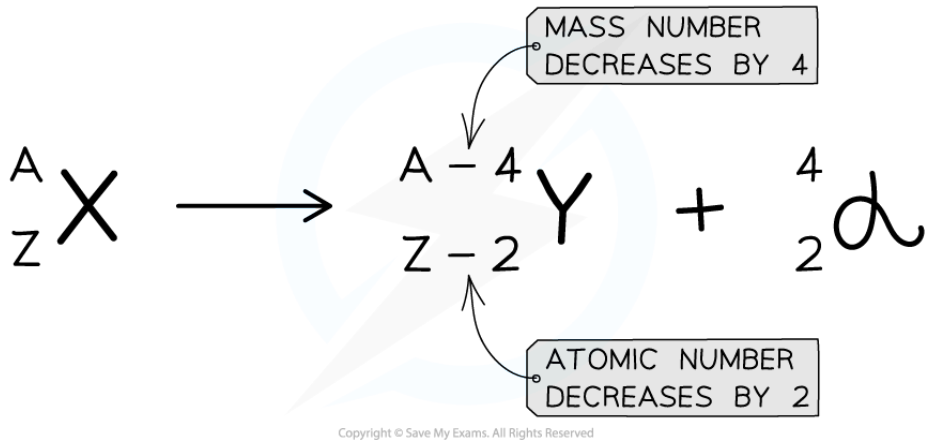
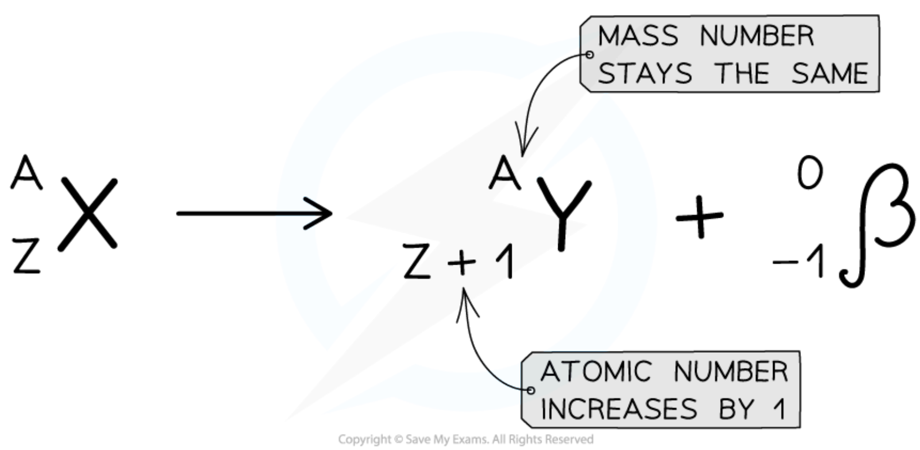
- The nucleon number of the daughter nucleus is 4 less than the parent
- The proton number of the daughter nucleus is 2 less than the parent



Alpha decay equation

Beta Minus Decay Equation

- In nuclear equations representing beta minus decay:
  - The nucleon number of the daughter nucleus is the same as the parent
  - The proton number of the daughter nucleus is 1 more than the parent



Beta-minus decay equation

Beta Plus Decay Equation

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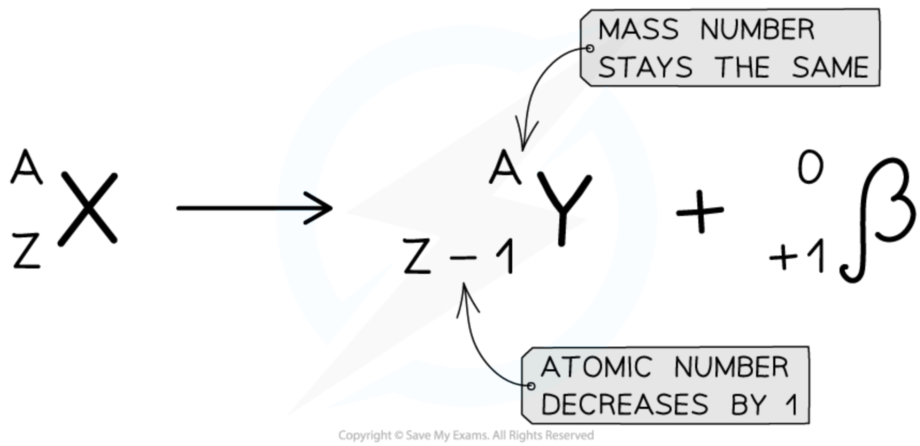
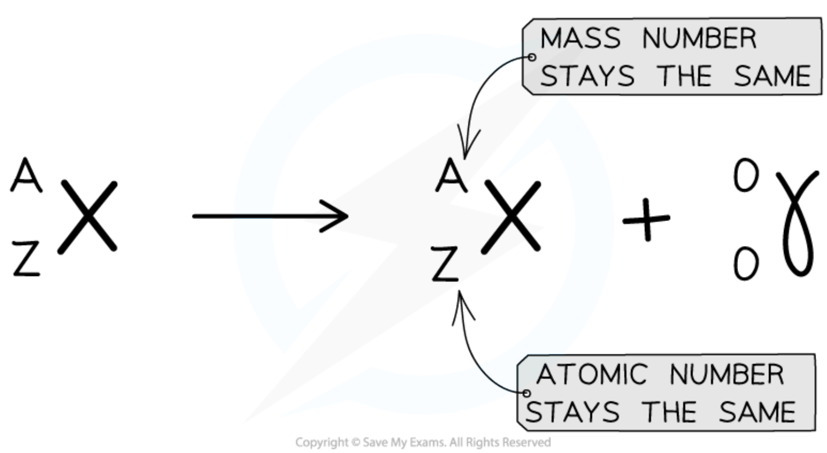
- In nuclear equations representing beta plus decay:
  - The nucleon number of the daughter nucleus is the same as the parent
  - The proton number of the daughter nucleus is 1 less than the parent



Beta-plus decay equation

Gamma Decay Equation

- In nuclear equations representing gamma decay:
  - The nucleon number of the daughter nucleus is the same as the parent
  - The proton number of the daughter nucleus is the same as the parent



Gamma decay equation

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Worked Example

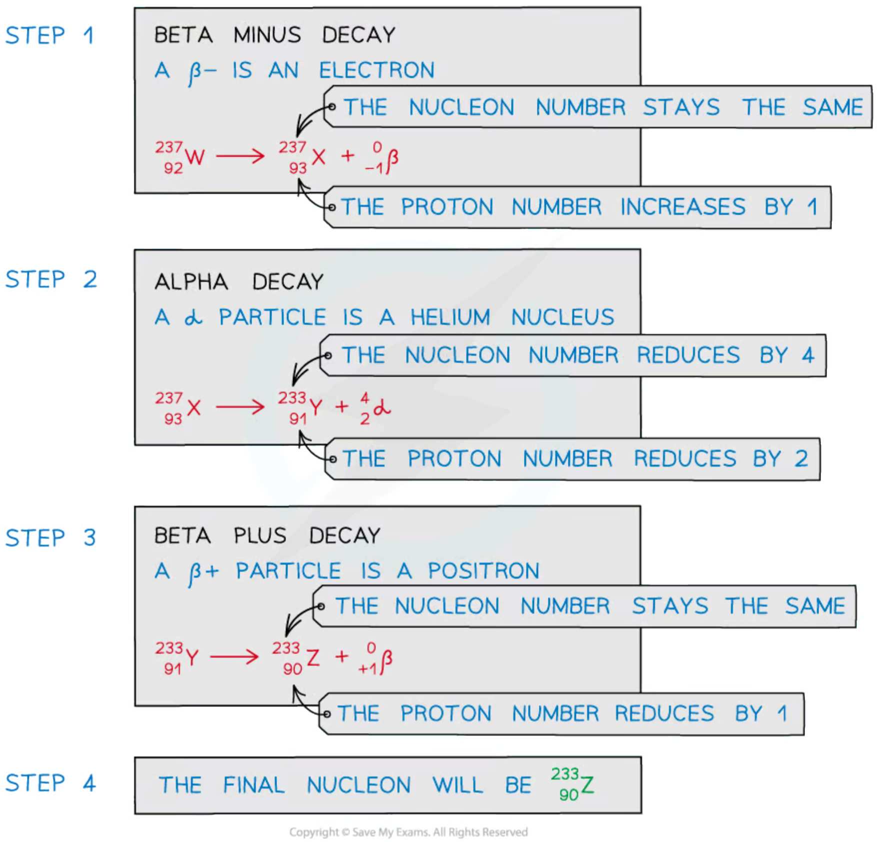
Three successive radioactive decays are shown in the diagram below; each one results in a particle being emitted.
The first decay results in the emission of β-particle. The second decay results in the emission of an α-particle. The third decay results in the emission of another β-particle.

$$^{237}_{92}W \xrightarrow{\beta-} X \xrightarrow{\alpha} Y \xrightarrow{\beta+} Z$$

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 β− IS AN ELECTRON
THE NUCLEON NUMBER STAYS THE SAME
$^{237}_{92}W \rightarrow ^{237}_{93}X + ^{0}_{-1}\beta$
THE PROTON NUMBER INCREASES BY 1
STEP 2
ALPHA DECAY
A α PARTICLE IS A HELIUM NUCLEUS
THE NUCLEON NUMBER REDUCES BY 4
$^{237}_{93}X \rightarrow ^{233}_{91}Y + ^{4}_{2}\alpha$
THE PROTON NUMBER REDUCES BY 2
STEP 3
BETA PLUS DECAY
A β+ PARTICLE IS A POSITRON
THE NUCLEON NUMBER STAYS THE SAME
$^{233}_{91}Y \rightarrow ^{233}_{90}Z + ^{0}_{+1}\beta$
THE PROTON NUMBER REDUCES BY 1
STEP 4
THE FINAL NUCLEON WILL BE $^{233}_{90}Z$
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The Random Nature of Decay

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The Random Nature of Decay

- It cannot be predicted when a particular unstable nucleus will decay
- 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 certain nucleus decaying in a given time period
- This is done by the **half-life** which enables the activity of a very large number of nuclei to be **predicted** during the decay process
  - During one half-life a particular nucleus will have a 50% chance of decaying
  - This means that, on average, 50% of nuclei will decay during one half-life
  - As a result, the number of nuclei remaining after each successive half-life will on average halve
  - However, even after a large number of half-lives, there is still a small probability that a particular nucleus will not have decayed
  - As a result, the number of nuclei remaining will never quite fall to zero
- A researcher might take some readings of background radiation
- If the researcher reset the counter to zero, waited one minute and then took the count reading and repeated the procedure, they might obtain results such as:

32 11 25 16 28

- The readings don't appear to follow a particular trend
  - This happens because of the **randomness** of radioactive decay

Dice Analogy

- An **analogy** is a way of understanding an idea by using a different but similar situation
- Rolling dice is a good analogy of radioactive decay because it is similar to the random nature of radioactive decay

Your notes

A dice roll is a random process because you don't know when you will roll a particular value. However, you can determine the probability of a particular result

- Imagine someone rolling a dice and trying to get a '6'
  - Each time they roll, they do not know what the result will be
  - But they know there is a 1/6 probability that it will be a 6
- If they were to roll the dice 1000 times, it would be very likely that they would roll a 6 at least once
- The random nature of radioactive decay can be demonstrated by observing the count rate of a Geiger-Muller (GM) tube
  - When a GM tube is placed near a radioactive source, the counts are found to be irregular and cannot be predicted
  - Each count represents a decay of an unstable nucleus
  - These fluctuations in count rate on the GM tube **provide evidence for the randomness of radioactive decay**

Your notes

The variation of count rate over time of a sample radioactive gas. The fluctuations show the randomness of radioactive decay

Activity & Decay

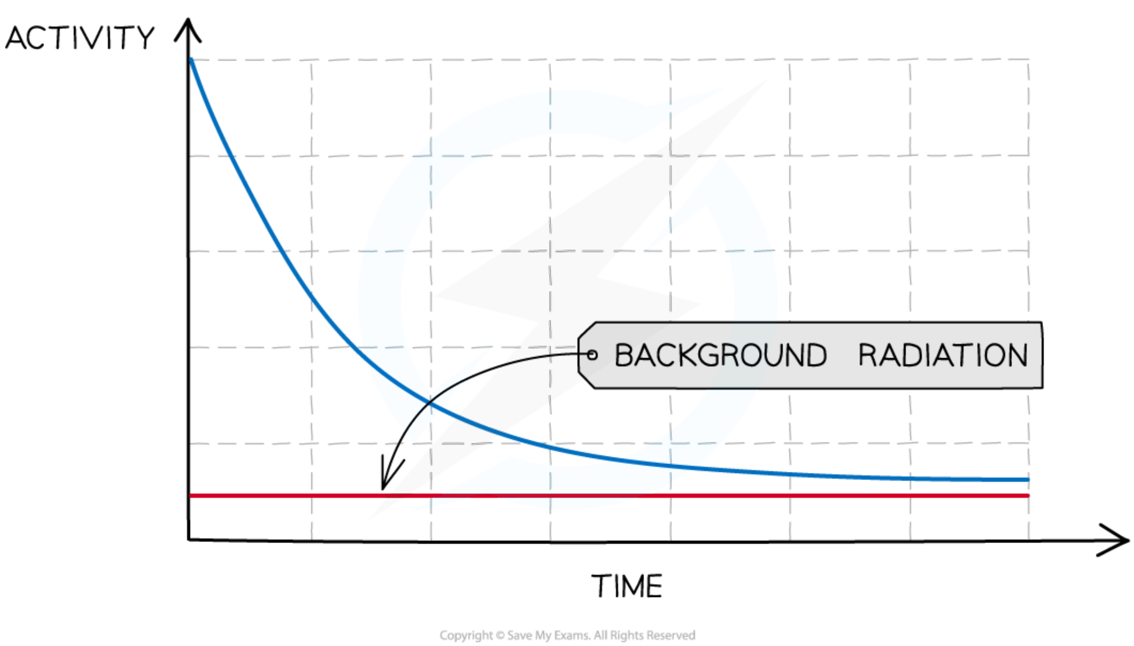
Your notes

Activity & Decay

- Objects containing radioactive nuclei are called **sources** of radiation
- Sources of radiation decay at different **rates** which are defined by their **activity**
- The activity is defined as

  The rate at which the unstable nuclei from a source of radiation decays

- Activity is measured in **Becquerels**
  - The symbol for Becquerels is **Bq**
- 1 Becquerel is equal to 1 nucleus in the source decaying in 1 second
- As an isotope decays, the number of nuclei of that isotope that remain will decrease
- As a consequence of this, **the activity of that isotope will also decrease over time**
- This can be shown on a graph of activity against time for a decaying source:



Activity decreasing with time for a radioactive isotope

Your notes

Worked Example

A source of radiation has an activity of 2000 Bq. How many unstable atoms decay in 2 minutes?

Answer:

Step 1: Determine the activity

- The activity of the source is 2000 Bq
- This means 2000 nuclei decay every second

Step 2: Determine the time period in seconds

- The time period is 2 minutes
- Each minute has 60 seconds
- The time period in seconds is:

$$2 \times 60 = 120 \text{ seconds}$$

Step 3: Multiply the activity by the time period

$$\text{Activity (Bq)} \times \text{Time period (s)} = 2000 \times 120 = 240\,000$$

- Therefore, 240 000 unstable nuclei decay in 2 minutes

Examiner Tips and Tricks

Do not confuse **activity** and **count rate**. Activity is the rate at which unstable nuclei decay, whereas count rate is the rate at which radioactive emissions are detected. Count rate has the units **counts per second**

Half-Life

Your notes

Half-Life

- 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:

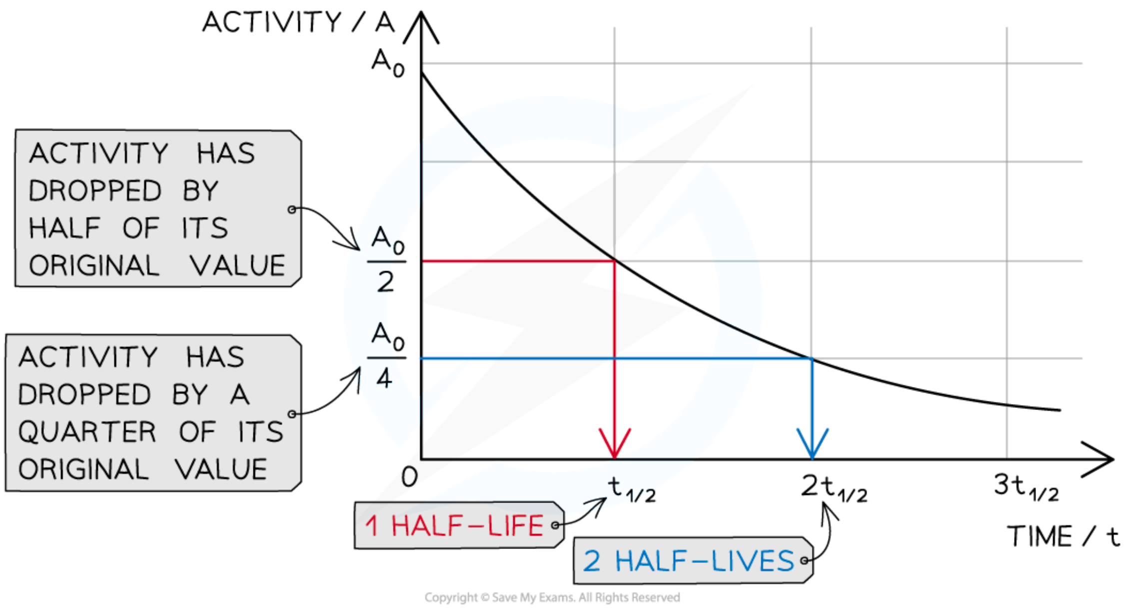
  The time taken for half the undecayed nuclei to decay or the activity of a source to decay by half

- 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

Using Half-life

- Scientists can measure the half-lives of different isotopes accurately:
- Uranium-235 has a half-life of 704 million years
  - This means it would take 704 million years for the activity of a uranium-235 sample to decrease to half its original amount
- Carbon-14 has a half-life of 5700 years
  - So after 5700 years, there would be 50% of the original amount of carbon-14 remaining
  - After two half-lives, or 11 400 years, there would be just 25% of the carbon-14 remaining
- With each half-life, the amount remaining **decreases by half**

Your notes



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

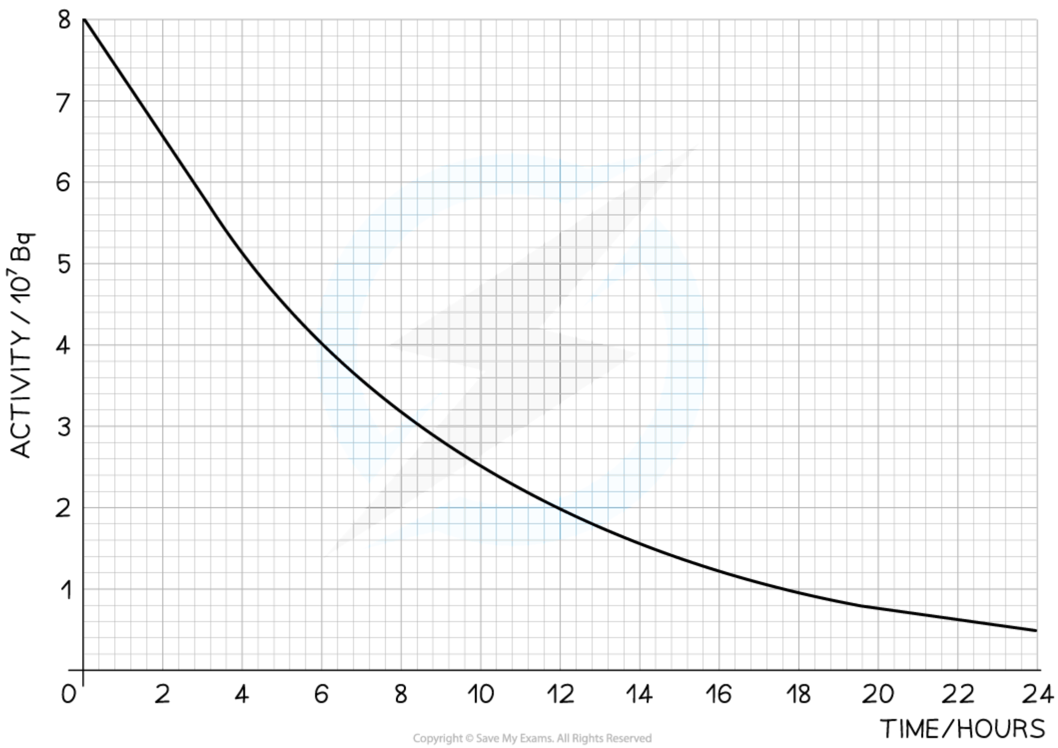
- The time it takes for the activity of the sample to decrease from 100 % to 50 % is the half-life
- It is the same length of time as it would take to decrease from 50 % activity to 25 % activity
- The half-life is **constant** for a particular isotope

Half-Life Calculations

- To calculate the half-life of a sample, the procedure is:
  - Measure the initial activity, A_0, of the sample
  - Determine the half-life of this original activity
  - Measure how the activity changes with time
- The time taken for the activity to decrease to half its original value is the **half-life**

Worked Example

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

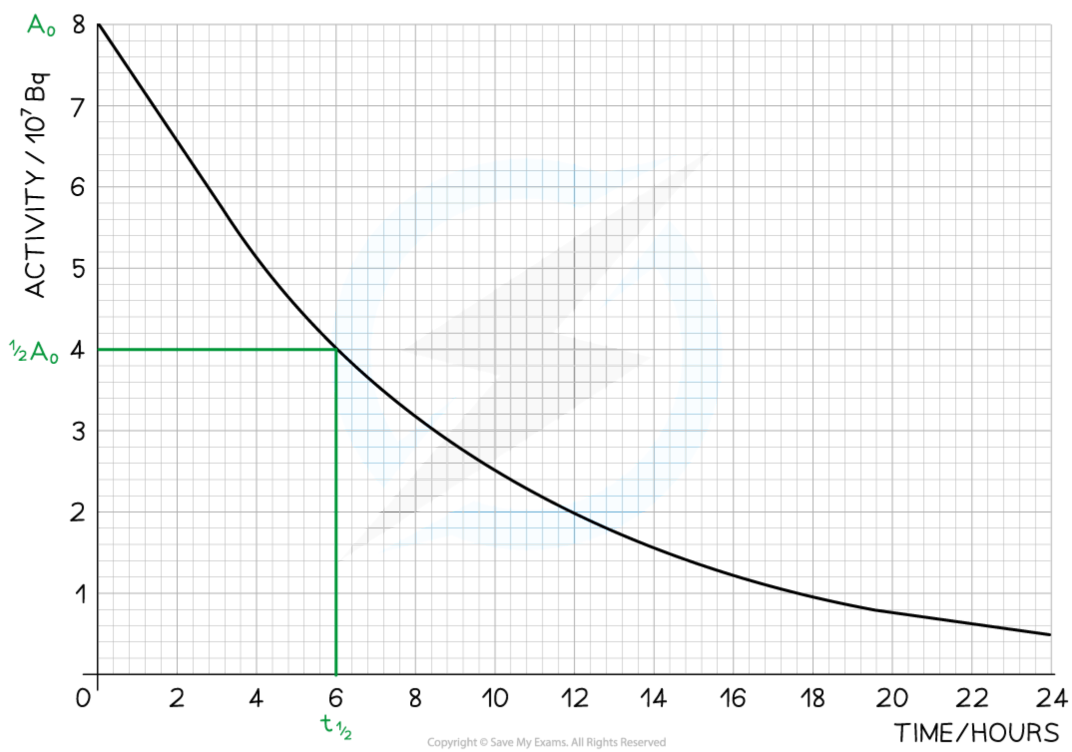


Your notes

Determine the half-life of this material.

Answer:

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



Your notes

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?

Answer:

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**

Your notes