<u>WJEC (Eduqas) Physics GCSE</u>

9.2: Emission and Absorption of Ionising Radiation

Detailed Notes

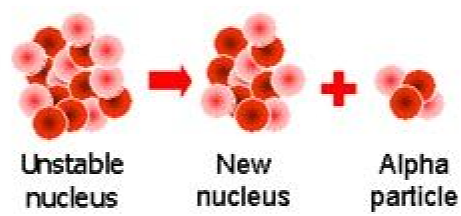
(Content in **bold** is for higher tier **only**)

Radioactivity

Nuclei of atoms are not always in a stable state depending on the **ratio of protons and neutrons**. Unstable nuclei emit **ionising radiation** through **radioactive decay** to become more stable. There are three main types of emission in radioactive decay: Alpha, Beta and Gamma.

Alpha Radiation

Alpha particles (α) are emitted as radiation when a nucleus undergoes **alpha decay**. An alpha particle is equivalent to a **helium nucleus ($_2^4He$)**, consisting of two protons and two neutrons. It has **no charge**.



Alpha decay (adapted from revisionscience.com).

Equations can be written for alpha decay using either $_2^4\alpha$ or $_2^4He^{2+}$. These must be **balanced** like chemical equations.

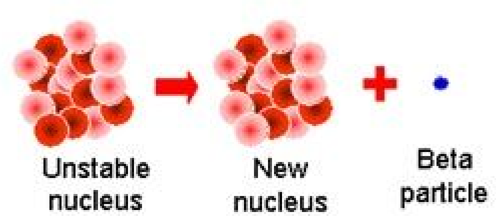
$$^{235}_{92}U \longrightarrow \underbrace{^{4}_{2}He}_{\alpha \text{ particle}} + \; ^{231}_{90}Th$$

Alpha decay equation for Uranium-235 (wou.edu).

Alpha radiation is relatively **low energy** and **weakly ionising**. This means it cannot travel very far through the air and can easily be stopped as it has a **low penetrating power**. The range of alpha radiation is **~5 cm** and it can be stopped (absorbed) by **thin paper**.

Beta Radiation

Beta particles (β) are emitted as radiation when a nucleus undergoes **beta decay**. A beta particle is equivalent to a **high energy electron**, with a -1 charge and zero (negligible) mass.



Beta decay (adapted from revisionscience.com).

Equations can be written for beta decay using either $_{-1}^{0}\beta$ or $_{-1}^{0}e$. These must be balanced like chemical equations.

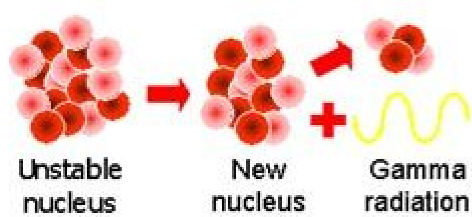
$$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + \underbrace{{}^{0}_{-1}\mathrm{e}}_{\beta \text{ Particle}}$$

Beta decay equation for Carbon-14 (wou.edu).

Beta radiation is **higher energy** than alpha and **more strongly ionising**. This means it travels **further** and requires a tougher material to be stopped as it **penetrates more**. The range of alpha radiation is **~1 m** and it can be stopped (absorbed) by **thin metal**.

Gamma Radiation

Gamma radiation is not a particle but a type of **electromagnetic (EM) radiation (γ)** and is emitted when a nucleus undergoes **gamma decay**. As a wave, gamma radiation has **no mass** and **no charge**.



Beta decay (adapted from revisionscience.com).

Gamma radiation is **very high energy** and **very strongly ionising**. This means it travels **long distances** and **highly penetrating**. The range of gamma radiation is much greater than 1 m and **thick lead** is required to stop (absorb) it.

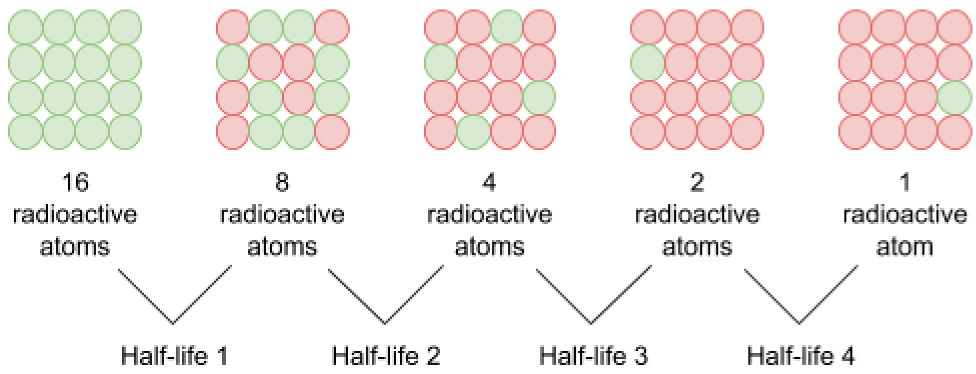
Radioactive Half-life

Random Decay Nature

Radioactive decay is **random** in nature meaning it is not possible to **predict** when a specific individual atom will decay. However, when measured over a longer period of time, an estimation of **half-life** can be made.

Half-life

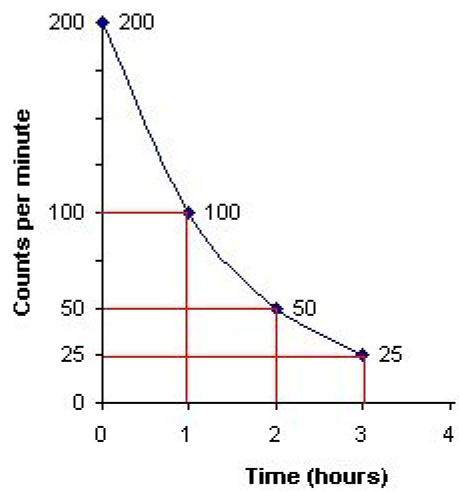
Half-life of a radioactive element is the time it takes for the **number of nuclei to halve** or the time it takes for the **count-rate** of radioactive radiation to **halve**.



Half-life is **unique** to each radioactive element and can range from a few minutes to millions of years. It can be found experimentally but **many repeat readings** are required over a **long period** of time to calculate an accurate estimate.

Decay Curves

Graphs of **count-rate against time** can be used to determine the half-life of a radioactive substance. These curves require lots of measurements over time to be accurate. Every time the count-rate **halves**, a **half-life** has passed.



Count-rate - time graph for a radioactive element with a half-life of 1 hour (darvill.clara.net).

Calculating Remaining Isotope

Using a known **half-life** and **initial amount** of radioactive isotope, the amount of isotope remaining after given time can be calculated. For each half-life passed, the **fraction of a half** is raised to that **power**.

$$\text{1 half-life} = (\tfrac{1}{2})$$
$$\text{2 half-lives} = (\tfrac{1}{2})^2$$
$$\text{3 half-lives} = (\tfrac{1}{2})^3$$

Example:
Cobalt-60 has a half-life of 5 years. Initially, there is a 100g sample of the cobalt, how much will remain after 15 years have passed?

15 / 5 = 3 => 3 half-lives have passed

=> amount remaining $= (\frac{1}{2})^3 \times 100$
$= (\frac{1}{8}) \times 100$
$= 12.5g$

The **age of a sample** containing the isotope can also be found in a similar way.

Example:
Carbon-14 has a half-life of 5,730 years. An old bone has 25% of the carbon-14 a living bone has. How old is the bone?

25% remaining means two half-lives have passed.
Two half-lives = 2 x 5,730 = 11,460 years

=> The bone is 11,460 years old.

Irradiation & Contamination

Irradiation

This is when an object is **exposed** to a **beam of radiation**. This ranges from **beams of light**, to **beams of radiation** from the decay of unstable nuclei. The object **absorbs** some of the radiation as the beam is incident on it and in **living things**, cells can be **damaged** or **killed** by the radiation.

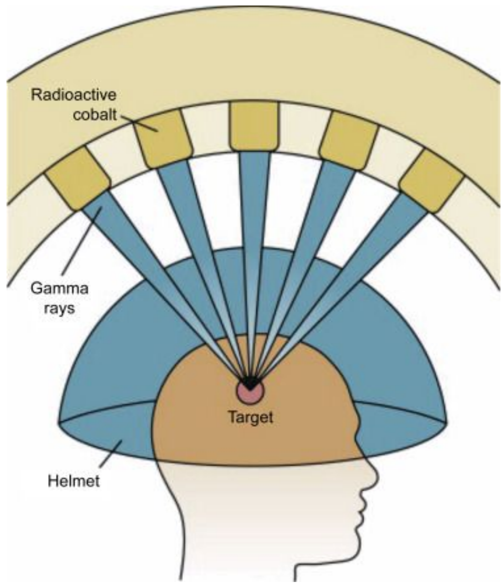
Irradiation has many uses in different environments, from the **sterilisation** of food to **medical treatments**.

Sterilisation
Cobalt-60, an emitter of **gamma radiation**, is used to **sterilise foods** such as fruit and vegetables. Any **bacteria** present on the surface of the fruit will be **killed** without damaging the fruit in any other way. The irradiation doesn't cause the fruit to become radioactive, meaning it **remains safe** for the consumer.

Sterilisation of **medical equipment** can also be carried out using irradiation. It kills more bacteria, more quickly than washing, ensuring it is safe to be used again.

Medical Treatment
Beams of high energy gamma radiation can be used to **kill cancers and tumours** inside the body. The beams are aimed at a lot of different angles towards the cancerous cells

building up a **maximum dose** of radiation over the tumour. This ensures that no healthy cells are damaged by the treatment as the gamma radiation is **pinpointed** so precisely. The treatment is sometimes referred to as '**Gamma Knife**' surgery as it is so accurate.



Gamma knife surgery (sciencedirect.com).

Contamination

An object becomes **contaminated** when **radiation** is introduced to it in a way that means the object then becomes **radioactive**. It differs significantly from irradiation but still had many different uses despite its potential harmfulness.

Medical Tracers

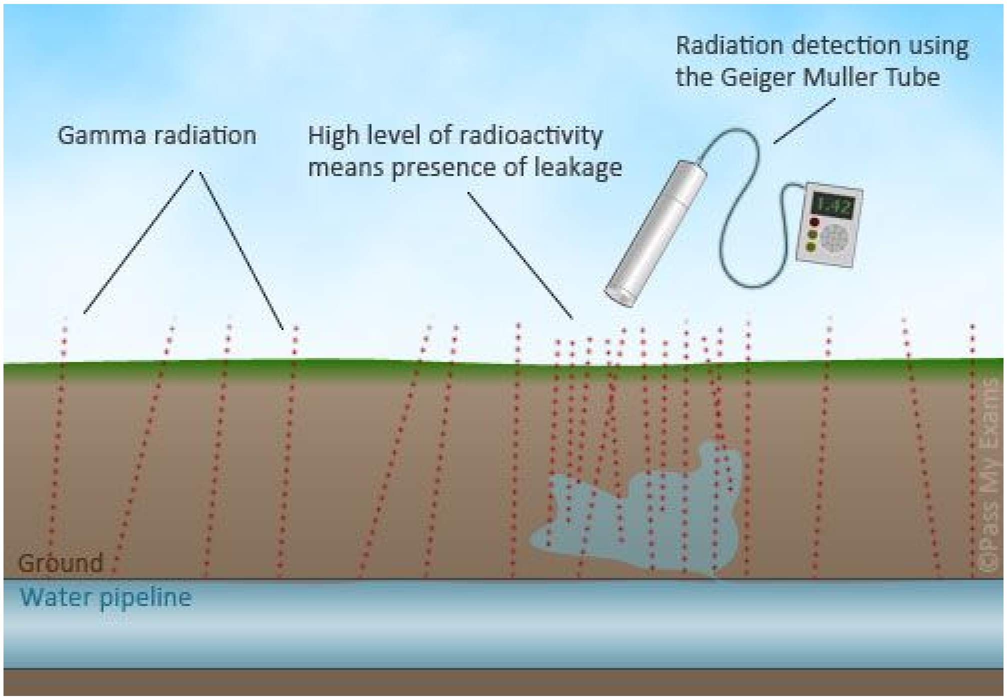
Radioactive materials can be used **inside the body** to help image organs or monitor fluid flows. **Technetium-99m** (m for medical) is a **gamma source** with a half-life of just **6 hours**. It is injected into blood vessels to check for arterial blocks or internal bleeds by detecting it from outside the body.

The **short half-life** of Technetium-99m means it remains detectable for a reasonable amount of time for surgery but won't remain dangerous for long periods of time afterwards.

Finding Leaks

If a domestic water supply system springs an **underground leak**, radioactive material can be introduced **temporarily** to the water supply to help **find the source** of the leak. As the water becomes contaminated, it will give off **radiation** which can then be detected by a **Geiger-Muller tube**, helping to identify the likely position of the leak.

For this use, a gamma emitting source with a **half-life of several days** is required. This allows a detectable source of radiation to build up in the soil. It must also be **non-toxic** to humans so that the water supply is still **safe** for use and consumption.



Using gamma radiation to find a water leak (passmyexams.co.uk).

Irradiation vs. Contamination

The two processes of irradiation and contamination are often confused, however they are very different and have different effects on the objects they are exposed to.

Irradiation	Contamination
• Caused when the **outside** of an object is exposed to the radiation from a radioactive source. • The object **doesn't become radioactive**. • Irradiation can be **blocked** with the correct type and thickness of material. • Irradiation **stops** when the object is **removed** from the beam of radiation.	• Caused when a radioactive source is placed **onto or within** an object. • The object **becomes radioactive** whilst the source is present. • The radiation **cannot be blocked** from the object. • Contamination is **difficult to remove**, especially for a source with a long half-life.