Edexcel Physics IGCSE

Topic 7: Radioactivity and Particles

Summary Notes

(Content in **bold** is for physics only)

Radioactivity

An atom consists of:

- A **positively charged nucleus** made of:
  - Positive **protons**
  - Neutral **neutrons**
- Surrounded by **negatively charged electrons** which orbit the nucleus

The radius of the nucleus is a lot smaller than the radius of the entire atom. Almost all the mass of the atoms lies in the nucleus.

Particle	Relative Mass	Relative Charge
Proton	1	+1
Neutron	1	0
Electron	0.0005	-1

Atoms of the same element have the **same** number of protons. **Isotopes** are forms of an element's atom with the **same number of protons** but a **different number of neutrons.**
For a given nuclide (distinct nucleus):

- X is the **symbol** of the element
- A is the **mass (nucleon) number** (number of neutrons and protons)
- Z is the **atomic (proton) number** (number of protons)

Radioactive decay is the **spontaneous** transformation of an **unstable** nucleus into a more **stable** one by the release of radiation. It is a **random** process which means one cannot know **what** nucleus will decay or **when** it will decay because it is down to chance.

Decay processes:

- Alpha:
  - A heavy nucleus emits an **alpha particle** (helium nucleus - 2A, 4X).
  - The nucleus changes to that of a different element according to the following equation: $ZAX \rightarrow (X - 4A - 2Z) + \alpha$
  - They are **highly ionising** and **weakly penetrating.** They are stopped by a sheet of paper.
- Beta:
  - A neutron turns into a proton and emits a **beta particle** (electron)
  - The nucleus changes to that of a different element according to the following equation: $ZAX \rightarrow (X - A - Z) + \beta^{-}$
  - They are **moderately ionising** and **moderately penetrating.** They are stopped by a thin sheet of aluminium.
- Gamma:
  - After a previous decay, a nucleus with excess energy emits a **gamma waves.**
  - Gamma waves are a form of electromagnetic radiation.
  - They are **lowly ionising** and **highly penetrating.** They are stopped by many centimetres of lead.
- Neutron radiation:
  - In neutron-rich nuclides, occasionally one or more **neutrons** are ejected. They are also emitted during nuclear fission.
  - The nucleus becomes a new isotope of the original element according to the following equation: $ZAX \rightarrow (X - A) + 1n$

Some ways of detecting radiation include:

- Photographic film:
  - The more radiation absorbed by the film, the **darker** it gets (the film is initially white).
  - They are worn as **badges** by people who work with radiation, to check how much exposure they have had.
- Geiger-Muller tube:
  - A Geiger-Muller tube is a **tube** which can detect radiation.
  - Each time it absorbs radiation, it transmits an electrical pulse to the machine, which produces a **clicking sound.** The greater the frequency of clicks, the more radiation present.

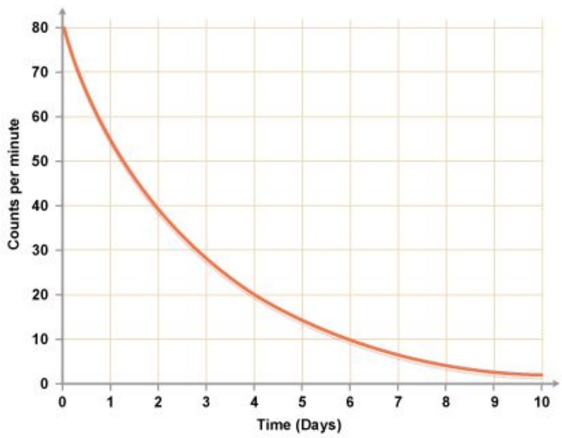
Weak radiation that can be detected from **external** sources is called **background radiation.** Sources of background radiation include:

- From space:
  - Cosmic rays include high-energy charged particles penetrating the atmosphere
- From Earth:
  - Radioactive rocks which give off radioactive radon gas
  - Food and drink which contains radioactive isotopes (such as Carbon 14)
  - Fallout from nuclear weapons testing
  - Medical sources such as x-rays from x-ray machines and CT scan
  - Nuclear power plants which produce radioactive waste

The **activity** of a radioactive source is the **number of decays** which occur **per unit time** and is measured in **becquerels (Bq where 1 Bq = 1 decay per second).** The activity of a radioactive source **decreases** over a period of time.

The **half-life** of an isotope is the **time taken for half the nuclei to decay**, or the **time taken for the activity to halve.** It is different for different radioactive isotopes.

- In the graph, the count rate drops from 80 to 40 counts per minute in 2 days, which means the half-life is around 2 days. Or from 40 counts per minute to 20 counts per minute in the next two days. Half-life is **constant** (it does not depend on how many nuclei have decayed).
- Background radiation must be **subtracted** before attempting to perform half-life calculations



Uses of radioactivity:

- Industry
  - Smoke detectors

Long half-life **alpha** emitters are used in **smoke detectors.** Alpha particles cause a **current** in the alarm. If smoke enters the detector, some of the alpha particles are **absorbed** and the current **drops,** triggering the alarm.

  - Thickness monitoring

Long half-life **beta** emitters can be used for **thickness monitoring** of metal sheets. A source and receiver are placed on either side of the sheet during its production. If there is a **drop** or **rise** in the number of beta particles detected, then the thickness of the sheet has changed and needs to be **adjusted.**

- Medicine
    - Sterilisation of equipment

Gamma emitters are used to **kill** bacteria or parasites on equipment so it is safe for operations (this means they can be sterilised through their protective packaging to eliminate the risk of contamination).

- Diagnosis and treatment
- Short half-life **gamma** emitters such as technetium-99m are used as **tracers** in medicine as they concentrate in certain parts of the body. The half-life must be long enough for diagnostic procedures to be performed, but short enough to not remain radioactive for too long.
- Other gamma emitters such as cobalt-60 can be used to **destroy** tumours with a **high dose** of radiation.

Contamination occurs when a **radioactive source** has been **introduced into or onto** an object. The contaminated object will be radioactive for as long as the source is in or on it.

Irradiation occurs when an object is exposed to a **radioactive source** which is **outside** the object. The irradiated object does **not** become radioactive.

Exposure to radiation can **destroy living cell membranes** by **ionisation,** causing the cells to **die,** or **damage DNA** which causes **mutations** that could lead to **cancer.**

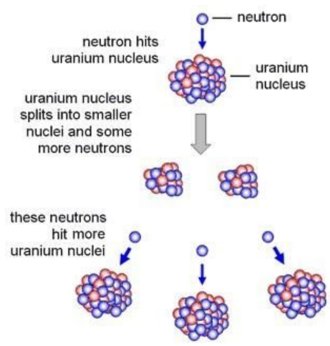
Safety measures include:

- **Minimising the time** of exposure to radiation, keeping as **big a distance** from the radioactive source as possible, and using **shielding** against radiation (such as protective clothing made from dense materials such as lead).
- Radioactive waste from nuclear reactors must be **disposed of carefully,** usually by burying it in sealed drums deep underground and **remotely handling** it after it has been thoroughly cooled.

Fission and fusion

Nuclear fission:

- The process of **splitting a nucleus** is called **nuclear fission.**
- When a **uranium-235** nucleus **absorbs a thermal** (slow-moving) **neutron,** it splits into **two daughter nuclei** and **2 or 3 neutrons,** releasing **energy** in the process.
- The neutrons then can induce further fission events in a **chain reaction** by striking other uranium-235 nuclei.
- In a nuclear reactor:
    - **Control rods** (usually made of boron) are used to **absorb neutrons** and keep the number of neutrons such that only **one** fission neutron per event goes on to induce further fission.
    - The **moderator** (usually water) **slows down neutrons** by **collisions** so that they are moving slow enough to be absorbed by another uranium-235 nucleus.
    - A coolant (also water) is used to prevent the system from overheating.
    - The reactor core is a **thick steel vessel** which withstands the **high pressures and temperatures** and **absorbs** some of the **radiation.** The whole core is kept in a building with **thick reinforced concrete walls** that act as **radiation shields** to **absorb** all the **radiation** that escapes the reactor core.



Nuclear fusion:

- The process of **fusing two nuclei** to form a larger nucleus is called **nuclear fusion.**
- There is a very small **loss of mass** in the process, accompanied by a **release of energy.**
- Nuclear fusion is how the sun and other **stars** release energy.
- Nuclear fusion does **not** happen at **low temperatures and pressures** because the **electrostatic repulsion** of the **protons** is too great.