OCR (A) Physics GCSE

Topic P6: Radioactivity

Summary Notes

(Content in bold is for Higher Tier only)

P6.1 Radioactive Emissions

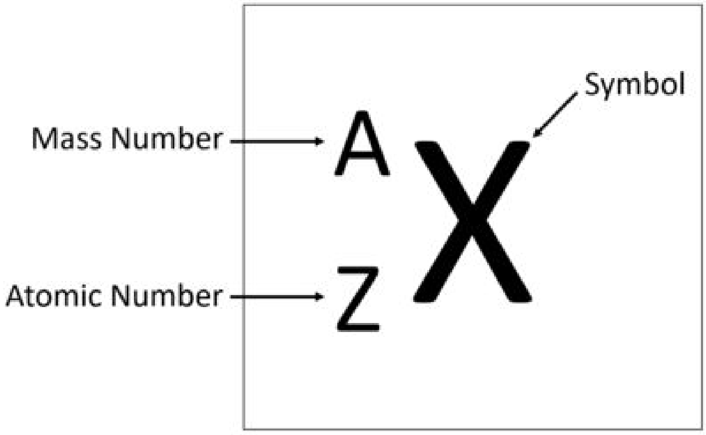
Atomic Nuclei

Nuclei are made up of protons and neutrons. Protons have a relative charge of +1 and Neutrons have no charge. This means that **nuclei** have an overall **positive charge.**

Isotopes

These are atoms of the **same element** but with **different numbers of neutrons,** meaning their **atomic number** must be the same but the **mass number** is different.

e.g. Carbon-12, Carbon-13 and Carbon-14.



X is the symbol of the element.
A is the **mass number** (neutrons + protons).
Z is the **atomic number** (protons) and determines what the element is.

N is the **charge**. On a neutral atom, the number of electrons = number of protons, so charges cancel out. If there are N more electrons than protons, then the charge is –N. If there are N fewer electrons than protons, then the charge is +N.

The number of protons is **fixed** for each individual element, so it is a defining feature for each element.

Some nuclei are **unstable** leading to **random decay**. This random nature means it is impossible to predict when any one nucleus will decay.

Types of Decay

Alpha Decay - Occurs for nucleus' that are too large. An **alpha particle** is emitted, which is equivalent to a helium nucleus (2 protons and 2 neutrons).

Beta Decay - Occurs when an atom has too many neutrons. A neutron is turned into a proton and a **beta particle** is emitted. A beta particle is equivalent to an electron.

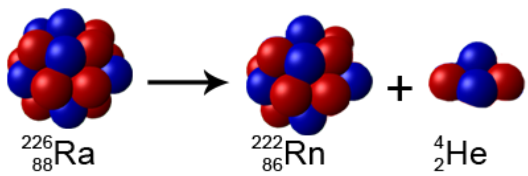
Electron Capture - This occurs when there are too many neutrons and the nucleus is too large. The nucleus absorbs a neutron and emits a **neutron**.

Gamma Emission - If a nucleus has too much energy, a **gamma ray** is emitted. Proton and neutron numbers do not change, the nucleus has lower energy.

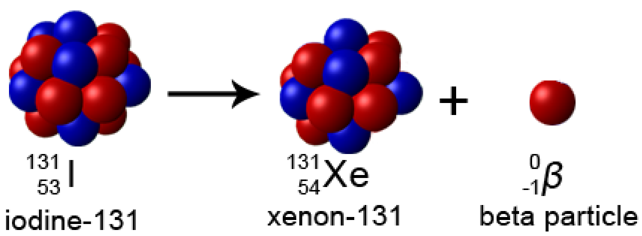
These decays result in changes in charge, mass or proton number. By analysing these changes, the type of decay occurring can be worked out.

Equations

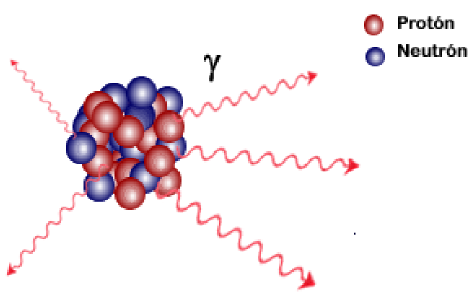
Alpha Decay



Beta Decay



Gamma



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Electrons

In each atom, electrons are arranged at different distances from the nucleus in energy levels. The lowest level is closest to the nucleus and known as ground state.

When EM radiation hits an atom, electrons absorb the energy and become **excited**, rising to a higher energy level. When the electrons fall back down to ground state, they lose this energy by emitting radiation.

When outer electrons are given lots of energy, they can be lost from the atom. This is called **ionisation**, and the atom becomes a charged **ion.** This is because the electron has gained enough energy to free itself from the atom completely.

The radiation required to excite or ionise atoms can be from any part of the EM spectrum. The higher the frequency (or the shorter the wavelength) the more energy it provides the electrons in the atoms. Therefore gamma rays ionise atoms most easily.

Half Life

This is the time taken for the **number of unstable nuclei** of an **isotope** in a sample to halve. The time for any given atom to decay cannot be determined, however, the time for half the atoms in a sample to decay is relatively constant. Therefore this approximation works best when there is a large number of atoms.

Half-life is used to show how long radioactive atoms will last for, and each half-life is specific to each isotope (i.e. half-life of Carbon-13 is different to Carbon-14).

> e.g. Carbon-13 has a half-life of around 5000 years and Technetium has a half-life of 6 hours, and an isotope of Uranium has a half-life of 4.47 *BILLION* years.

By analysing the proportion of decayed and undecayed isotopes in a sample **radioactive dating** methods can be used to work out the age of the sample.

Net Decline

The ratio of net decline is the ratio of isotope present now to the initial isotope.

$$net\ decline = \frac{initial\ number - \ number\ after\ X\ half\ lives}{initial\ number}$$

Example:
There were initially 80 nuclei of an element with a half-life of 15 minutes. What was the net decline after 3 half-lives?

$$1^{st}\ half\ life = 40$$
$$2^{nd}\ half\ life = 20$$
$$3^{rd}\ half\ life = 10$$

$$=>\ net\ decline = \frac{80-10}{80} = \frac{7}{8}$$

Penetration Properties

Alpha radiation is **most** ionising and **least** penetrating meaning it cannot penetrate further than ~5cm of air and can be stopped by paper.

Beta radiation has **medium** penetrating **power** and medium ionising power ionisers as beta particles are lighter than alpha particles but heavier than gamma rays, which have no mass. Beta radiation is stopped by around 5m of air, or a few millimetres of aluminium.

Gamma radiation has **least** ionising power and **most** penetrating power. It is only stopped by a several of lead, or several metres of concrete.

P6.2 Uses and Hazards

Hazards

Contamination:
Radioactive material lasts for a **long** period of time, transferring radiation to an object.
e.g. radioactive dust settling on your skin so your skin becomes contaminated.

Irradiation:
Only lasts for a **short** period of time as the source emits radiation, which reaches the object.
e.g. radioactive dust emitting beta radiation, which “irradiates” your skin.

Medical items are irradiated sometimes to kill bacteria on its surface, but not enough to make the medical tools themselves radioactive.

Half-Life Hazards (Physics only)

Short half-life:
The source presents **less** of a risk if it has a short half-life, as it does not remain strongly radioactive for as long. Initially it is very radioactive, but **quickly** dies down, so presents less of a long-term risk.

Long half-life:
The source remains **weakly radioactive** for a long period of time.

e.g. **Americium** has a half-life of 432 years. It is an alpha emitter and this half-life means it is used in **smoke alarms.**

It is emitted into the air around the alarm and does not travel far since alpha is weakly penetrating. If smoke reaches the alarm, the number of alpha particles in the surrounding air drops causing the alarm to sound.

It is suitable because it will not need to be replenished, and its weak activity means it won't be harmful to anyone.

Medical Uses of Radioactive Materials (Physics Only)

Tracers
Technetium is used as a medical tracer. It has a half-life of **6 hours** and decays into a safe isotope that can be excreted by the body. It is injected or swallowed and there is enough time for it to flow through the body and be detected before it decays away. Technetium is a **gamma emitter**, so can pass through the body tissue without being absorbed as it is the most penetrating.

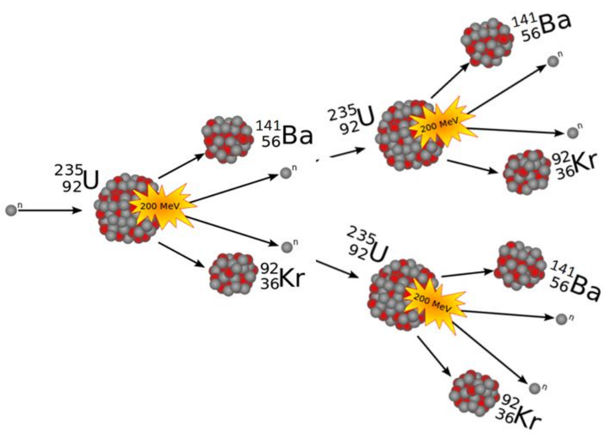
Chemotherapy
Gamma emitters are used to emit gamma radiation, which can be directed onto certain areas of the body with **cancerous cells.** The cells absorb the energy and are killed. It is used to control any other unwanted tissue too.

However, as it is hard to accurately target the cancerous cells, surrounding **healthy cells** may also be irradiated, and their destruction causes unhealthy side effects.

Nuclear Fission (Physics Only)

Some nuclei are **unstable**, and may split into two smaller nuclei. In this process a neutron is released along as energy in the form of EM radiation. This neutron may **collide** with another radioactive nucleus and be absorbed, making it unstable. The nucleus then splits, releasing another neutron and more energy.

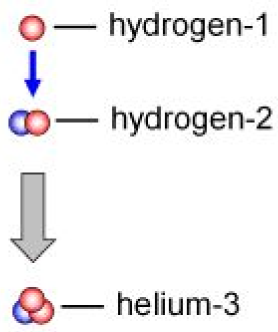
A **chain reaction** is set up, as the energy is being released from one split causes another split to occur. This process is used in **nuclear fission**, and typically occurs with **uranium** nuclei.



Nuclear fission chain reaction (tes.com)

Nuclear Fusion (Physics Only)

This is when two **small** nuclei fuse to form a heavier nucleus, releasing large quantities of **energy** in the process. The sum of the masses of the two nuclei is more than the mass of the heavier nucleus because some of the mass is **converted into energy** and released as **radiation**.



Nuclear fusion (bbc.co.uk)