

OCR (B) Physics GCSE

Chapter 5: Radioactive Materials Summary Notes

(Contents in bold is for Higher Tier Only)



P5.1 What is Radioactivity?

Atomic Structure

Positively charged nucleus (which contains **neutrons** and **protons**) surrounded by **negatively charged electrons**.

Subatomic Particle	Relative Mass	Relative Charge
Proton	1	+1
Nucleus	1	0
Electron	0 (0.0005)	-1

Typical radius of an atom: 1×10^{-10} metres

- And the radius of the nucleus is **10 000 times smaller**
- Most (nearly all) the **mass** of the atom is concentrated at the **nucleus**

Electron Arrangement:

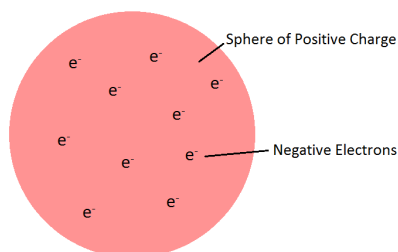
- Electrons lie at different distances from the nucleus (different **energy levels**). The electron arrangements may change with the **interaction with EM radiation**.

How and why the atomic model has changed over time

1800 - **Dalton** said everything was made of **tiny spheres** (atoms) that could not be **divided**

1897 - **JJ Thomson** discovered the **electron**

The **Plum Pudding Model** was formed: The overall charge of an atom is **neutral**, so the negative **electrons** were **dispersed** through the positive “pudding” to **cancel out the charges**.

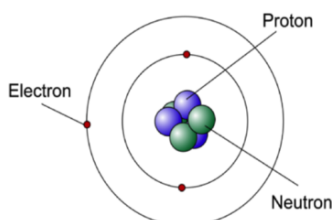


1911 - **Rutherford** realised most of the **atom** was **empty space** From the Gold Foil Experiment he found:

- Most particles went **straight through**: So most of atom is **empty space**
- Some particles were **slightly deflected**: So nucleus must be charged, **deflecting positive**
- Few particles were **deflected by >90**: So nucleus contained **most of the mass**

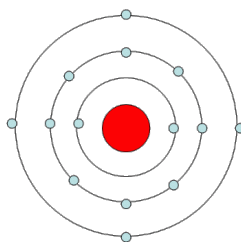
1913 - **Rutherford Model**

Now there is a **positive nucleus** at the centre of the atom, and **negative electrons** existing in a cloud around the nucleus.



1913 – Bohr produced the final model of the atom

If Rutherford was right, the electrons in the cloud close to the nucleus would get attracted and cause the atom to collapse. So now the electrons exist in fixed 'orbitals'

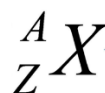


Later on:

- Positive charge of nucleus could be subdivided into smaller particles, each with the same amount of charge – the proton
- 20 years after the 'nucleus' was an accepted scientific idea, James Chadwick provided evidence to prove neutrons existed (don't need specifics)

Isotopes and Elements

- All atoms of the same element have the same number of protons
- Neutral atoms have the same number of electrons and protons
- Isotopes are atoms of the same element, but with different masses, which have the same number of protons but different number of neutrons.
- For example Carbon-12, Carbon-13 and Carbon-14
- X is the letter of their element
- A is the mass number (number of neutrons and protons)
- Z is the proton number
- N is the charge
 - On a normal neutral atom, electrons = protons, so cancels out
 - If N more electrons than protons, then -N charge
 - If N fewer electrons than protons, then +N charge
 - The number of protons does not change for a certain element



Radioactive Decay

Some atomic nuclei are unstable. The nucleus gives out radiation as it changes to become more stable. This is a random process called radioactive decay.

Activity is the rate at which a source of unstable nuclei decays

- So a sample with high activity has a fast rate of decay
- Measured in Becquerel, Bq

Count-rate is the number of decays recorded by a detector per second.

- E.g. a Geiger-Muller Tube

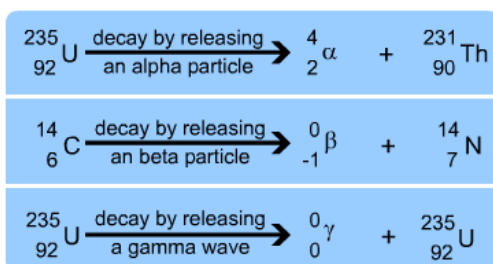


Forms of decay

- **Alpha α (a helium nucleus)**
 - Highly ionising
 - Weakly penetrating (~5cm of air)
- **Beta Minus β (electron)**
 - Medium ionising
 - Medium penetration (~50cm of air, sheet of paper)
- **Gamma γ (radiation)**
 - Low ionising
 - Highly penetration (very far in air, few cm of lead)
- **Neutrons**

Nuclear Equations

The emission of the different types of nuclear radiation may cause a **change in the mass** and /or the **charge** of the nucleus.



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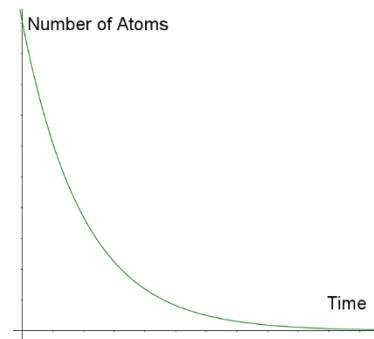
Alpha Decay: both the mass and charge of the nucleus to decrease

Beta Decay: does not cause the mass of the nucleus to change but does cause the **charge of the nucleus to increase**.

Gamma Decay: Does **not cause the mass or charge to change**.

Half Life

- The half-life of an isotope is the **time taken for half the nuclei in a sample to decay** or the time taken for the activity or count rate of a sample to decay by half.
- It **cannot be predicted** when any one nucleus will decay, but the half-life is a constant that enables the activity of a **very large number of nuclei** to be predicted during the decay.
- So if 80 atoms falls to 20 over 10mins, the half-life?
 - $80/2 = 40$
 - $40/2 = 20$ – so two half lives in 10mins
 - So half-life is 5mins



Net Decline

- Calculate the ratio of net decline of radioactive nuclei after X half-lives
 - **Half the initial number of nuclei, and keep doing so X number of times**
 - **Net Decline=initial number - number after X half-lives initial number**



P5.2 How can Radioactive Materials be used Safely?

Safety Issues

Contamination

- Lasts for a **long period of time**
- The source of the radiation is transferred to an object
- Radioactive contamination is the **unwanted presence of radioactive atoms** on other materials – the hazard is the decaying of the contaminated atoms releasing radiation
- E.g. radioactive dust settling on your skin (your skin becomes contaminated)

Irradiation

- Lasts only for a **short period of time**
- The source emits radiation, which reaches the object
- Exposing an object to nuclear radiation, but **does not make it radioactive**
- E.g. radioactive dust emitting beta radiation, which “irradiates” your skin
- Medical items are irradiated sometimes to **kill bacteria on its surface**, but not to make the medical tools themselves radioactive

Practical Applications of Radioactive Materials

Tracers e.g. **Technetium** is used as a medical tracer

- Half-life of **6hrs**
- Decays into a **safe isotope** that can be excreted by the body
- It is **injected/swallowed** and there is enough time for it flow through the body and be detected before it decays away but is **only present for a short enough time to minimise any harm from radiation**.
- It 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 rays, which are directed onto certain areas of the body with **cancerous cells**, which **absorb the energy and die**, controlling the disease
- It is used to control any other unwanted tissue too
- However, as it is **hard to direct accurately**, surrounding **healthy cells may also be irradiated**, and their destruction causes **unhealthy side effects**

Smoke Alarms

- Americium has a half-life of 432 years
- It is an **alpha emitter**, and used in smoke alarms
- It is emitted into the **air around the alarm**, and does not reach far because **alpha is weakly penetrating**
- If **smoke reaches the alarm**, the amount of alpha particles in the surrounding air **drops**
- This causes 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.

Short half-life- The source presents **less of a risk**, as it does not remain strongly radioactive. This means **initially it is very radioactive**, but quickly dies down.

Long half-life - The source remains **weakly radioactive** for a long period of time, so presents more of a **long-term risk**.



P5.3 How can Radioactive Materials be used to Provide Energy? (Physics Only)

Nuclear Fission (Physics Only)

- Nuclear fission is the **splitting of a large and unstable nucleus** (e.g. uranium or plutonium).
- For fission to occur the unstable nucleus must first **absorb a neutron**.
- When the unstable nucleus absorbs a neutron, it **splits into two smaller nuclei**, roughly equal in **size** and it then emits **two or three neutrons** and gamma rays.
- Energy is **released** by the fission reaction.
- This neutron may **collide** with another radioactive **nucleus**.
- This nucleus absorbs the neutron and becomes unstable
- This **nucleus splits**, releasing another neutron and produces **more energy**
- This is a **chain reaction**, as energy is being released and one 'split' causes another to occur
- A neutron needs to be **absorbed initially** before it splits, because it needs a little extra energy before it can split and release lots of energy – like a ramp on a cliff, the neutron gives it enough of a kick to get over the ramp to fall
- The daughter nuclei along with the neutrons have **kinetic energy**
- If the chain reaction is not controlled, it will **increase at an exponential rate** – which is what happens in a nuclear weapon
- This process is used in nuclear fission, with **uranium nuclei**

Nuclear Fusion (Physics only)

- This is when **two small nuclei fuse to form a heavier nucleus**, releasing (lots of) **energy**
- The **sum of the masses of the two nuclei is more than the mass of the heavier nucleus**
- Some of the mass is **converted into energy**. (released as **radiation**)
- The **sun** is a **natural fusion reactor**.
- Fusion would be a much **more efficient** way of producing energy compared to fission however no design has been produced that could accomplish **positive net energy** on earth.

