26 Radioactivity

26.1 The Discovery of the Nucleus

α Particle Scatter Experiment

It was known that α radiation consists of **fast-moving positively charged particles**.

1. Using a **narrow beam** of α particles all of the **same energy**.
2. A **thin metal foil** is placed in the path of the beam.
3. α particles scattered by the metal foil were detected by a detector which could be moved around at a constant distance from the point of impact of the beam on the metal foil.

The result showed that

- Most α particles pass straight through the foil with **little to no deflection**.
- About 1 in 2000 were deflected.
- 1 in 10000 α particles were deflected through angles of more than $90°$.

It can be concluded that

- Most of the atom's mass is **concentrated in a small region** called the nucleus, in the centre of the atom.
- The nucleus is **positively charged** because it repels α particles that approaches it too closely.

Estimation of Size of the Nucleus

For a **single scattering** by a foil of n layers of atoms, the probability of an α particle being deflected by a given atom is 1 in $10000n$.

For a nucleus of diameter d in an atom of diameter D

$$\frac{\frac{1}{4}\pi d^2}{\frac{1}{4}\pi D^2} = \frac{1}{10000n}$$

$$d^2 = \frac{D^2}{10000n}$$

A typical value of $n = 10^4$ gives $d = \dfrac{D}{10000}$.

26.2 The Properties of α, β and γ Radiation

Rutherford found that radiation emitted

- **Ionises air**, making it conduct electricity.
- Is of three types, α, β and γ.
- A **magnetic field** deflects α and β radiation in opposite directions, and has no effect on γ radiation.

Ionisation Experiments

The ionising effect of each type of radiation can be investigated using an **ionisation chamber** and a **picoammeter**, containing air at atmospheric pressure.

Ions created in the chamber are attracted to oppositely charged electrodes where they are discharged, causing a current proportional to the number of ions per second created.

- α radiation causes **strong ionisation**.

  Ionisation ceases beyond a certain distance, because α radiation has a range in air no more than a few centimetres.

- β radiation is **muck weakly ionising**, and range in air up to a metre.

  A β particle therefore produces **less ions per millimetre** along its path than an α particle does.

- γ radiation has a **much weaker ionising effect** than α or β radiation. This is because photons carry no charge, so have less effect.

Cloud Chamber Observations

A cloud chamber contains air **saturated with vapour** at a very low temperature.

An α or β particle passing through the cloud chamber leaves a **visible track of condensed vapour droplets**.

- α particles create straight tracks and are easily visible.

  The tracks from a given isotope are **all of the same length**, indicating they have the same range.

- β particles produced **wispy tracks** and are **easily deflected** as a result of collisions with air molecules.

  The tracks are not as easy to see as α particle tracks.

Absorption Tests

A **Geiger tube and a counter** is used to investigate absorption by different materials. Each particle of radiation that enters the tube is registered by the counter as a single count.

The **count rate** is the number of counters divided by time taken.

1. The count rate due to background radioactivity is measured.
2. The count rate is then measured with the source at a **fixed distance** from the tube, **without any absorber** present.

   The **corrected count rate** is the background count rate subtracted from the count rate with source present.
3. The count rate is then measured with the **absorber present** between the source and the tube.
4. The corrected count rate with and without the absorber present can then be compared.

The Geiger Tube

The Geiger tube is a **sealed metal tube**, containing

- **Argon gas** at low pressure.
- A tiny mica window at the end to allow α and β particles in.
- A **metal rod** with positive potential down the middle of the tube.
- **Tube walls** are connected to the negative terminal of the power supply.

When a particle of ionising radiation enters the tube,

- The particle ionises the gas atoms along its track.
- **Negative ions** are attracted to the tube, and **positive ions** to the wall.
- The ions accelerate and collide with other gas atoms, **producing more ions**.
- Causing many ions to **discharge at the electrodes**.
- A **pulse of charge** passes round the circuit through resistor R, causing a **voltage pulse** which is recorded as a single count by the **pulse counter**.

26.3 More about α, β and γ Radiation

- α radiation consists of **positively charge particles** - each α particle is composed of two protons and two neutrons.
- β radiation from naturally occurring radioactive substances consists of **fast-moving electrons**.

This is proved by measuring the **deflection of a beam of β particles**, which is used to work out the **specific charge** of the particles, to be the same as the electron.

A nucleus with too many proton emits a **positron**.

- γ radiation consists of photon.

  A γ photon is emitted if a nucleus has excess energy after it has emitted an α or β particle.

Inverse Square Law for γ Radiation

The **intensity** of radiation is the **radiation energy per second** passing normally through unit area.

- For a point source that emits n γ photons per second, each energy hf, radiation energy per second from the source is nhf.
- At distance r from the source, all photons pass through a total area of $4\pi r^2$.

$$I = \frac{nhf}{4\pi r^2}$$

Equations for Radioactive Change

- α emission: ${}^{A}_{Z}X \rightarrow {}^{4}_{2}\alpha + {}^{A-4}_{Z-2}Y$
- β^- emission: ${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + {}_{-1}^{0}\beta + \bar{\nu}_e$
- β^+ emission: ${}^{A}_{Z}X \rightarrow {}_{Z-1}^{A}Y + {}_{+1}^{0}\beta + \nu_e$
- Electron capture: ${}^{A}_{Z}X + {}_{-1}^{0}e \rightarrow {}_{Z-1}^{A}Y + \nu_e$