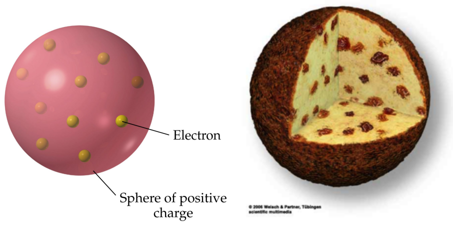
Radioactivity

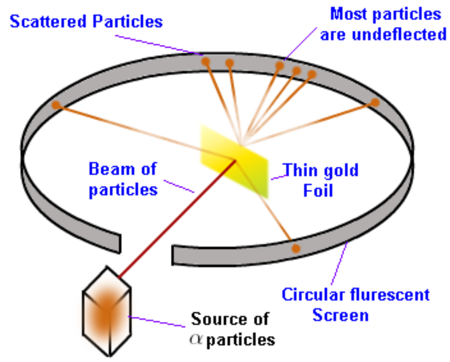
1 Rutherford Scattering

1.1 The plum pudding model



The plum pudding model was the initial model of the atom, stating a sphere of positive charge with electrons embedded into it.

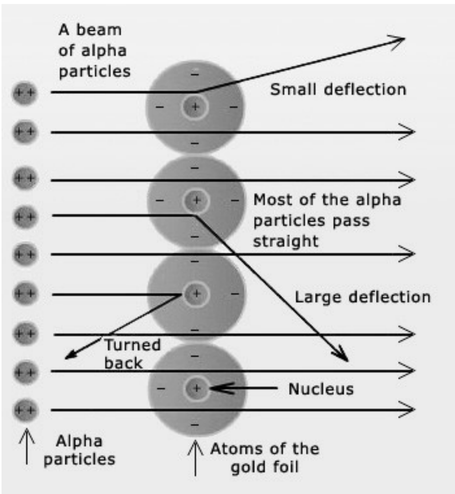
1.2 Rutherford's experiment



Rutherford's experiment involved firing a beam of alpha particles at gold foil and measuring the paths of particles from the foil.

- Gold was used as it was expected to have a large nucleus
- The screen fluoresces when collided with
- This showed the atom was mostly empty space with a positive nucleus

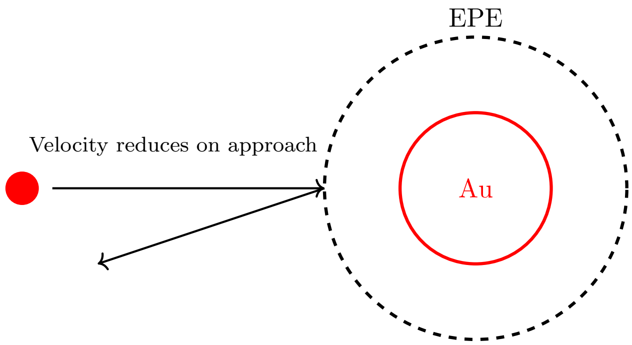
1.2.1 Results



Observation	Explanation
Most electrons pass all the way through	Atoms are mostly empty space
Some are deflected	The atom has a positive centre
Some are deflected by significant angles	The positive charge is condensed in a small area

1.3 Estimating the size of the nucleus

1.3.1 Closest approach method



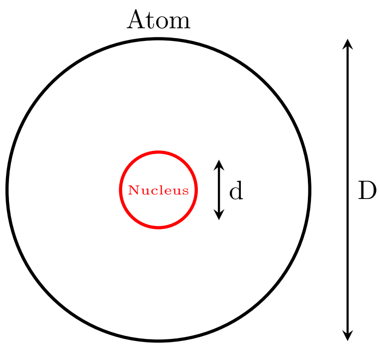
KE=EPE

$$8.0 \times 10^{-13} = \frac{1}{4\pi\epsilon_0} \times \frac{Q_{Au}}{r} \times Q_\alpha$$

$$r = 4.55 \times 10^{-14}$$

1.3.2 Estimate from scattering data

- About $\frac{1}{10,000}$ deflected through more than 90°
- Foil had n layers of atoms



$$\frac{\frac{1}{4}\pi d^2}{\frac{1}{4}\pi D^2} = \frac{d^2}{D^2} = \frac{1}{10,000n}$$

$n = 10^4$ layers

$$\frac{d^2}{D^2} = \frac{1}{10,000 \times 1 \times 10^4}$$

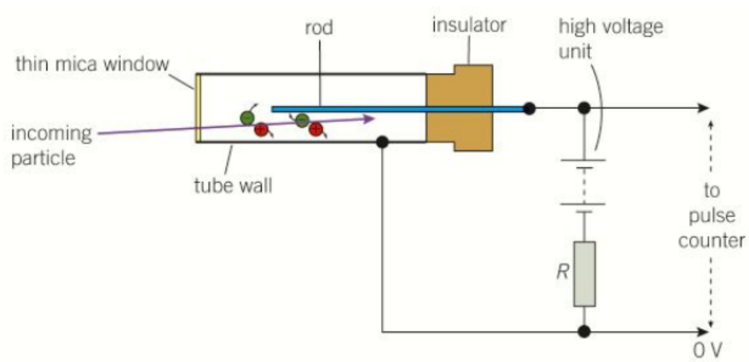
$$d = \frac{D}{10,000}$$

2 Radioactive materials

2.1 Sources of background radiation by most common

1. Air (e.g. radon gas)
2. Medical
3. Ground and buildings
4. Food and drink
5. Cosmic rays
6. Nuclear weapons
7. Air travel
8. Nuclear power

2.2 Geiger Müller tube



When a particle of ionising radiation enters the tube, the particle ionises the gas atoms along its track. The negative ions are attracted to the rod and the positive ions to the wall. These ions cause further ionisation, creating enough ions for a current to flow. A pulse of charge passes round the circuit through resistor R, causing the voltage pulse across R which is recorded as a single count by the pulse counter

The dead time of the tube, the time taken to regain its non conducting state after an ionising particle enters it, is typically of the order of 0.2ms.

3 Radioactive decay

	Alpha	Beta	Gamma
Nature	2 Protons+2 Neutrons	High speed electron or positron	High energy photon
Range	Up to 10cm	Up to 1m	Infinite
Deflection in a magnetic field	Deflected	Opposite direction to α particles and more easily deflected	Not deflected
Absorption	Paper	Aluminium	Lead
Ionisation	10^4 ions per mm	100 ions per mm	Very weak ionising effect
Energy of each particle	Constant for a given source	Varies up to a maximum for a given source	Constant for a given source

3.1 α Decay

$$^{238}_{92}U \rightarrow ^{4}_{2}\alpha + ^{234}_{90}Th$$

3.2 β^- Decay

Neutron to proton and β^- particle

$$^{14}_{6}C \rightarrow ^{0}_{-1}\beta + ^{14}_{7}N$$

3.3 β^+ Decay

Proton to neutron and β^+

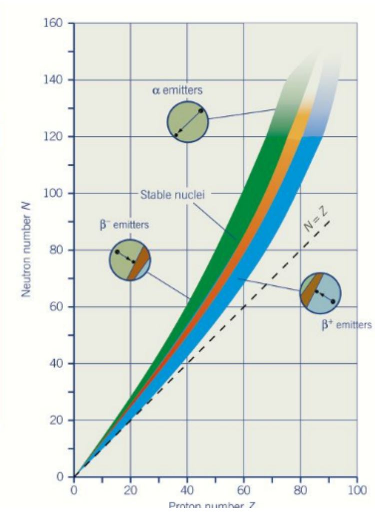
3.4 Electron Capture

Proton+Electron$\rightarrow$ Neutron

3.5 Gamma Emission

No change to the structure of the nucleus.
Often follows alpha or beta emission. Daughter nucleus can be in an excited state. It emits gamma radiation as it returns to its ground state.

3.6 NZ Plot



3.7 Half life

The half life of a radioactive substance is the time taken for half the atoms in the sample to decay.

$$\text{The rate of decay} \propto \text{The number of nuclei left}$$

$$-\frac{\Delta N}{\Delta t} \propto N$$

The LHS of this equation is called the activity and has units Bq

$$-\frac{\Delta N}{\Delta t} = \lambda N$$

The solution to this equation

$$N = N_0 e^{-\lambda t}$$

This can also be written as:

$$\frac{N}{N_0} = e^{-\lambda t}$$

3.7.1 Linking the formula to half life

After a time, t=$T_{\frac{1}{2}}$ the fraction remaining is 0.5.

$$0.5 = e^{-\lambda t}$$

$$ln(2) = \lambda t$$

$$t = \frac{\ln(2)}{\lambda}$$

λt is a "Pure Number". As long as the same units are used for both, you can use any unit of time.

λ is the fraction of nuclei decaying per unit time or the probability of an individual nucleus decaying per second.
As N is proportional to Activity, Mass and Count Rate N can be replaced with any of these in the formula.

4 Nuclear radius

4.1 High energy electron diffraction

When a beam of high energy electrons is directed at a thin solid sample of an element they are diffracted by the nuclei of the atoms.
The electrons are diffracted by the nuclei because of their de Broglie wavelength, this is approximately equal to the radius of the nuclei. The detector measures the number of electrons per second at different angles.
The scattering of the beam of electrons occurs due to the charge, this causes intensity to decrease as angle increases.
The minimum on the graph can then be used to find the radius of the nucleus.

4.2 Dependence of nuclear radius on nucleon number

It can be shown that radius depends on mass according to:

$$R = r_0 A^{\frac{1}{3}}$$

Where r_0 is the constant 1.05fm

The graph of $\ln(R)$ against $\ln(A)$ gives a line with gradient $\frac{1}{3}$ and y intercept equal to $\ln(r_0)$

The graph of R against $A^{\frac{1}{3}}$ gives a straight line through the origin with gradient r_0

$$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi(r_0 A^{\frac{1}{3}})^3 = \frac{4}{3}\pi r_0^3 A$$

As Density = $\frac{\text{Mass}}{\text{Volume}}$

$$\text{Density} = \frac{Au}{\frac{4}{3}\pi r_0^3 A} = \frac{1u}{4\pi r_0^3} = \frac{1.661 \times 10^{-27}}{\frac{4}{3}\pi(1.05 \times 10^{-15})^3} = 3.4 \times 10^{17} kgm^{-3}$$