Atomic Structure

What does an atom look like inside?

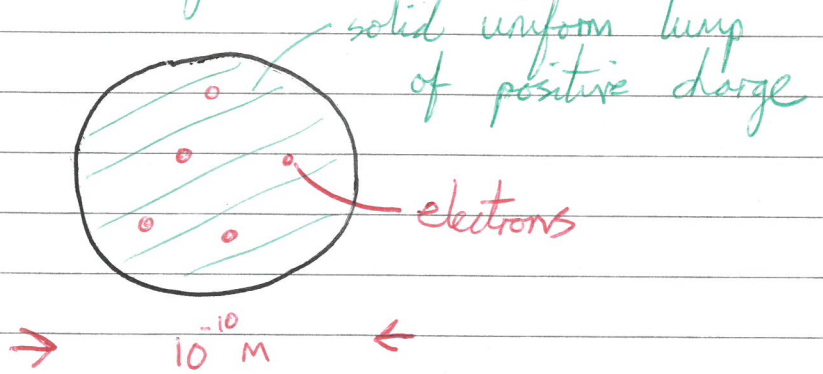
- Early clues
  - Periodic table (Mendeleev 1869)
    ↳ Periodic patterns in elements' properties
  - Radioactivity (Becquerel 1896, Curie 1898)
  - Atoms emit/absorb light at specific discrete wavelengths (Balmer, 1884) [see L4]

Spectra

  - Discovery of the electron (Thomson, 1897)
    'Cathode rays' - heat metal in a vacuum with electric field applied [see Y1 Labs]
    ↳ Negative charge, very light (1/2000th atom mass)

⇒ "Plum Pudding model"

What is a Plum Pudding?



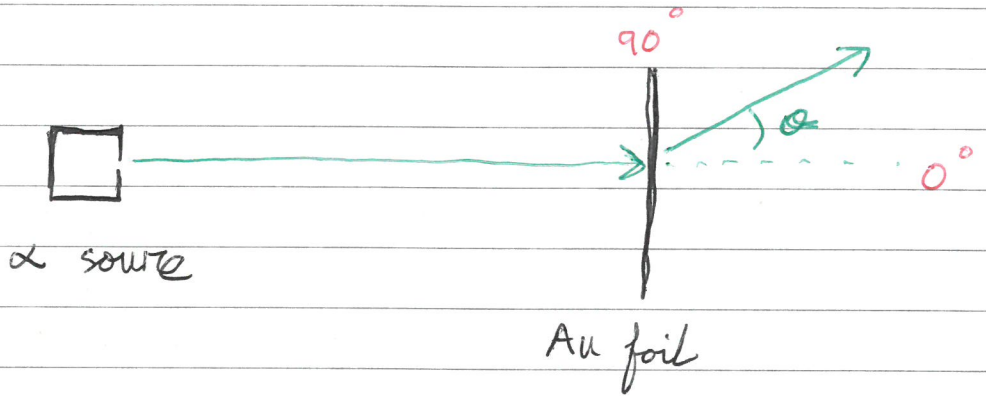
- Discovery of the nucleus - Geiger and Marsden Experiment (1908-13)

Fired alpha particles at thin gold foil, measured deflection/scattering

α is a helium nucleus

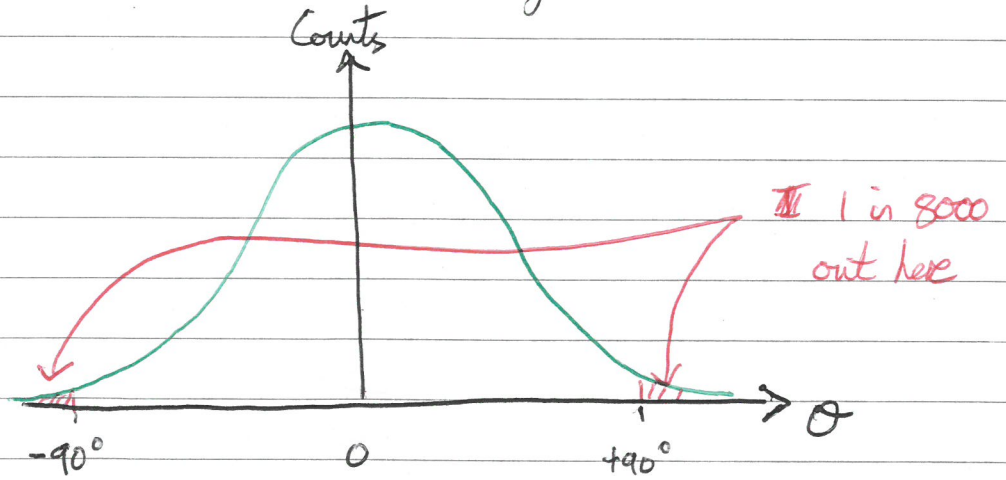
$Q = +2e$ $M = 4$ a.mass units

Energy (KE) ~ 5 MeV



Result: - Most α are scattered through small angles, $\theta \sim 0$

- But (surprise), a small number are scattered through $\theta > 90°$

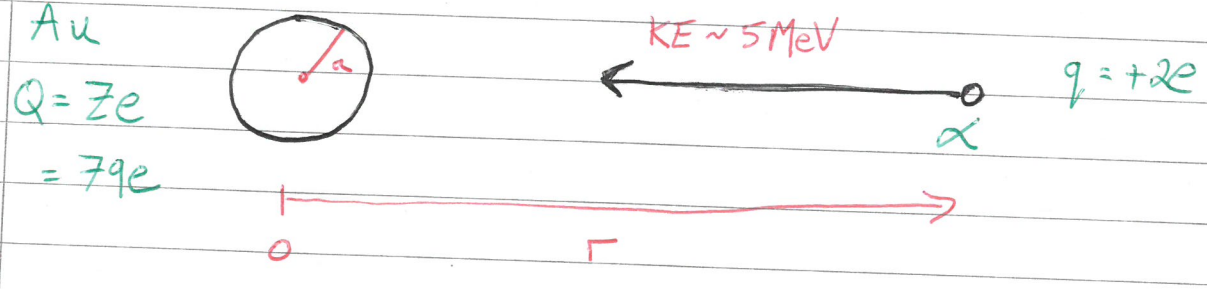


Can we explain this with the Plum Pudding? (no..)

|| Scattering Distribution

- Calculation: work done in taking an α from ∞ to the pudding centre
  → enough to stop the α?

[If we can't stop it we can't back-scatter it]



Assume:

→ Atom stays still (heavy)

→ Ignore Au electrons. Note - they would make repulsion weaker. If we can't stop the α without them, the real scenario is even worse..

- In general:

Coulomb Potential Energy: $U(r) = \frac{qQ}{4\pi\varepsilon_0 r}$

Force $F(r) = -\frac{dU}{dr} = \frac{qQ}{4\pi\varepsilon_0 r^2}$

Or, change in P.Energy = work done: $\int_{U_1}^{U_2} dU = -\int_{r_1}^{r_2} F(r)\,dr$

$$U_2 - U_1 = -\int_{r_1}^{r_2} F(r)\,dr$$

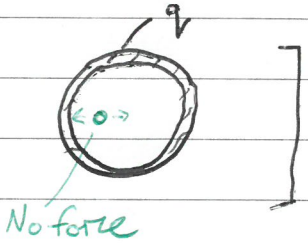
ΔU → change in potential energy

⇒ Enough to kill the KE? (stop the α)

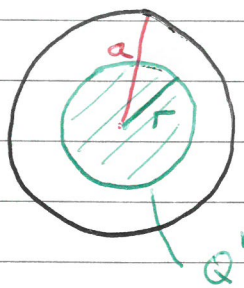
- Outside atomic pudding, treat as point charge Q
- Inside ($r < a$), treat as a smaller point charge $Q'(r)$

[only the charge within radius r counts..

Force is zero inside a hollow sphere of charge - see EM1 next term ∴



Inside the pudding



If charge is spread uniformly, total charge is ~~prop.~~ to volume

$$\frac{Q'}{Q} = \frac{4\pi r^3}{4\pi a^3}$$

$$Q' = Q\frac{r^3}{a^3}$$

Inside ($r < a$)

$$F = \frac{qQ'}{4\pi\varepsilon_0 r^2}$$

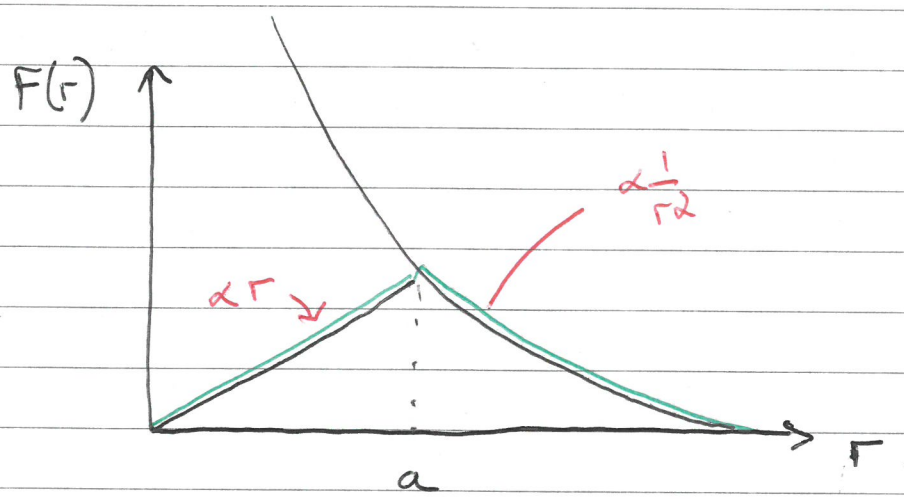
$$F = \frac{qQr^3}{4\pi\varepsilon_0 r^2 a^3}$$

$$F \propto r$$

Outside ($r \geq a$)

$$F = \frac{qQ}{4\pi\varepsilon_0 r^2}$$

$$F \propto \frac{1}{r^2}$$



$$\Delta U = -\int_{r_1}^{r_2} F(r)\,dr$$

$$= -\int_{\infty}^{a} \frac{qQ}{4\pi\varepsilon_0 r^2}\,dr - \int_{a}^{0} \frac{qQr}{4\pi\varepsilon_0 a^3}\,dr$$

[show that..] $\Delta U = \frac{3}{2} \frac{qQ}{4\pi\varepsilon_0 a}$

$$\Delta U = \frac{3}{2} \frac{2 \times 79 \times (1.602 \times 10^{-19})^2}{4\pi (8.854 \times 10^{-12}) \times 10^{-10}}$$

$\Delta U = 5.45 \times 10^{-16}$ J [1 eV = 1.602×10^{-19} J]

$\Delta U = 3.41$ keV $\ll E_\alpha = 5$ MeV

⇒ Conclusion: A plum pudding, while tasty, could not back-scatter a 5 MeV α particle

A smaller volume of charge could though ($\Delta U \propto 1/a$)

... how small?

If it's really small, let's now assume the α doesn't penetrate. Just a point charge:

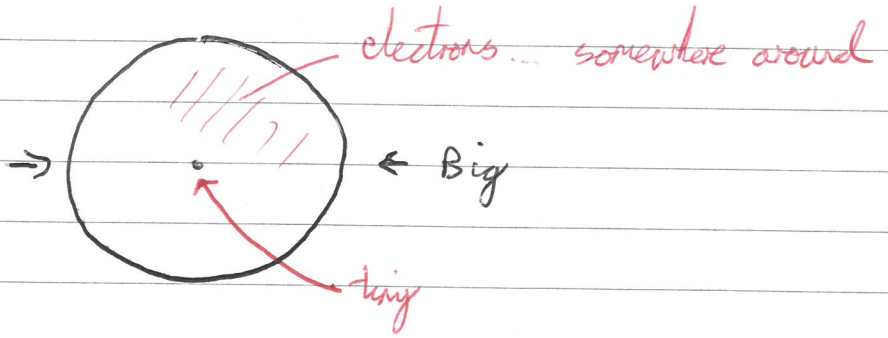
$$\Delta U = \int_{\infty}^{r_{max}} \frac{qQ}{4\pi\varepsilon_0 r^2} dr = 5 \text{ MeV}$$

[show that] $r_{max} = 4.5 \times 10^{-14}$ m

$= 45$ fm

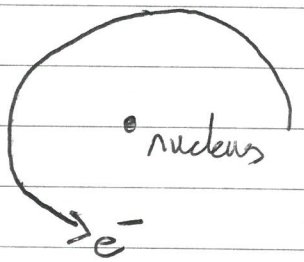
So: Atom is 10^{-10} m $\Rightarrow$ 100,000 fm

Nucleus is 45 fm



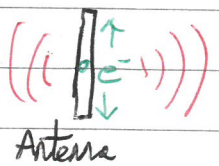
- Next idea: 'Solar System Model' ~~Rutherford~~

|| Solar system Model



- But there's a problem...

$\Rightarrow$ An accelerating charge radiates energy

[This is how a radio works 

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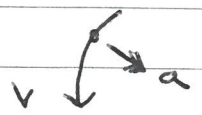
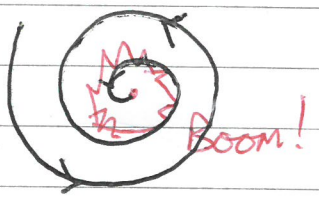
$\rightarrow$ Circular motion means acceleration



→ So electrons should lose energy over time



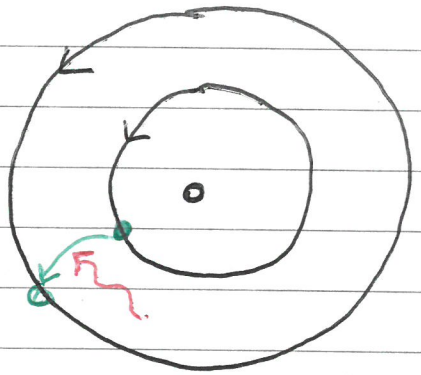
Atoms exist, so we know this doesn't happen.

- Next idea! Bohr model (Niels Bohr)

2 crazy postulates from Bohr:

1. The e^- in hydrogen moves in set, non-radiating, circular orbits

2. Radiation is emitted/absorbed only when e^- moves from one orbit to another



This works (at least for H)

→ Explains emission spectrum of H [L4, L7]

→ Introduces idea that energy levels are quantised

But has no physical grounding yet.

[Real / more modern understanding more complex than this simple model]

In conclusion:

- Discovery of electron → Plum Pudding Model
- Backscattering of α proved nucleus is actually tiny
- Solar system model... but accelerating charges radiate...
- Idea of the Bohr model - quantised energy levels