Structure of Matter? → Atoms

Saw now have pretty clear evidence that atoms have substructure.

What are atoms made of? $\begin{cases} e^-\text{'s} & Q<0 \quad Q^{A}=0 \\ + \text{ charged stuff} \end{cases}$

How can we find out?

"Shake them" or "Poke them"

Bathe them in light

hit them w/ high E particles

1

2

Start w/ 1

Heating up matter makes it glow
(Now all experts on that)

Plank Spectrum (Continuous)

Many other spectrum known to be Discrete
(Went over this before | Sun (Dark lines)
| Fire (Bright lines)

Whats up w/ these lines?

→ No Classical Physics (E&M) Answer!

Super useful to Chemists: Fingerprint atoms (etc)

Crying out for deeper explination.
→ If understood obviously tell us something about atomic structure

Big effort to find patterns in the obsered lines

<u>More numerology than science!</u>

Simpler atoms have Simpler spectrum. Start there.

1st Success High-School teacher "Balmer"

Visible + UV lines described by

$$\lambda_n = 364.6\text{ nm}\ \frac{n^2}{n^2-4} \qquad n \in \{3,4,5,\ldots\}$$

"Balmer Series" Maybe part of bigger pattern?

$$\frac{1}{\lambda_n} = \underbrace{\frac{4}{364.6\text{nm}}}_{10^7\ m^{-1}} \left(\frac{1}{4} - \frac{1}{n^2}\right) \qquad n > 2$$

Also a square

Maybe

$$\frac{1}{\lambda_{mn}} = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right) \qquad n > m$$

m = 2 Balmer, what about m = 1?

eg m = 1 n = 2

Prediction!

$$\frac{1}{\lambda_{1,2}} = 10^7\left(1 - \frac{1}{4}\right) = \frac{1}{120\text{ nm}}$$

m = 3 n = 4

$$\frac{1}{\lambda_{34}} = 10^7\left(\frac{1}{9} - \frac{1}{16}\right) = \frac{1}{1870\text{ nm}}$$

These lines were then found! "Rydberg" Const R

Something right about this formula: But no underlying theory

- why $\frac{1}{n^2}$?
- why subtract terms?
- where does the scale R come from?

Lets try to put some science behind these #'s.

Need some "Atomic Model"

Idea being something into the atoms

Atoms: - made of $\bar{e}$'s $\begin{cases} r_e \sim 10^{-12}\,m \ll r_{atom} = 10^{-10}\,m \\ m_e \ll m_{atom} \quad Q_e < 0 \end{cases}$

- made of other (+) stuff $\quad Q_{atom} = 0$
- other stuff must be most of atom

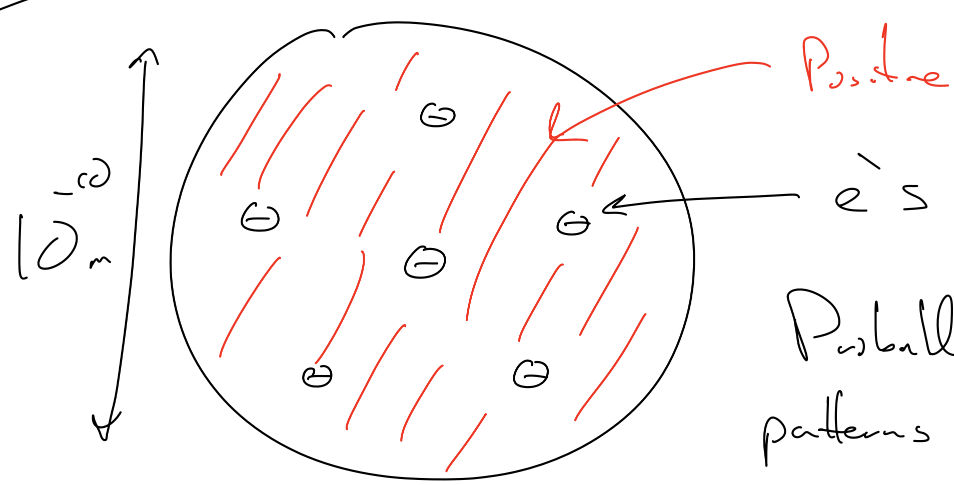
$m_{atom} \gg m_e \qquad r_{atom} \gg r_e$

- Accelerated charges radiate (continuous) light

↳ Not seen $\Rightarrow$ $\bar{e}$'s at rest.

Obvious Model

Thomson Model "Choc Chip Cookie"



Probably need discrete patterns of $\bar{e}$'s to be stable

then maybe the Oscillations near stable equil give discrete spectra?

Calculated frequencies didn't work...

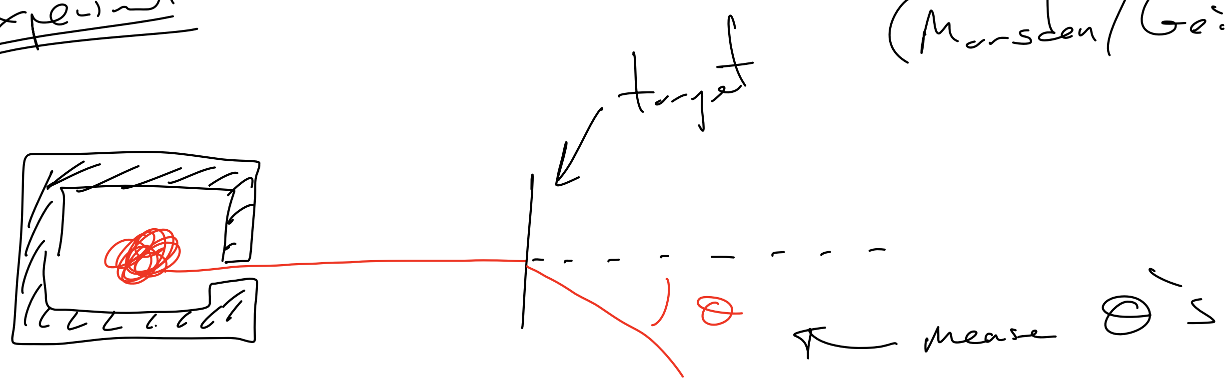
Lets try banging into the atoms (Rutherford)

- What to hit the e's w/ ?

Just recently discovered the perfect Bullets

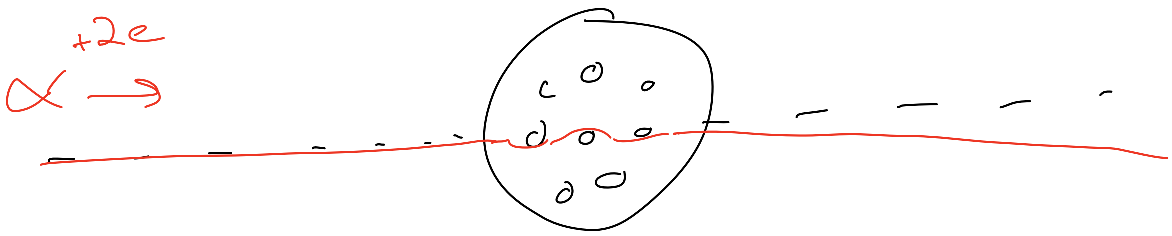
α - particles
- Largest E's
- massive $10^4 m_e$
- Known to interact strongly w/ matter (easy to stop)

Experiment (Marsden/Geiger)



Worlds 1st collision experiment.

What do we expect to happen?



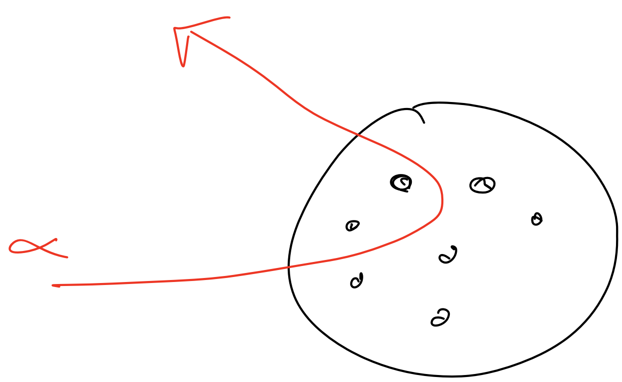
Expect "small" angle scattering.

- Positive stuff ~ equally distributed
- α's won't be much affected by e^-'s

  $m_\alpha \sim 10^4 m_e$ "Cannon ball hitting tissue paper"

Results

- Most α's indeed had small θ
  ~undeflected or θ very small indeed
- Smaller θ's than expected
- However some deflected by $\theta > 90^\circ$!!



Rutherford's Interpretation

Thomson's model "too soft"

Big θ's $\Rightarrow$ "hard core" much heavier & smaller radius

$\downarrow$

"nucleus"

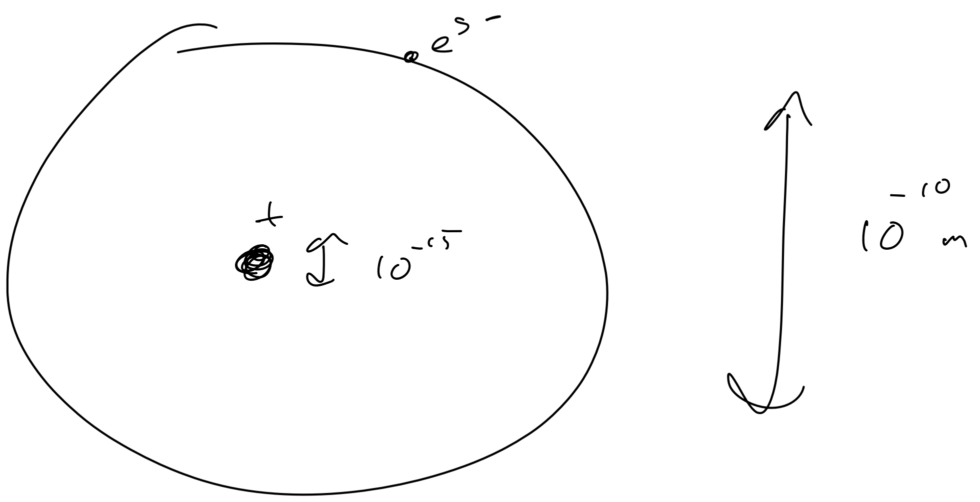
r_n can be measured from scattering experiments (HW)

$r_n \sim 10^{-14} - 10^{-15}$ m

$\uparrow$

fm

$\Rightarrow$ "Solar System" model



Looks OK...

- EM Interaction attractive
- System Bound (like planets) $\frac{1}{r^2}$

Classical Life time of Atom

$$[P] \sim \left[\frac{E}{s}\right] \sim G_c V^2 \sim a^2$$

$$f = \frac{v}{2\pi r_{atom}} \sim \frac{v}{r_{atom}}$$

$$F = ma \qquad \frac{\alpha}{r^2} = \frac{mv^2}{r}$$

$$\Rightarrow \sqrt{\frac{\alpha}{mr}} = v$$

$$\& \quad f \sim \sqrt{\frac{\alpha}{m}}\; r^{-3/2}$$

$$E = \frac{\alpha}{r} \qquad a = \frac{v^2}{r} = \frac{\alpha}{mr^2}$$

$$t = E/P \sim \frac{E}{a^2} = \frac{\alpha}{r} \Big/ \frac{\alpha^2}{m^2 r^4} = \frac{m^2 r^3}{\alpha} = \frac{m^2}{\alpha^4 m^3}$$

$$= \frac{1}{\alpha^3 \alpha m} = \underbrace{10^{+6}}_{2\,10^6}\, 10^{-10}\, m \times \frac{1}{3\,10^8\, m}\, s = 2\cdot 10^6\; 0.3\; 10^{-18}\, s$$

$$= 10^{-12}\, s$$