Atomic Structure

"atom" (Greek) = "indivisible"

Properties known ca. 1910

- Small ! ~0.1nm (electrolysis, molar weights, Avagadro's #)

- Stable - <u>most</u> atoms do not decay, or transform into other elements (alchemy)

- Contain electrons (e^-) (Thomson, Millikan)

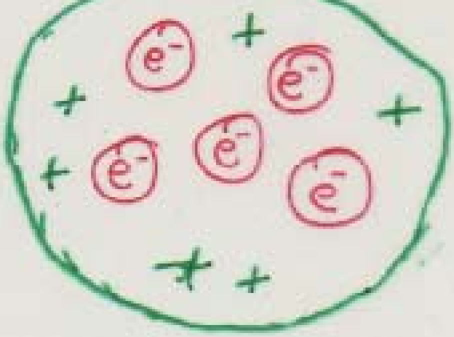
  <u>but</u> - atoms are neutral
  - atomic mass $\gtrsim$ 2000 × electron mass

- Absorb / emit EM radiation
  - sometimes only at specific values of λ (spectral lines)

Atomic Models - Nuclear Atom

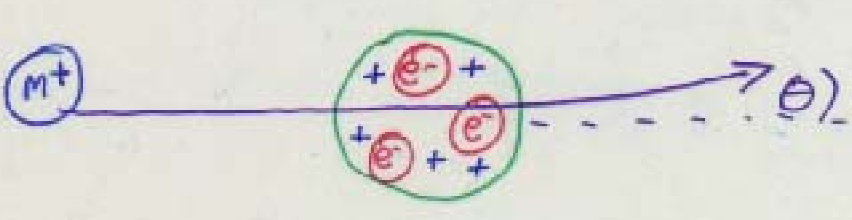
1. J. J. Thomson's "Raisin Pudding" Model

electron "raisins" embedded in a "pudding" of positive charge (which has most of atom's mass)



Predictions:

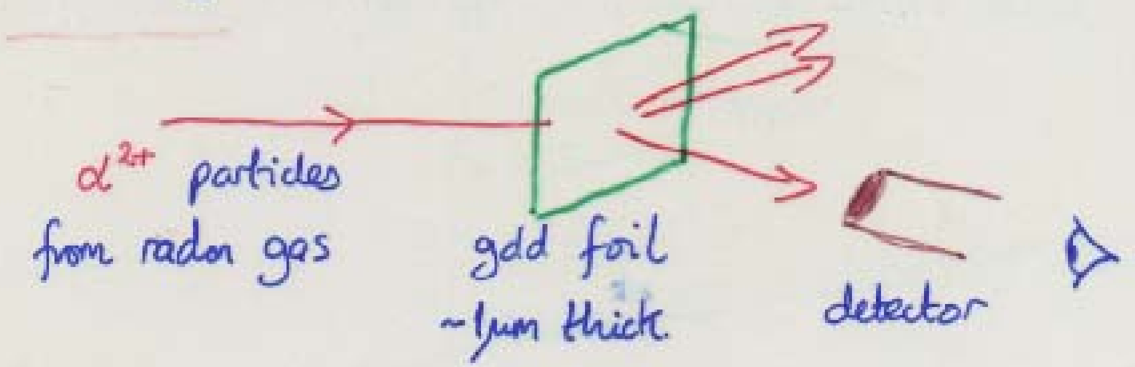
- electrons vibrate around mean position in pudding
  $\Rightarrow$ should radiate at $\lambda = 50$ nm ??
- If we pass a beam of charged particles with $M \gg M_e$ through layer of atoms .....



.... deflection of particles should be small

2. Rutherford's Nuclear Model

Geiger + Marsden's Gold Foil experiment:



Measure: number of particles deflected for each angle θ

Results: • most α-particles → no deflection

BUT • some deflected through large angles, even scattered backwards!

Rutherford: "like firing a cannon shell at tissue paper, and it comes back and hits you!"

Conclusion:

Can explain if mass and +ve charge of atom is concentrated in a nucleus.

Physics of Rutherford Scattering

Projectile: α-particles from radioactive decay,

charge $ze = +2e$, mass $M_\alpha \approx M_{He} >> m_e$

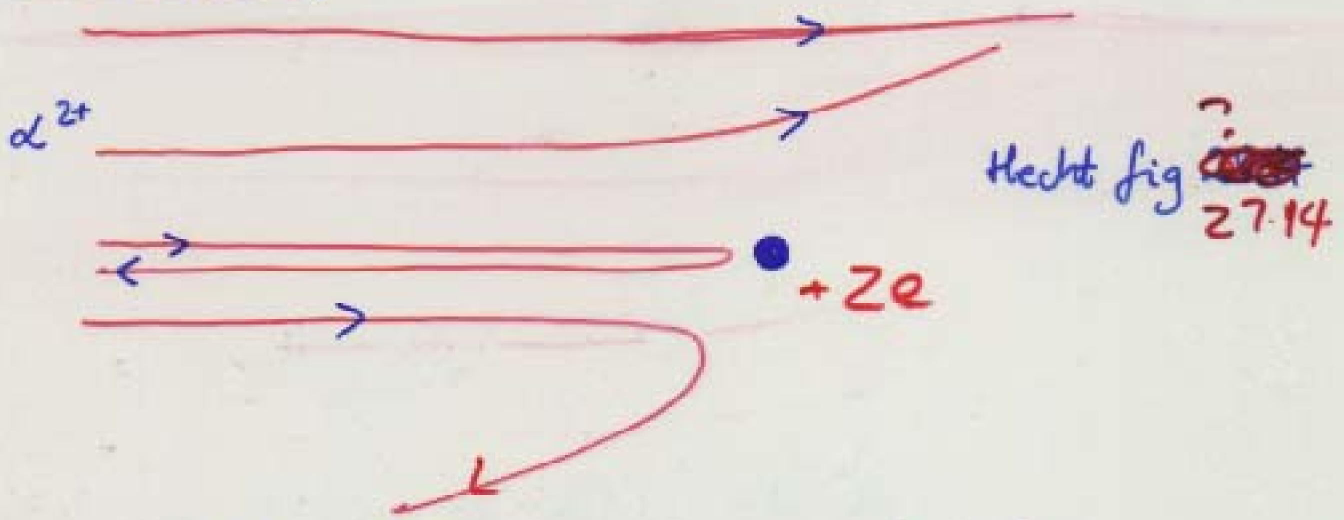
kinetic energy $\frac{1}{2} M_\alpha v^2 = 6\ \text{MeV} \Rightarrow v \approx 2 \times 10^7\ \text{m/s}$.

Target: Gold atoms (Au), nuclear charge $Z = +79$

(= atomic number)

nuclear mass $\approx$ atomic mass $M_{Au} \approx 197\, M_H$

Close Encounters:



Hecht fig ? 27.14

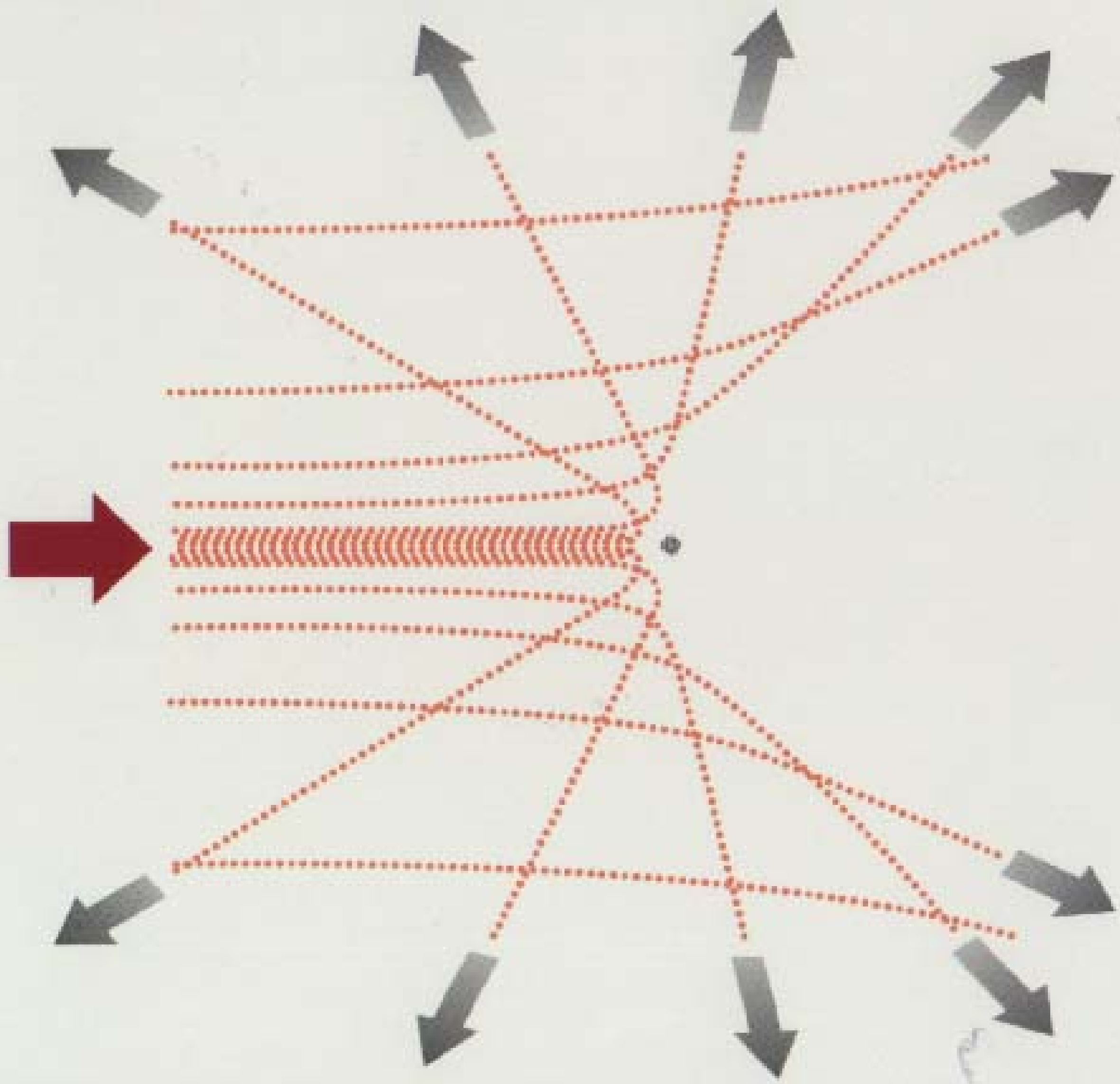
Force on α particle $F = \dfrac{q_1 q_2}{4\pi\varepsilon_0 r^2} = +\dfrac{Zze^2}{4\pi\varepsilon_0 r^2}$

$\Rightarrow$ trajectory is a HYPERBOLA (c.f. fast comets around sun)

Transparency 156

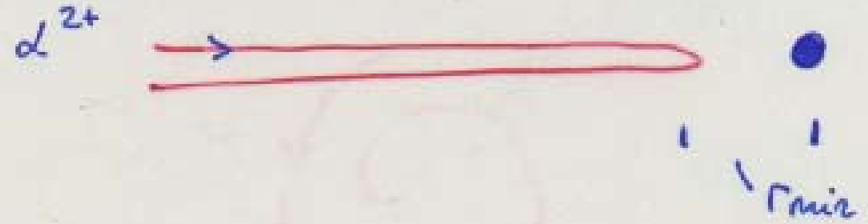
Figure 27.14

Scattering of α-particles by a positive massive nucleus



Closest Approach Distance : Size of Nucleus

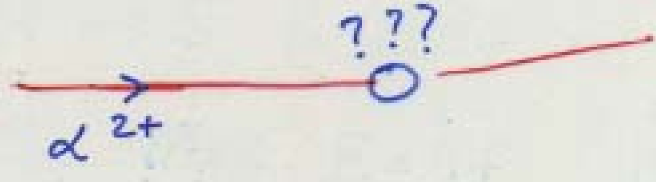
- A few α particles deflected through $180°$



Closest approach distance r_{min} (α^{2+} turns around) where initial k.e. = electrostatic p.e.

i.e. $\frac{1}{2} m_\alpha v^2 = \dfrac{Zze^2}{4\pi\varepsilon_0 r_{min}}$ $\Rightarrow$ value for r_{min}

- Rutherford et al. repeated expt. with 'fast' α particles



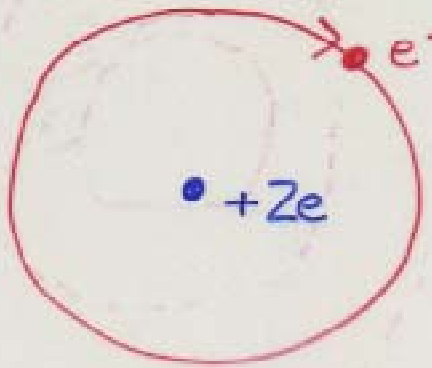
Now $r_{min} \lesssim r_{nuc}$ so particle interacts

$\Rightarrow$ loss of $180°$ deflections

$\Rightarrow$ can estimate $r_{min} \approx r_{nuc}$

Found that : $r_{nuc} \sim 10^{-14}$ m , i.e. 10,000 times smaller than size of atom !

Bohr Model of the Atom : "Planetary" Orbits



electrons orbit massive nucleus in circular / elliptical paths (cf. planets around sun)

Force on bound e^- due to nucleus:

$$\underset{\sim}{F} = -\frac{Ze^2}{4\pi\varepsilon_0 r^2} \qquad \text{c.f. } F = -\frac{GMm}{r^2}$$

For circular orbit, centripetal force $= \frac{m_e v^2}{r}$

So $\frac{m_e v^2}{r} = \frac{Ze^2}{4\pi\varepsilon_0 r^2} \Rightarrow \frac{1}{2} m_e v^2 = \frac{1}{2} . \frac{Ze^2}{4\pi\varepsilon_0 r}$

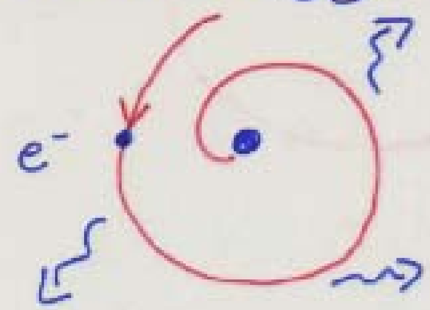
kinetic energy $K = \frac{1}{2} m v^2$. Potential energy $U = -\frac{Ze^2}{4\pi\varepsilon_0 r}$

So $K = \frac{1}{2} m_e v^2 = -\frac{1}{2} . U \Rightarrow \boxed{2K + U = 0 : \text{circular orbit}}$

$\therefore$ total energy of orbit $E = K + U = -K = -\frac{Ze^2}{8\pi\varepsilon_0 r}$

Problem: Classical Physics $\Rightarrow$ accelerating charges must <u>radiate</u>

$\Rightarrow$ electron loses energy, spirals into nucleus



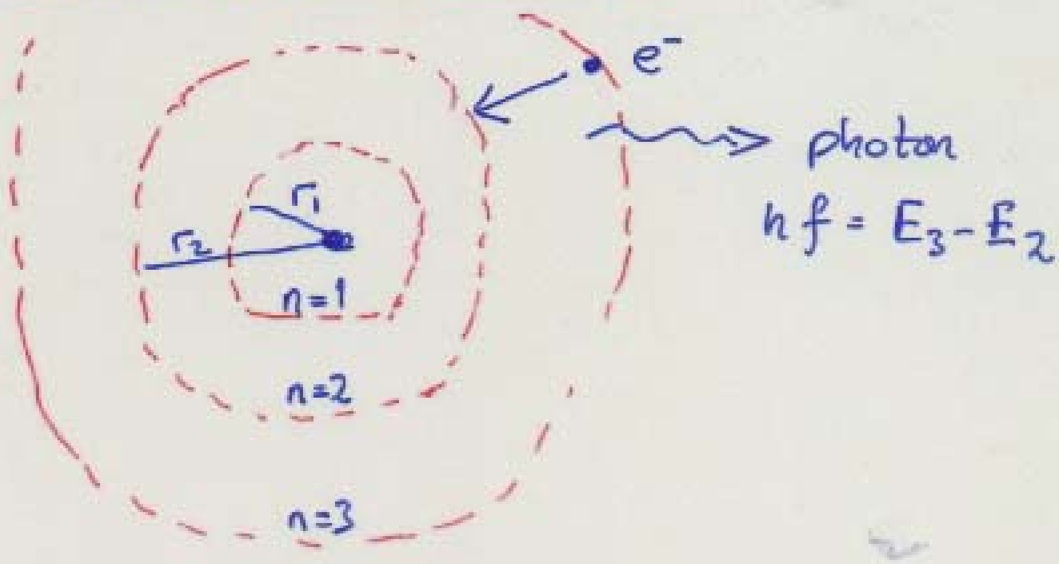
estimate lifetime $<< 1s$!

Bohr's Postulates (1913):

1. electrons occupy "stationary states" in atom - do <u>not</u> radiate
2. electron orbits are <u>quantized</u>: only certain energies allowed.
3. Transitions between orbits by absorption / emission of a photon with energy $E = hf = E_1 - E_2$.

$\Rightarrow$ Spectral lines

The Rutherford - Bohr Atom



Quantized orbits: can explain spectral line wavelengths

$\frac{hc}{\lambda} = E_n - E_m$ if we restrict

angular momentum $L \equiv \underline{mvr} = nh/2\pi : n = 1, 2, 3 \ldots$

Already have : $2K + U = 0$ i.e. $mv^2 - \frac{Ze^2}{4\pi\varepsilon_0 r} = 0$ for all orbits (1)

$L = mvr = \frac{nh}{2\pi} \Rightarrow v = \frac{nh}{2\pi m r}$ (2)

Eliminate v, solve for radius of orbit r

$$\Rightarrow r_n = \underbrace{\left(\frac{4\pi\varepsilon_0}{e^2 m}\right)}\frac{n^2}{Z} = a_0 \frac{n^2}{Z}$$

Bohr radius $a_0 = 0.0529\,nm$ ~ atomic diameter!