BOHR MODEL OF THE ATOM

THEO HUGHES

EDUCATION MANAGER – SCHOOL OF PHYSICS & ASTRONOMY

For a hydrogen atom:

Electron wave resonance

$n = 1$

$\lambda_1 = 2\pi r_1 = 6.28 a_0$

$n = 2$

$2\lambda_2 = 2\pi r_2$

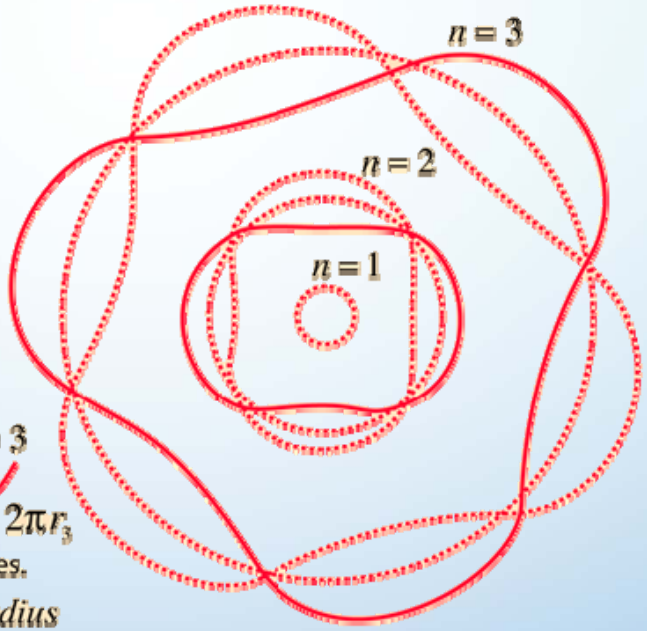
$\lambda_2 = 12.57 a_0$

$n = 3$

$\lambda_3 = 18.85 a_0 \qquad 3\lambda_3 = 2\pi r_3$

Wavelengths for hydrogen states.

$a_0 = 0.0529 nm = Bohr\ radius$



http://hyperphysics.phy-astr.gsu.edu/hbase/bohr.html

Video – Vibrating Wire Analogy of Electron Waves in Atom

MATCHING THEORY TO EXPERIMENTAL EVIDENCE

- Experiment : Discrete spectral emission lines of hydrogen
- Guess (Rydberg Formula) : $\frac{1}{\lambda} = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right), \quad n > m$
- Bohr's Model?

LET'S HAVE A LOOK!

- Hydrogen discharge lamp plus mechanical spectrometer (using grating).

BOHR'S MODEL?

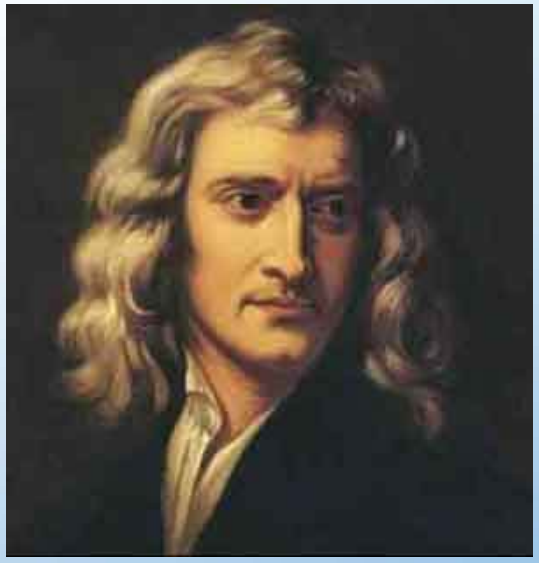
- Surprisingly simple – see exactly where quantisation arises
  - Later look at historical development – insight into how physics *really* develops
- Interesting because semi-classical… what does this mean?... and how is it so?
  - Insight into e.g. Hawking radiation – a semi-classical model (mixture of quantum theory and GR)
- Linking experiment to theory
  - Interplay of theory & experiment – validation of theory & limitations
  - Even where it "supported" theory, reality can be frustratingly different!

HARALD BOHR

- Bohr's Brother
- 1908 Summer Olympics, Silver medal, Danish Football Team
- Eminent Mathematician
- Rutherford a soccer fan – helped to cement Neils Bohr / Rutherford relationship

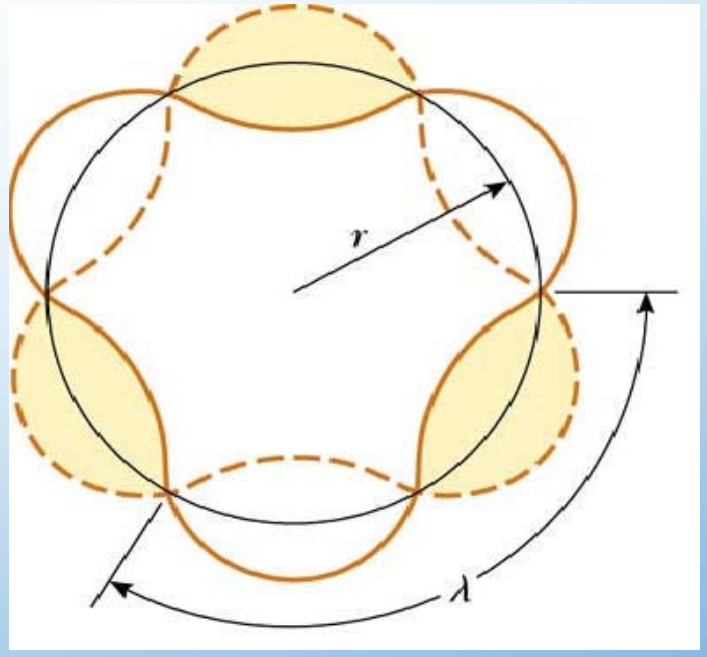
CLASSICAL

- Energy = KE + PE = $\frac{1}{2}mv^2 - \frac{e^2}{4\pi\varepsilon_0 r}$
- Dynamics
  - $F = \frac{e^2}{4\pi\varepsilon_0 r^2}$
  - $a = \frac{F}{m} = \frac{e^2}{4\pi\varepsilon_0 m r^2} = \frac{v^2}{r}$
  - $v^2 = \frac{e^2}{4\pi\varepsilon_0 m r}$



QUANTUM CONDITIONS

- Standing wave: $2\pi r = n\lambda, \quad n = 1, 2, 3 \ldots$
- de Broglie: $\lambda = \frac{h}{p} = \frac{h}{mv}$
- So
  - $2\pi r = n\frac{h}{mv}$
  - $v_n = \frac{nh}{2\pi mr}$



http://imgbuddy.com/de-broglie-atomic-model.asp

SEMI-CLASSICAL

- $v^2 = \frac{e^2}{4\pi\varepsilon_0 mr}$ & $v_n = \frac{nh}{2\pi mr}$
- Combining : $r_n = n^2 \frac{4\pi\varepsilon_0\hbar^2}{me^2} = n^2 a_B$ (a_B = Bohr Radius)

LINK TO EXPERIMENT

- $E_n = \frac{1}{2}mv_n^2 - \frac{e^2}{4\pi\varepsilon_0 r_n} = -\frac{1}{n^2}\left(\frac{1}{4\pi\varepsilon_0}\frac{e^2}{2a_B}\right)$
- $\frac{1}{\lambda} = \frac{E_n - E_m}{hc} = R_H\left(\frac{1}{m^2} - \frac{1}{n^2}\right), \quad n > m$
- Bohr predictions matched closely, but…
  - Additional spectral discharge lines (Fowler in lab, Pickering in stellar spectra)
    - Ionized Helium (simply replace e by 2e for nuclear charge).
  - Bohr predicted $R_{He} : R_H = 4$ but experimental (Fowler) = 4.0016
    - Replace *m* with effective mass $\frac{mM}{(m+M)}$

REAL LIFE

- Our students predict four visible (about 400nm – 700nm) lines
  - Generally only see three!… 410nm (violet) line generally not visible
  - Very feint, towards limit of vision, (possibly) absorption by glass.

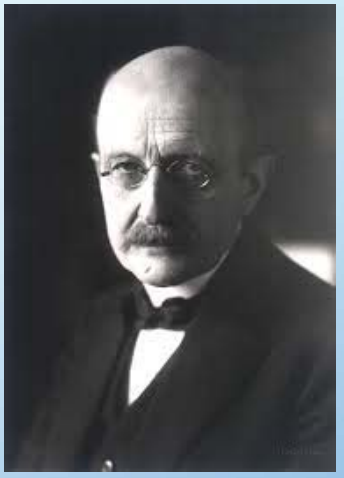
FAILURES OF MODEL

- Doesn't explain brightness of lines, width of lines, lines for more complex atoms, explain details of transition process etc. (hopefully quick look using digital spectrometer)
- HOWEVER, model still very useful…
- …provides direction for future models and future models (e.g. Schrodinger, Feynman) must make same prediction!... and extend model / predictions… don't throw away existing models that match experiment (e.g. relativity & Newtonian mechanics… newton wasn't "wrong" just limited applicability of model / assumptions need to be revised etc.)

NOT THE BOHR MODEL!

- I cheated!!... what has been presented is not the Bohr Model!... though nice package for students
- Wave "fitting" based on later work by de Broglie
  - Wave nature of "particles" (electrons) subsequently confirmed by Davisson & Germer diffraction experiment.
  - Sophisticated wave model of atomic orbitals = Schrodinger
- Does this matter?
  - I would argue "Yes"… in terms of actual story better shows how physics "really" develops

REAL BOHR MODEL



- Planck had already used the idea of energy transfer of multiples, *n*, of *hf* (Planck's constant times frequency of light wave).
- Bohr : emission of the same packets *nhf* (*n* = 1, 2 etc., Bohr uses τ instead of *n* in his paper).
  - where f = $\omega/2$ (have angular frequency)?... why?
    - well… it fits the theory ☺
    - also he cleverly developed the "correspondence principle"
- Correspondence principal : quantum system must match classical results in "classical domain"
  - Simply : current theories match some experiments, so new theories better match current theories for those experiments!

BOHR'S TRICK

- Bohr imagined "really large" atom (i.e. electron orbit = metres) and (taking limits) his results should match existing results.
- See paper (printed hand-out… and: http://web.ihep.su/dbserv/compas/src/bohr13/eng.pdf)
- Good background / context at:
  - The Bohr Atom http://galileo.phys.virginia.edu/classes/252/Bohr_Atom/Bohr_Atom.html
  - From Bohr's Atom to Electron Waves http://galileo.phys.virginia.edu/classes/252/Bohr_to_Waves/Bohr_to_Waves.html
- Indicates how others' ideas were involved… Bohr was good, but didn't pluck ideas out of thin air, or have all the ideas e.g. wave model.