Physics 123 - April 1, 2013

- Exam 2 is This Thursday April 4 0800

  Dewey 1101

  Will Announce Q+A session soon

- Have you made out your formula sheet yet ??

- Just kidding ... This is my April 1 lecture After all. ☺
- Exam 2 – April 11 0800 Dewey 1101
  - More info forthcoming
- http://t2k-experiment.org/

Last Time

we made a mess . . .

$$\nabla^2 E = \frac{1}{v^2}\frac{\partial^2 E}{\partial t^2}$$

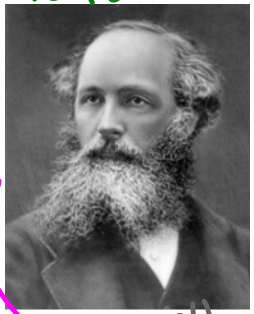
$$\nabla^2 B = \frac{1}{v^2}\frac{\partial^2 B}{\partial t^2}$$

refraction

Diffraction

Interference!

1870's

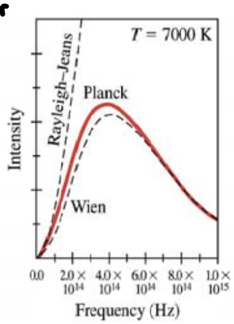


Maxwell

light ?

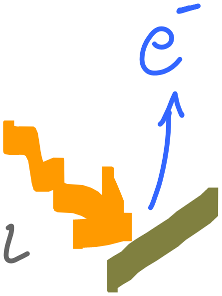
'Tis a Wave, of course

Perhaps... But E=hν

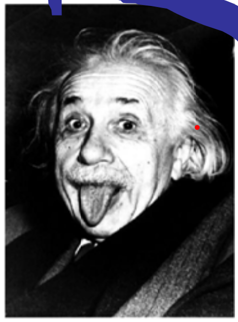


1900

Planck

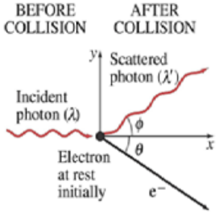


It seems E=hν. Really. Trust me, I'm having a good year



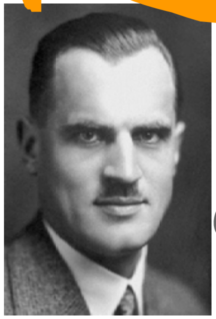
1905

Einstein



$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\phi)$$

Yeah, What he said E=hν



Compton

1923

No reason, in particular, for photons to hog the limelight.

Louis de Broglie

de Broglie's hypothesis

$\lambda = h/p$ for any particle … including ones w/ mass

Example

(let $m = 1\,\text{kg}$)

What is the de Broglie wavelength of a baseball moving at 100 mi/hour ?

$$100\ \text{mi/hr} \times \frac{1\ \text{hr}}{60\ \text{min}} \times \frac{1\ \text{min}}{60\ \text{s}} \times \frac{5280\ \text{ft}}{1\ \text{mi}} \times \frac{12\ \text{in}}{1\ \text{ft}} \times \frac{2.54\ \text{cm}}{1\ \text{in}} \times \frac{1\ \text{m}}{100\ \text{cm}} \cong 45\ \text{m/s}$$

$$\lambda = \frac{h}{p} = \frac{6.6\times10^{-34}\ \text{J}\cdot\text{s}}{1\ \text{kg}\ 45\ \text{m/s}} = 1.4\times10^{-35}\ \text{m} = 1.4\times10^{-25}\ \text{Å}$$

… rather small

Example

What is the de Broglie Wavelength of a 100 eV electron?

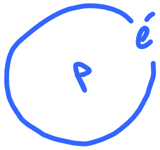
Should we worry about relativity?

$$\underbrace{100\,\text{eV} \times 1.6\times10^{-19}\,\frac{\text{J}}{\text{eV}} = \frac{1}{2}\,9.1\times10^{-31}\,\text{kg}\;V^{2}}_{\longrightarrow\; v = 5.9\times10^{6}\,\text{m/s}} \qquad Ⓐ$$

$<2\%$ of c

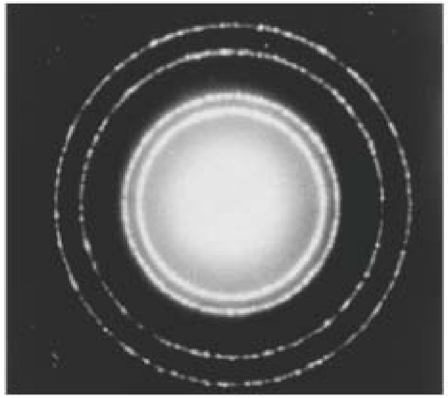
$\Rightarrow$ non relativistic

$$\lambda = \frac{h}{p} = \frac{6.6\times10^{-34}\,\text{J}\cdot\text{s}}{9.1\times10^{-31}\,\text{kg}\cdot 5.9\times10^{6}\,\text{m/s}} = 1.2\times10^{-10}\,\text{m} = 1.2\,\text{Å}$$



Bohr radius ~ .53 Å (most probable radius of ground STATE H)

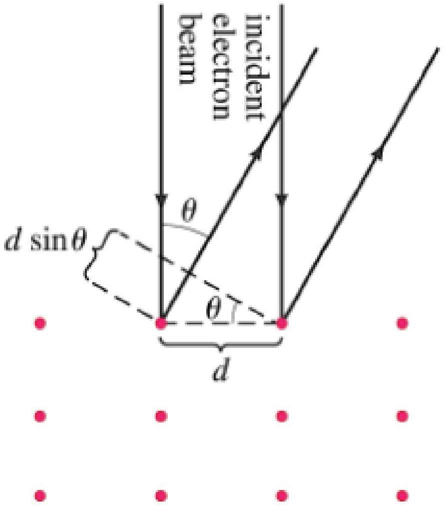
Clinton Davisson and Lester Germer
Experimental confirmation of the wavelike nature of electrons - 1927 - Bell Labs



Diffraction pattern of electrons scattered from Al foil.

George Paget Thomson
1892-1975
son of J.J. Thomson
Aberdeen Univ.
independent discovery of same phenomenon

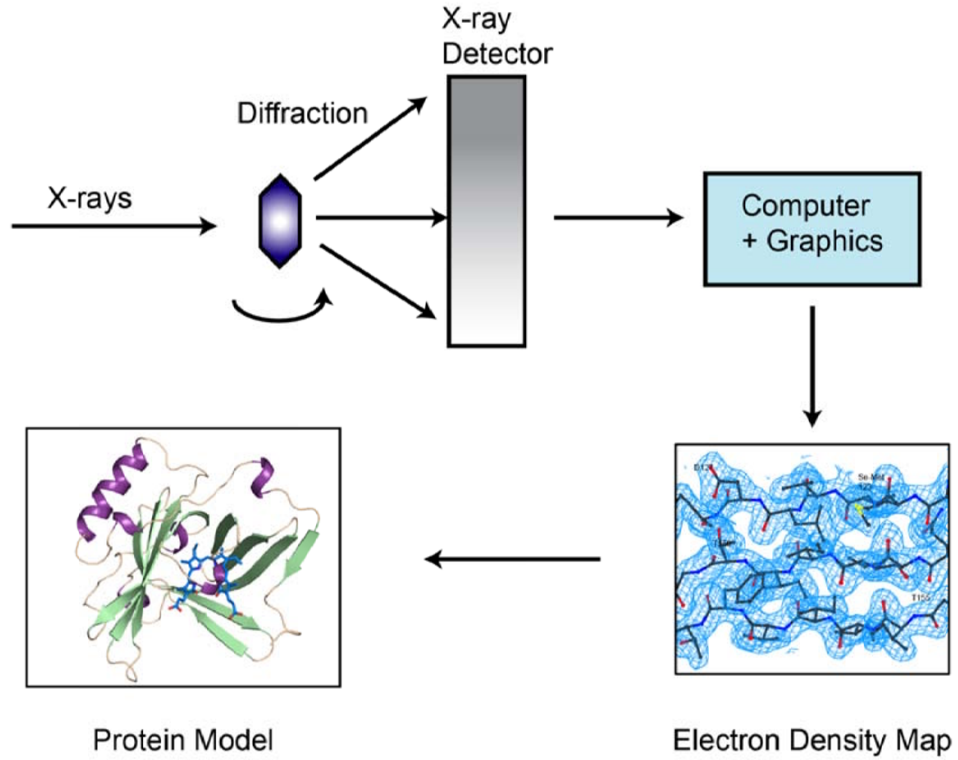
Davisson and Thomson won the Nobel Prized in Physics in 1937 "for their experimental discovery of the diffraction of electrons by crystals"



- x-ray diffraction
- x-ray crystallography
- electron diffraction
- neutron diffraction

Very important techniques for determining molecular/crystal structures in chemistry + Biology

Overview of the X-ray Crystallographic Method


X-rays

Diffraction

X-ray Detector

Computer + Graphics

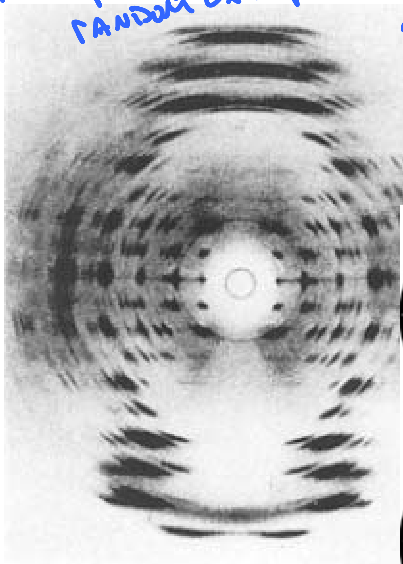
Protein Model

Electron Density Map

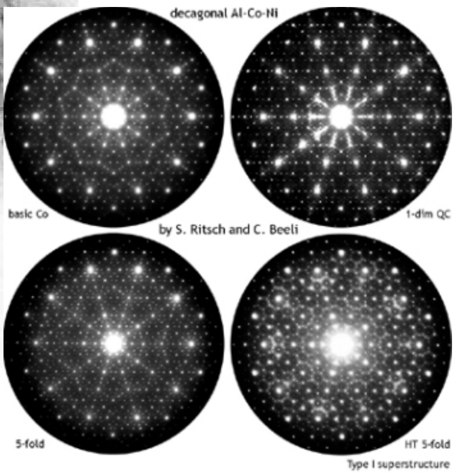
http://www.projectcrystal.org/hl-xray-crystallography.html

A couple of random examples

X-ray diffraction

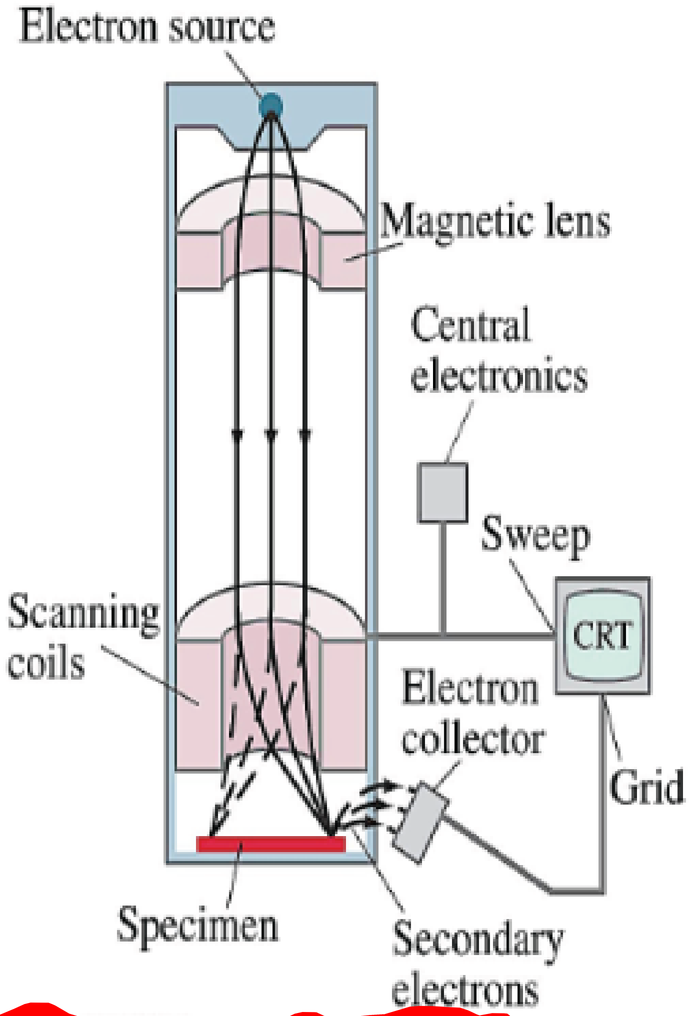


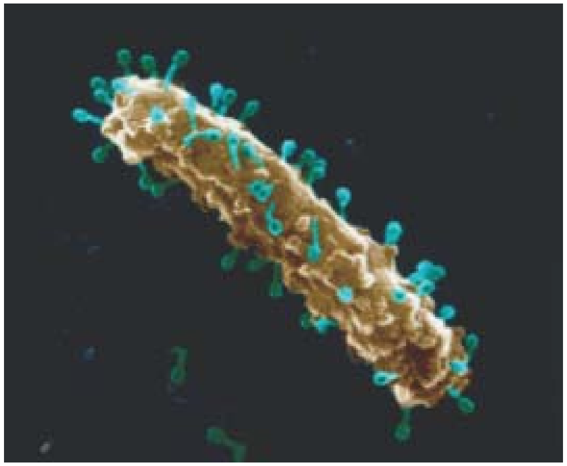
e^- diffraction



... And you thought diffraction patterns from multiple slits was a pain ...

⑨



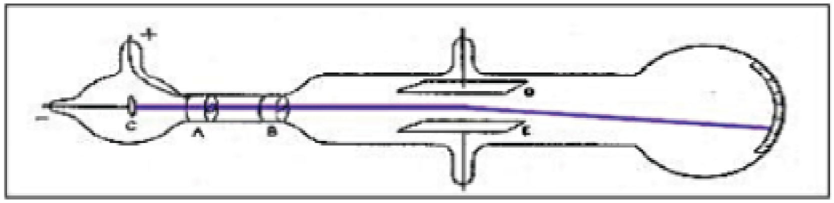


Scanning electron Microscope

resolution ~ 1 nm

end of Exam 2 material

The Atom



1897

J.J. Thomson

"corpuscles"

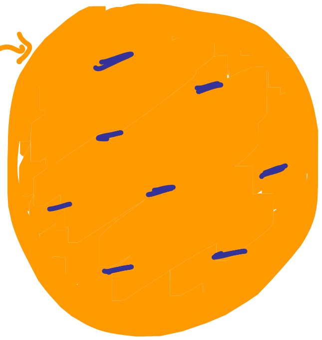
$Q/M \sim 1840 \times H^+$

1894 George Stoney coined "electron" as the fundamental quantity of electricity

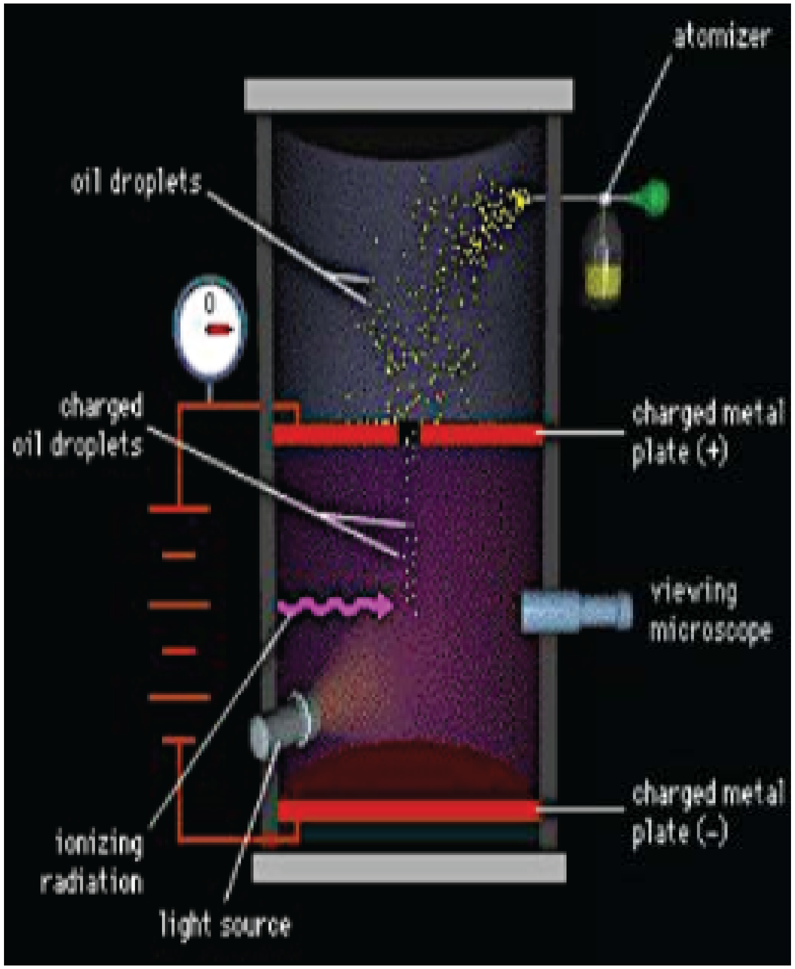
Nobel Prize in 1906

7 of his research Assistants won Nobel Prizes

Son won Nobel Prize in 1937 (see p. 6)

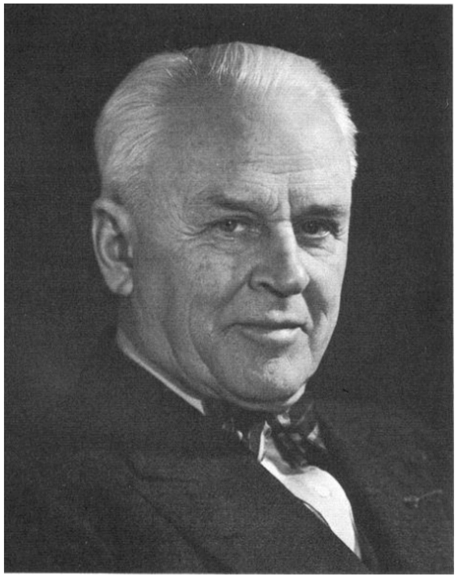


plum pudding Model of the atom



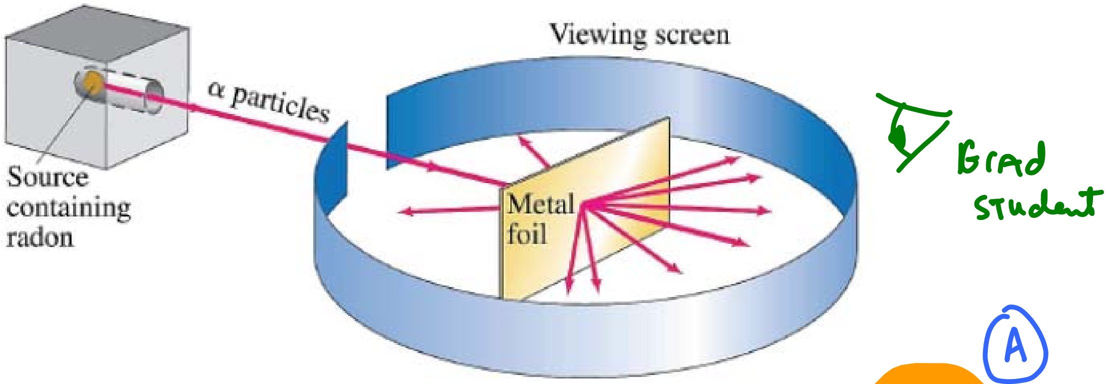
1913
Robert
Millikan

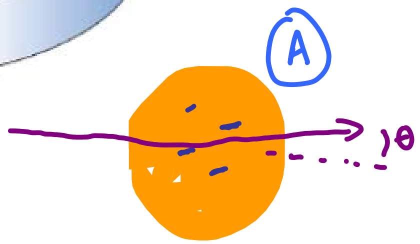
Measured
the
Fundamental
charge of
the electron

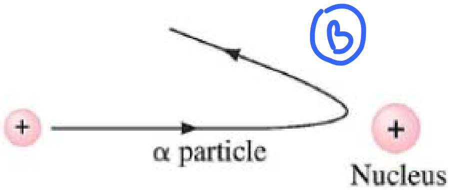


1923
Nobel Prize

Ernest Rutherford
1908 Nobel Prize in Chemistry







1909 w/ Geiger + Marsden
1911 Nuclear Model of Atom

A fellow named Niels Bohr
was visiting Rutherford's lab as a Post doc in 1911

Bohr model of the Atom

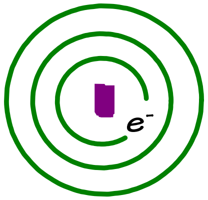
Niels Bohr
1885-1962
Denmark

1922 Nobel Prize in physics
"for his services in the investigation ofthbe structure of atoms and the radiation emanating from them"

~1912, 1913
(before deBroglie)

Atomic (planetary) model with fixed orbits

nicely motivated by de Broglie's matter waves in 1924

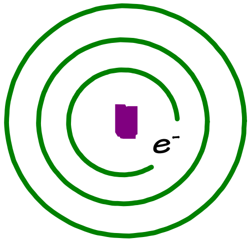


Bohr model of the atom

- Positive Nucleus
- electrons orbit in circles, Proton too heavy to Move
- only particular "discrete" orbits allowed

↑ known as quantization

- electric (coulomb) Force holds electron on Circle as it orbits

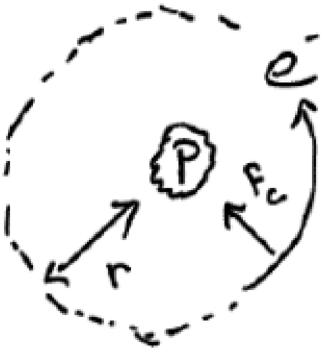


Important pre-quantum mechanics Model of Atom

Bohr Atom

1913 ↳ impt for giving us intuition about Atoms

Assume e^- orbits proton in a circular orbit



$$F_{cent} = \frac{m_e v^2}{r}$$

$\frac{kZe^2}{r^2}$ if single e^- atom w/ atomic # Z

$$\underbrace{\frac{k|e|^2}{r^2}}_{\text{Coulomb attraction between p and } e^-} = \underbrace{\frac{m_e v^2}{r}}_{\text{Centripetal force}}$$

Equation I

Since e^- is a wave

imagine e^- as a Circular STANDing wave

only works for certain λ that satisfy

Ⓐ $2\pi r = n\lambda$ $n = 1, 2, 3 \ldots$

From DeBroglie

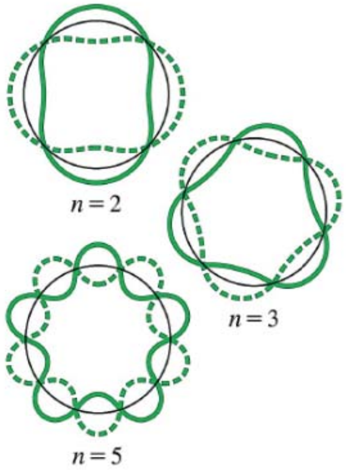
Ⓑ $2\pi r = n\frac{h}{p}$

This is where Things become discrete or quantized

Ⓒ $\hbar = \frac{h}{2\pi}$ = called h-bar

Bohr's work was pre-DeBroglie

Put in quantization to get discrete spectra



Ⓓ So, $pr = n\hbar$

Ⓔ $mvr = n\hbar$ same as $L = n\hbar$

Angular Momentum

So can also say Bohr quantized Angular Momentum

Eqn 2 $v = \frac{n\hbar}{mr}$ Substitute into Equation 1 Above (p. 15)

From eqn on p15 → $\frac{k|e|^2}{r^2} = \frac{mv^2}{r} \longrightarrow$ Ⓐ $\frac{ke^2}{r^2} = \frac{m n^2 \hbar^2}{r\, m^2 r^2}$ Solve for r

Ⓑ $r_n = \frac{n^2 \hbar^2}{ke^2 m}$ $n = 1, 2, 3 \ldots$

Says that electron only exists at discrete radii

If done for single e^- atom of atomic # Z in initial eqns

$$\frac{ke^2}{r^2} \longrightarrow \frac{kZee}{r^2}$$

Ⓒ $\boxed{r_n = \frac{n^2 \hbar^2}{kZe^2 m}}$ good for single e^- atom w/ At. # Z

r_1 = Ground state orbital radius

Ⓓ $\boxed{r_n = \frac{n^2}{Z} r_1}$

Ⓐ $$K.E. = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{n\hbar}{mr}\right)^2 = \frac{n^2\hbar^2}{2mr^2}$$

From Eqn 2

Substitute in for r (from p.17)

Ⓑ $$K.E. = \frac{n^2\hbar^2}{2m}\,\frac{k^2z^2e^4m^2}{n^4\hbar^4} = \frac{mk^2z^2e^4}{2n^2\hbar^2}$$

Ⓒ $$E_{TOTAL} = KE + PE$$

What is P.E.? recall $\text{Potential} = \frac{\text{work}}{\text{chg}}$

$$P.E. = -\frac{kze^2}{r}$$

"−" because ATTRACTIVE

Ⓓ

Sub in for r $$P.E. = -kze^2\,\frac{kze^2m}{n^2\hbar^2} = -\frac{k^2z^2e^4m}{n^2\hbar^2}$$

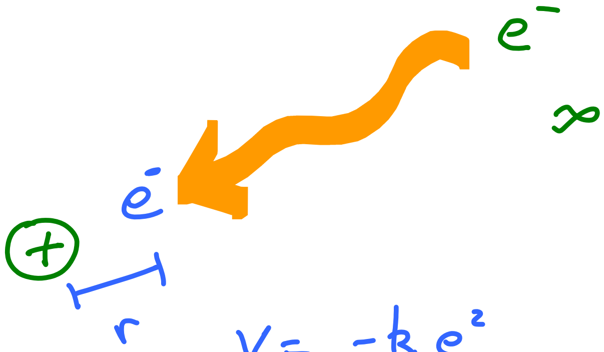
$$E_{\text{TOTal}} = KE + PE = \frac{1}{2}\frac{mk^2z^2e^4}{n^2h^2} - \frac{mk^2z^2e^4}{n^2h^2}$$

Ⓐ

Ⓑ

$$\boxed{E_{n_{\text{TOTal}}} = -\frac{mk^2z^2e^4}{2n^2h^2}}$$

What does it mean that this Energy is negative?



$$V = -\frac{k e^2}{r}$$

what does this - sign mean

- "–" energy means bound STATE
- Must put energy into the system to free the e^-
  "ionize" the atom

For $Z=1$ (H)

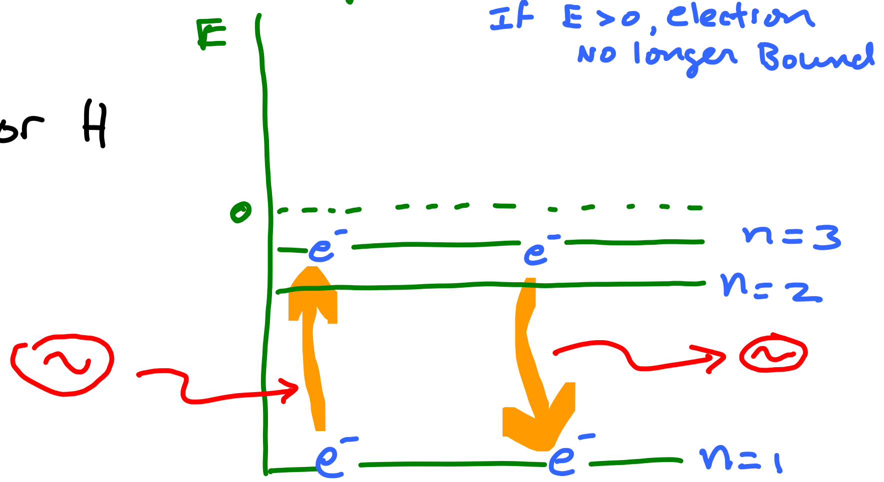
$n=1$ corresponds to the most tightly bound Energy level for H

Worth remembering … sets the scale for atomic and chemical processes

$$\boxed{E_1 = -13.6\,\text{eV}}$$

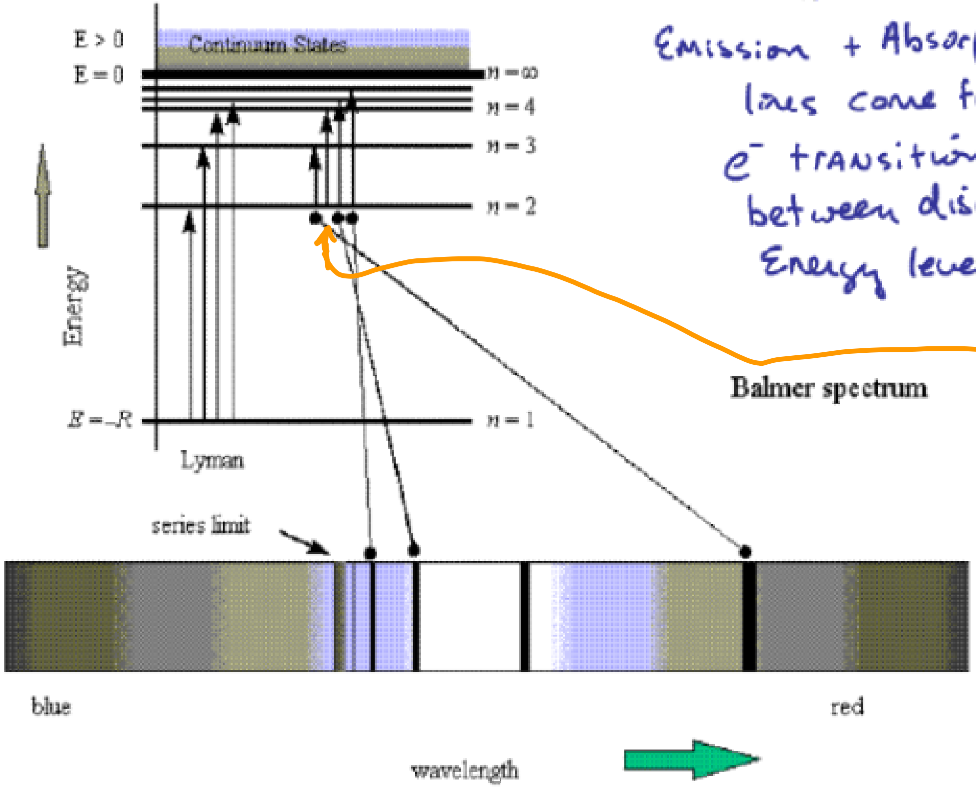
$$E_n = \frac{Z^2}{n^2} E_1$$

Energy level diagram



photons emitted or absorbed as e^- shifts levels $E_\gamma = h\nu$

Ⓐ



Discrete Atom

Emission + Absorption lines come from e^- transitions between discrete Energy levels

Figure from http://www.uclan.ac.uk/facs/science/physastr/x99/PAM98/UCert/Ch06/6_6ato~1.htm

Ⓑ

For Z=1 → Hydrogen

What is the frequency of the absorption line corresponding to a transition between n= 2 and n=4 ?

$$\Delta E = E_\gamma = \frac{1}{16} E_1 - \frac{1}{4} E_1$$

$$E_\gamma = -\frac{13.6}{16} - \frac{-13.6}{4}$$

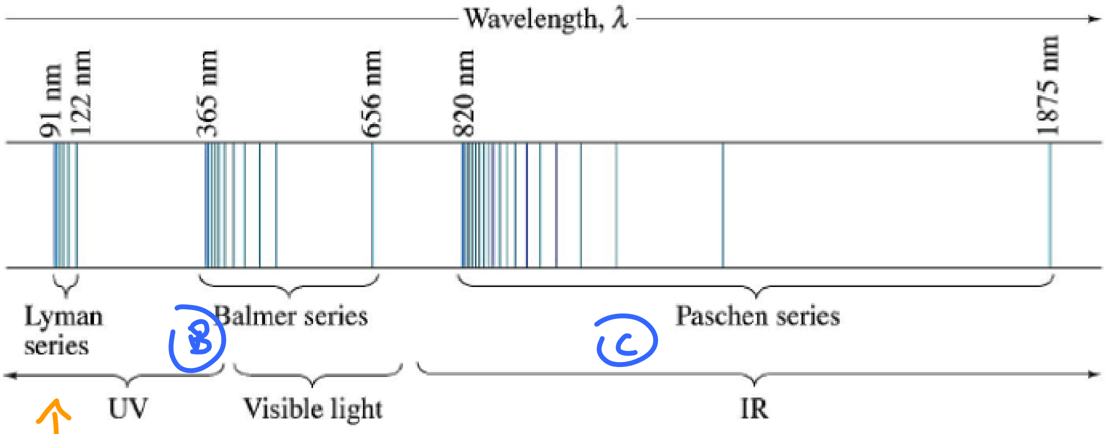
$$E_\gamma = -0,85 + 3.4 = 2,55 \text{ eV}$$

$$\nu = E_\gamma / h = \frac{2.55 \text{ eV}}{4.13 \times 10^{-15} \text{ eV}\cdot\text{s}}$$

$$\nu = 6.2 \times 10^{14} \text{ s}^{-1} \rightarrow 4.8 \times 10^{-7} \text{ m}$$

480 nm ~ Blue-green

For hydrogen



A

B

C

Transitions to n=1

Transitions to n=2

Transitions to n=3

D

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right) \qquad n = 2,3,4,5\ldots$$

E

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \qquad n = 3,4,5\ldots$$

F

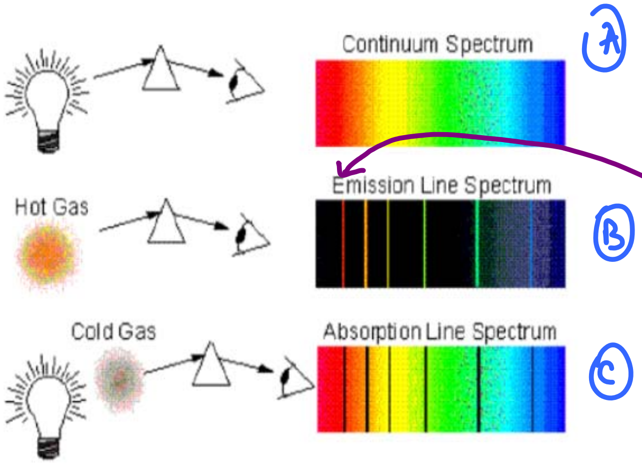
$$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right) \qquad n = 4,5\ldots$$

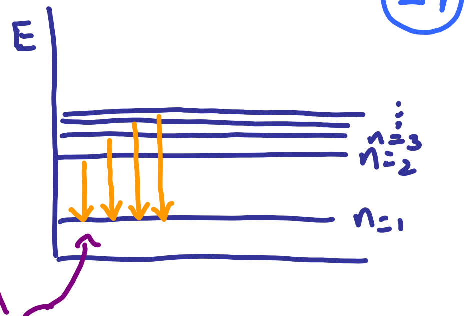
G

$$\frac{E_1}{hc} = \frac{13.6}{(4.3\times10^{-15})(3\times10^{8})}$$

$R = 1.0974\times10^{7}\ \text{m}^{-1}$ ... called the Rydberg constant

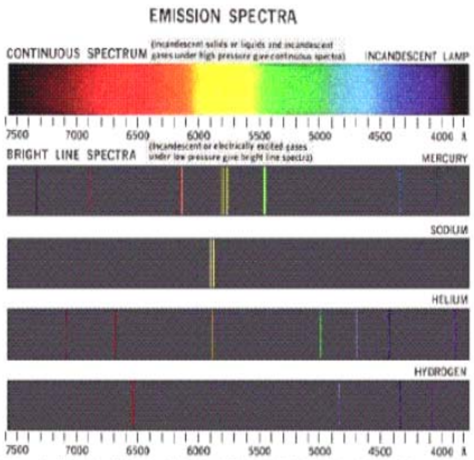
Emission vs. Absorption





Each discrete jump corresponds to particular energy (frequency) photon ... particular line in the emission spectrum

Different Atoms → different discrete frequency pattern



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Atomic Fingerprinting