Physics 2D Lecture Slides
Nov 3

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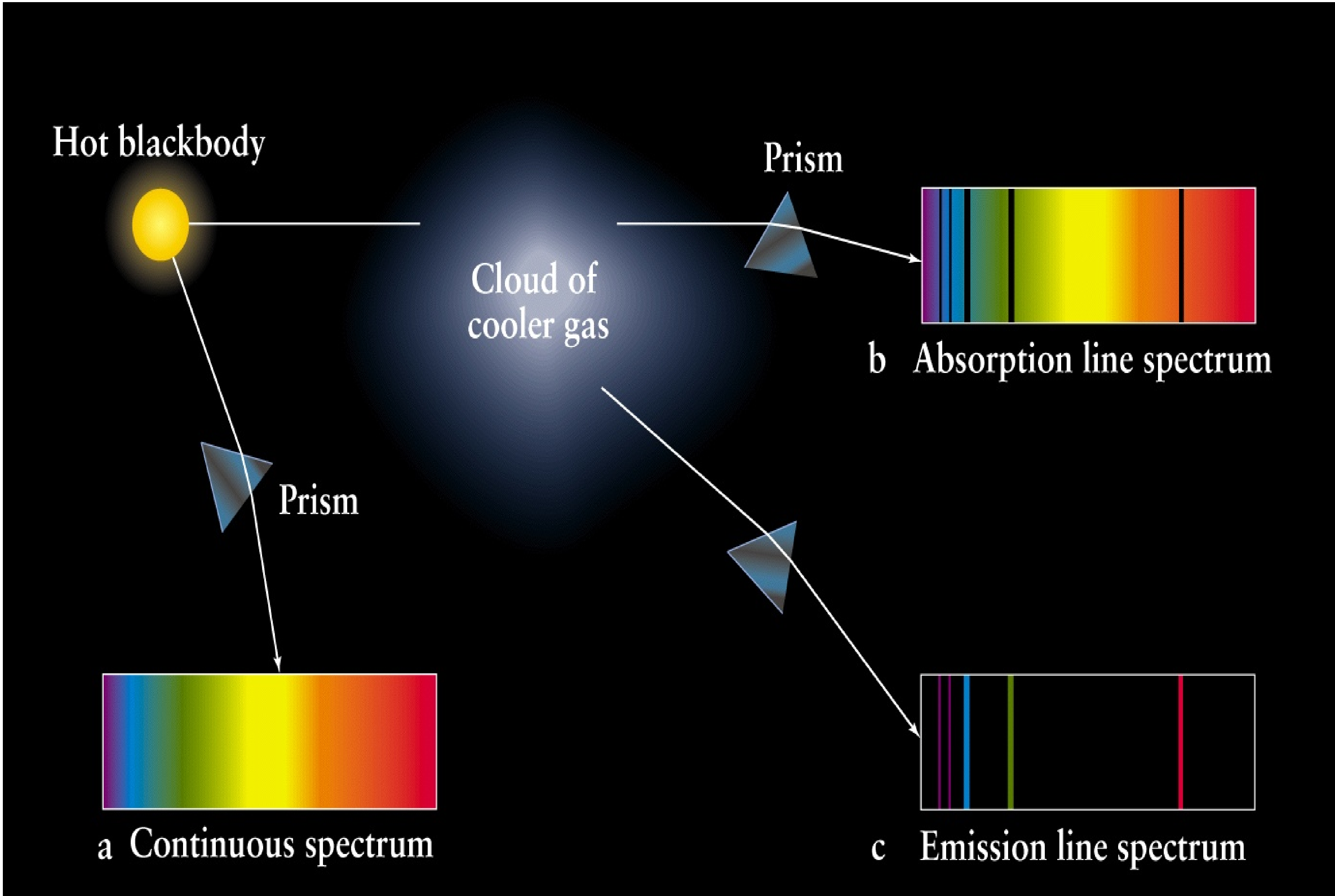
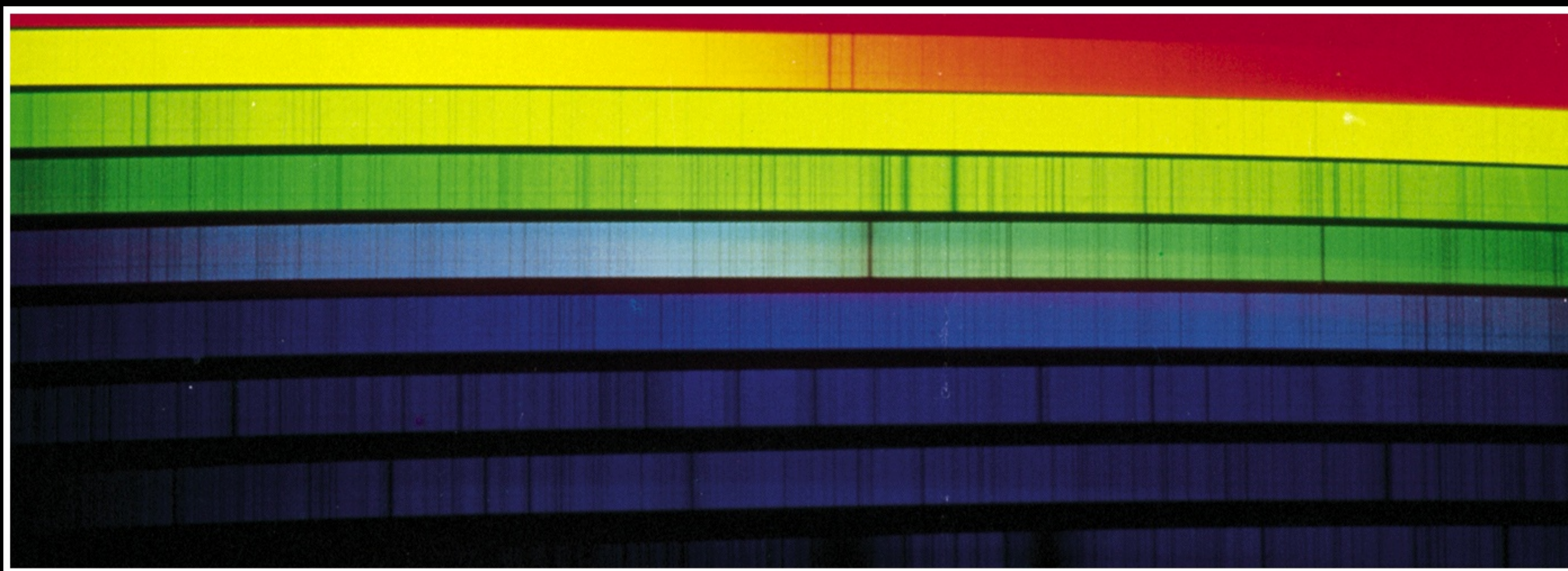
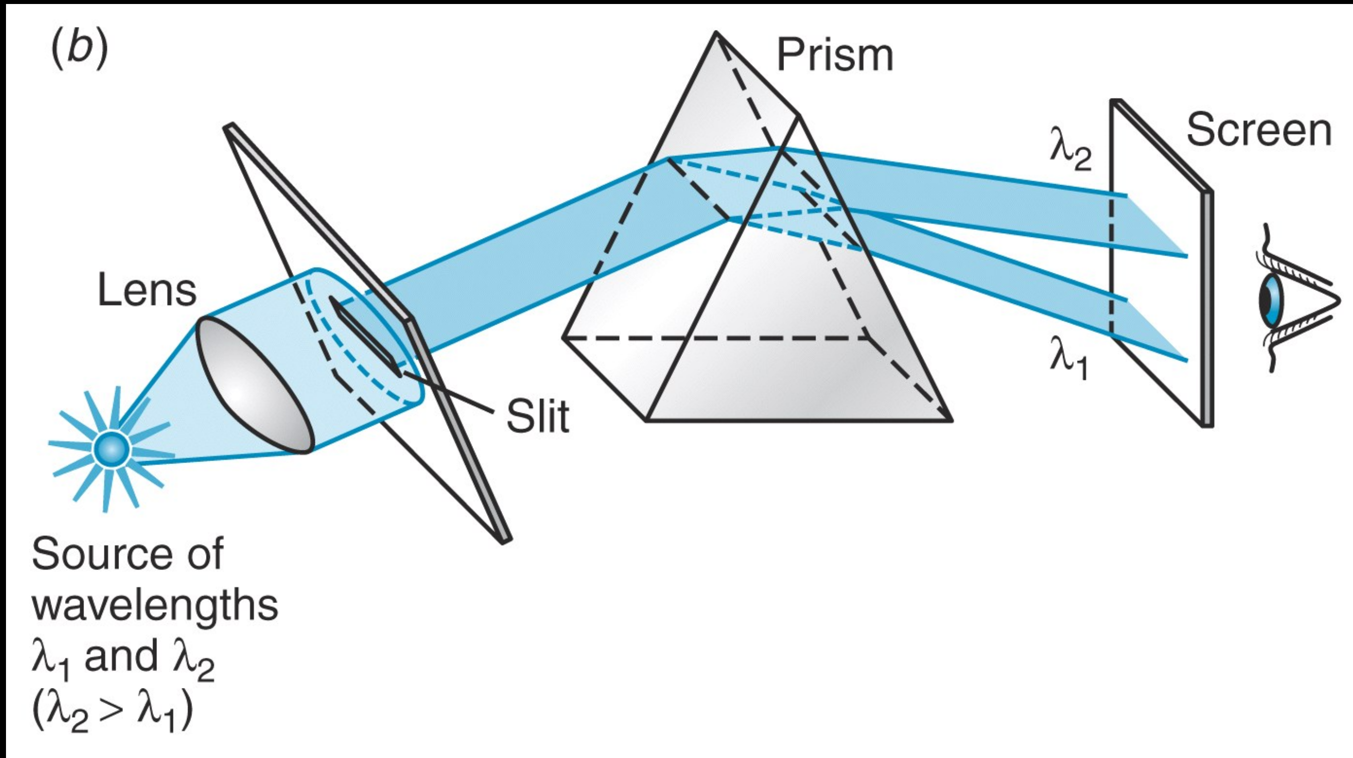
Continuous & discrete spectra of Elements

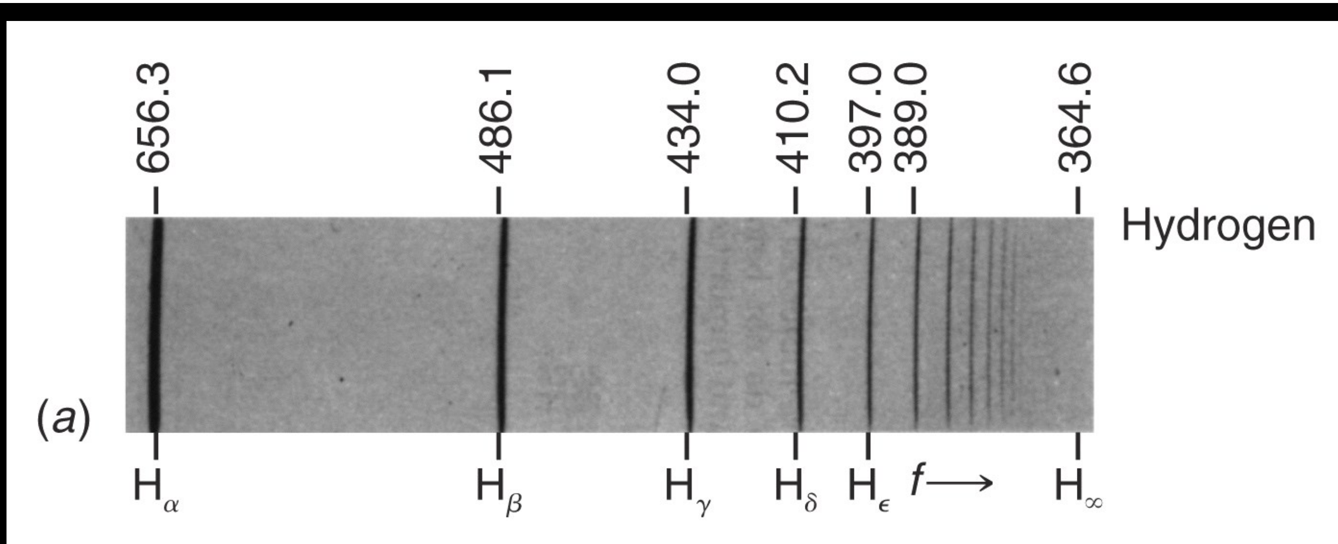


Visible Spectrum of Sun Through a Prism

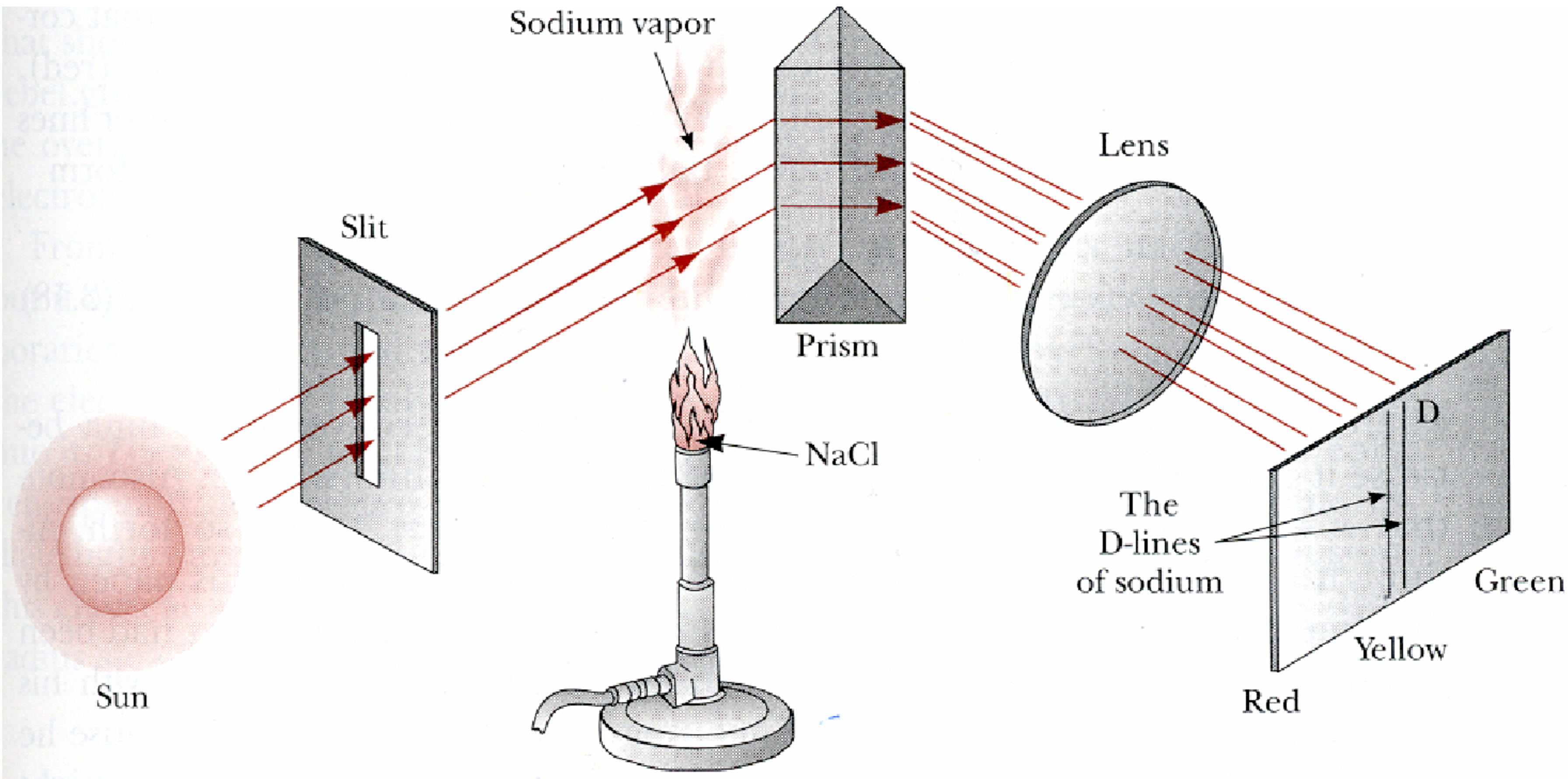


Emission & Absorption Line Spectra of Elements



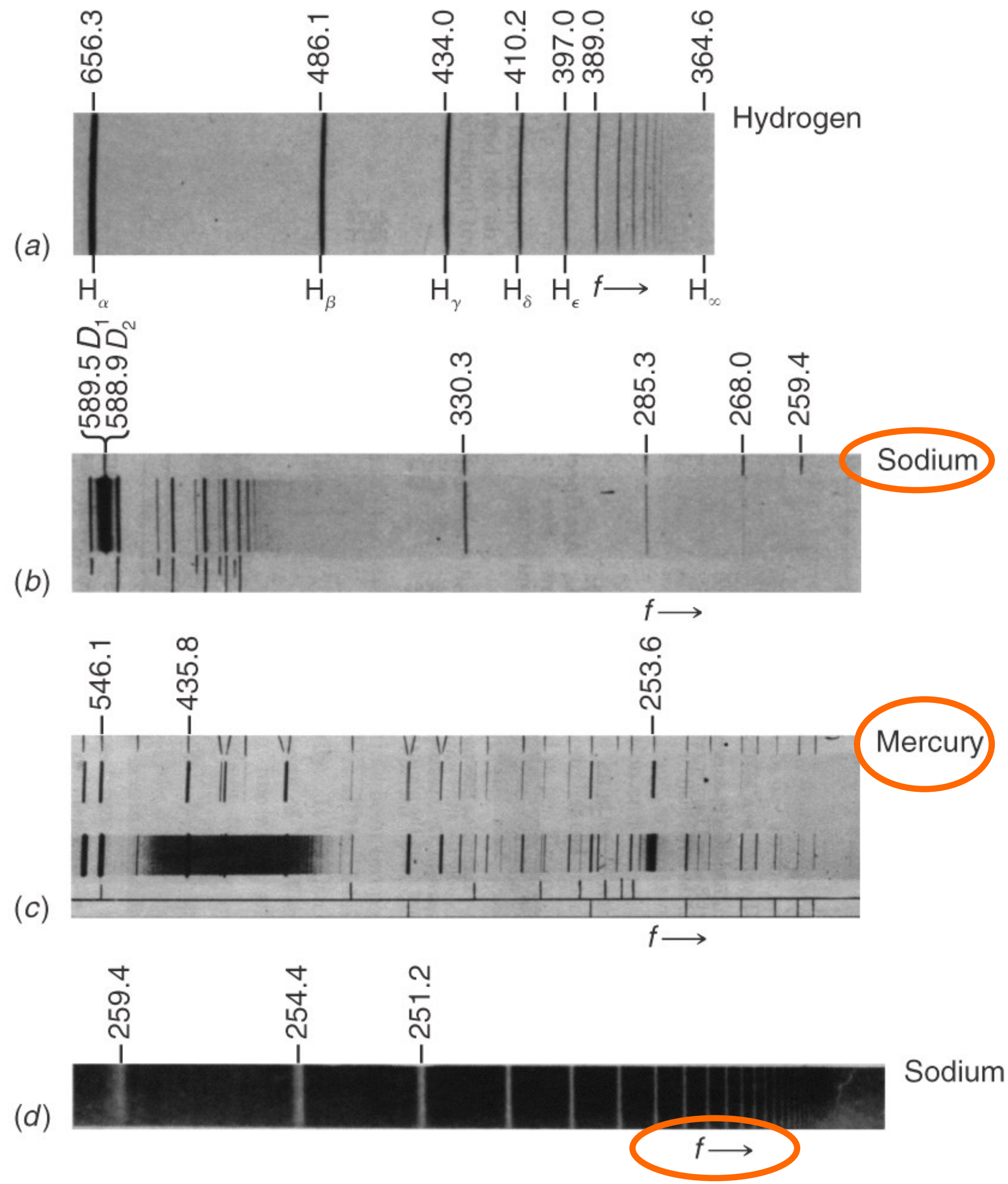


Kirchhoff' Experiment : "D" Lines in Na



D lines darken noticeably when Sodium vapor introduced
Between slit and prism

Emission & Absorption Line Spectrum of Elements

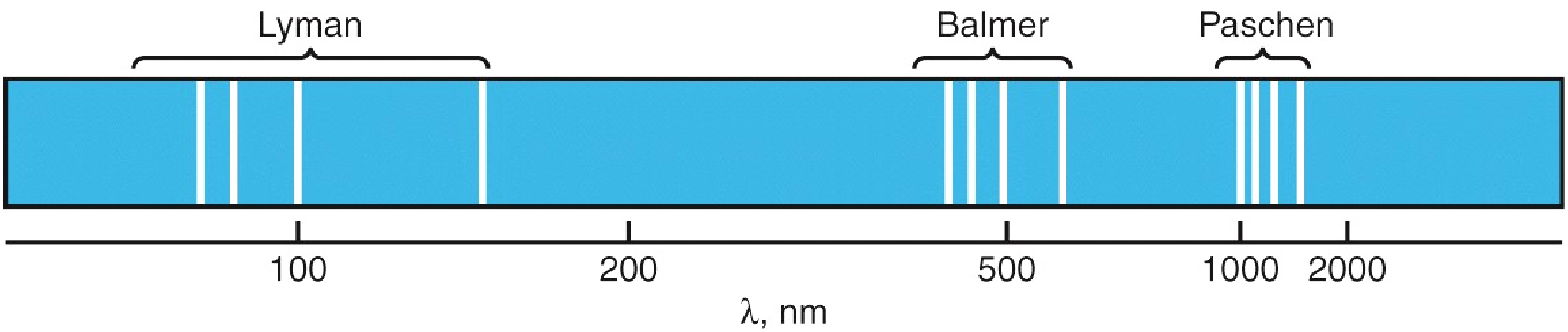


- Emission line appear dark because of photographic exposure

Absorption spectrum of Na

While light passed thru Na vapor is absorbed at specific λ

Spectral Observations : series of lines with a pattern



- Empirical observation (by trial & error)
- All these series can be summarized in a simple formula

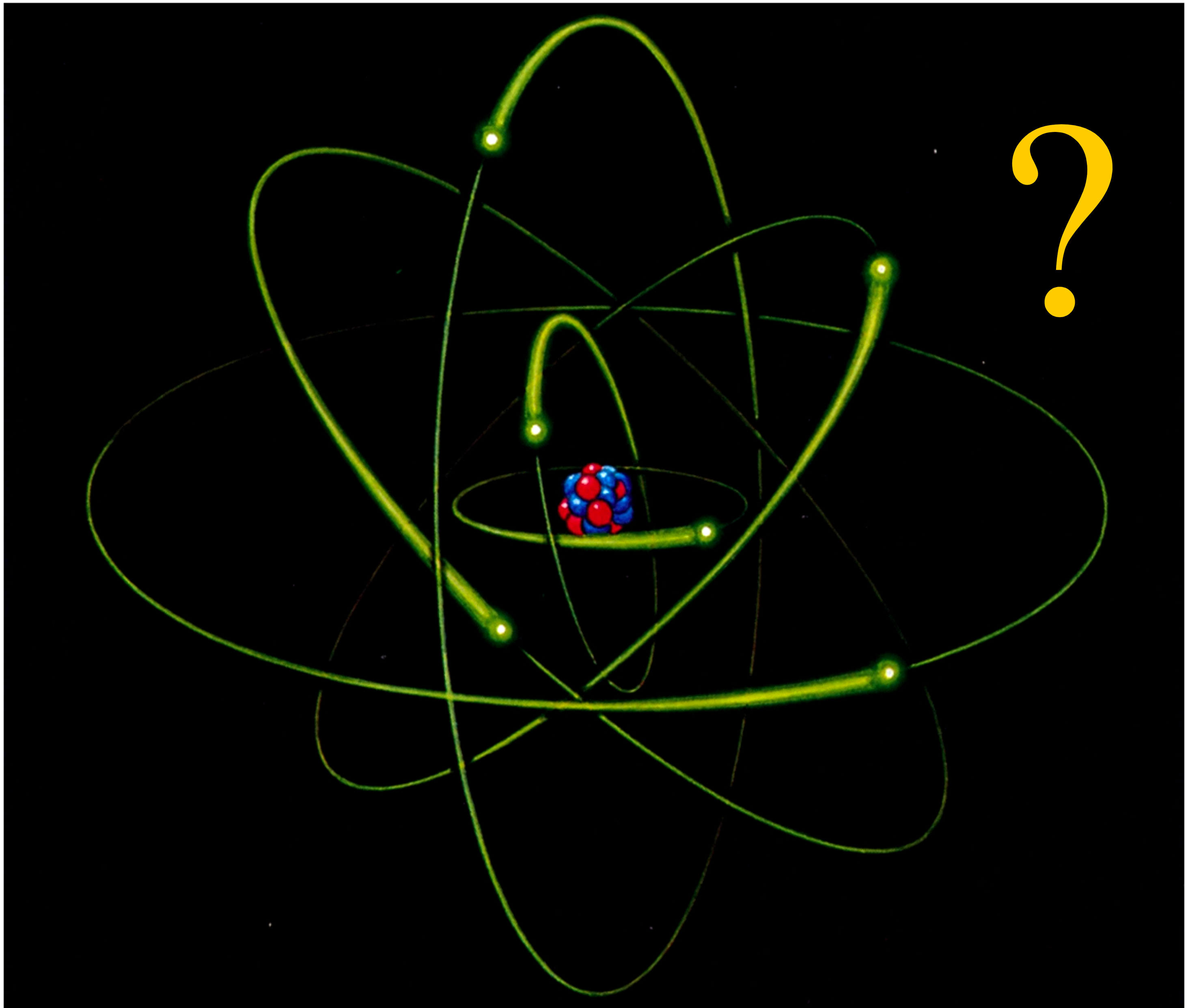
$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right), n_f > n_i, n_i = 1, 2, 3, 4..$$

Fitting to spectral line series data

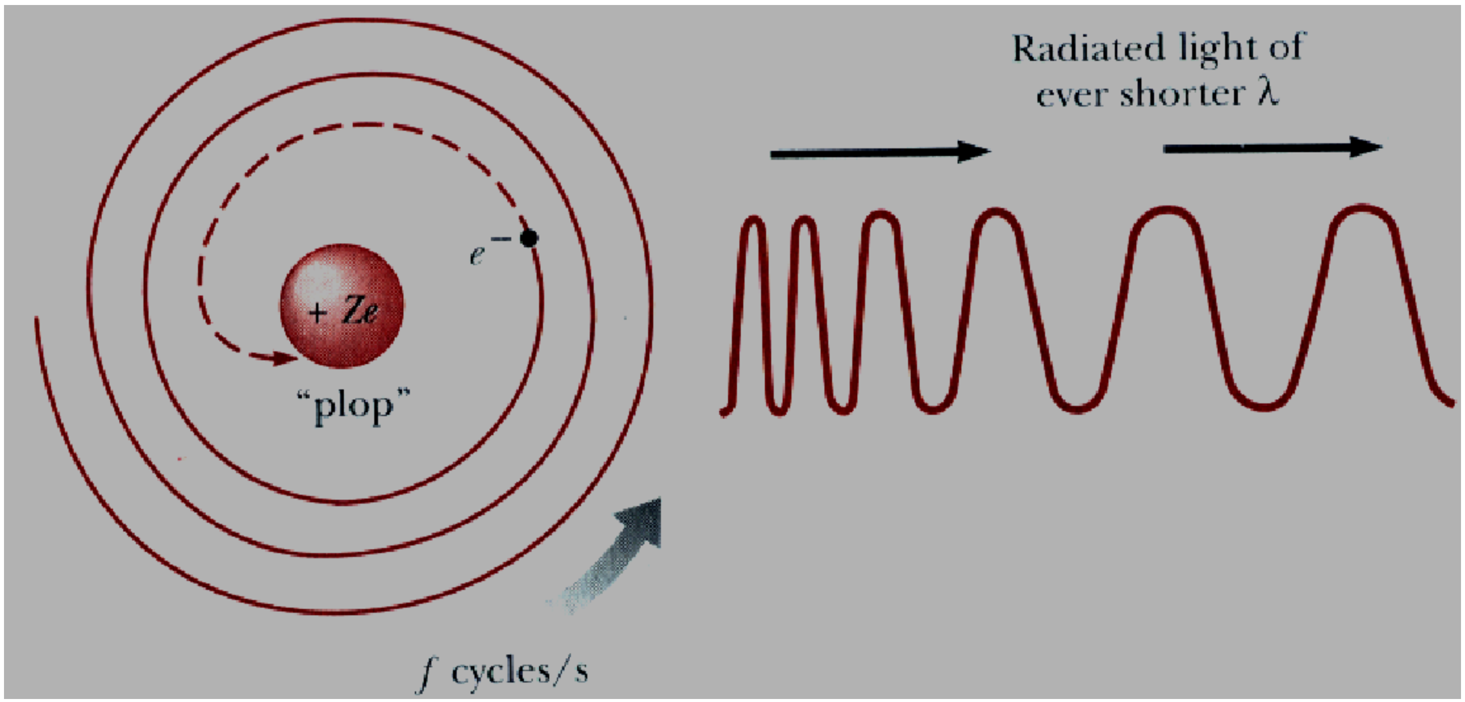
$$R = 1.09737 \times 10^7 m^{-1}$$

How does one explain this ?

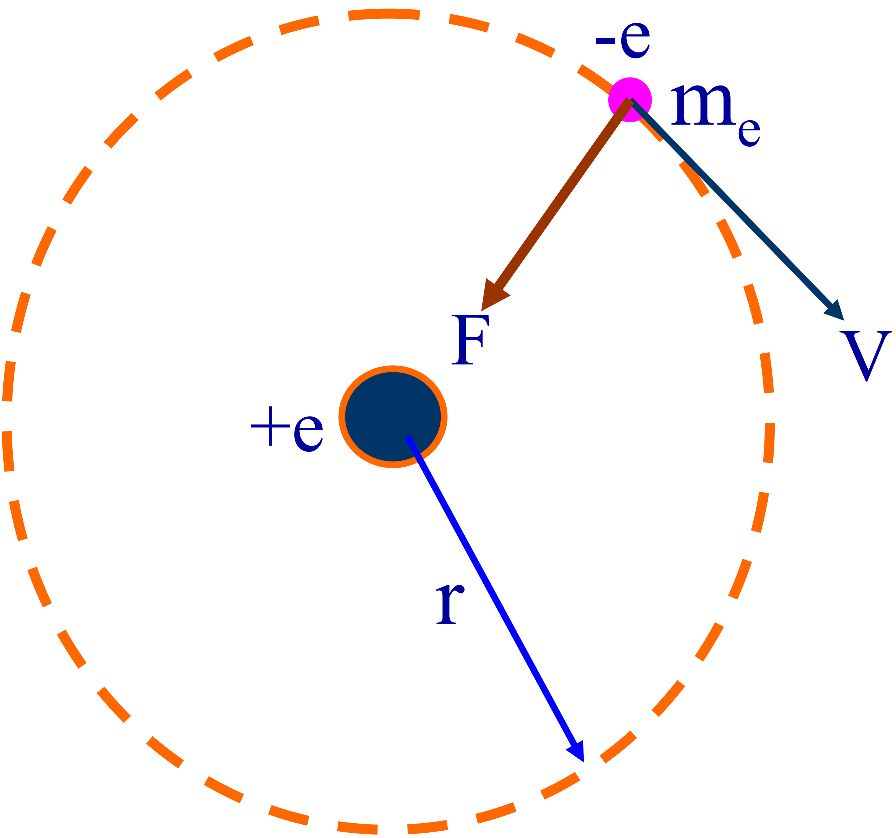
Rutherford Atom & Classical Physics



Atom: The Classical disaster



Bohr's Bold Model of Atom: Semi Quantum/Classical

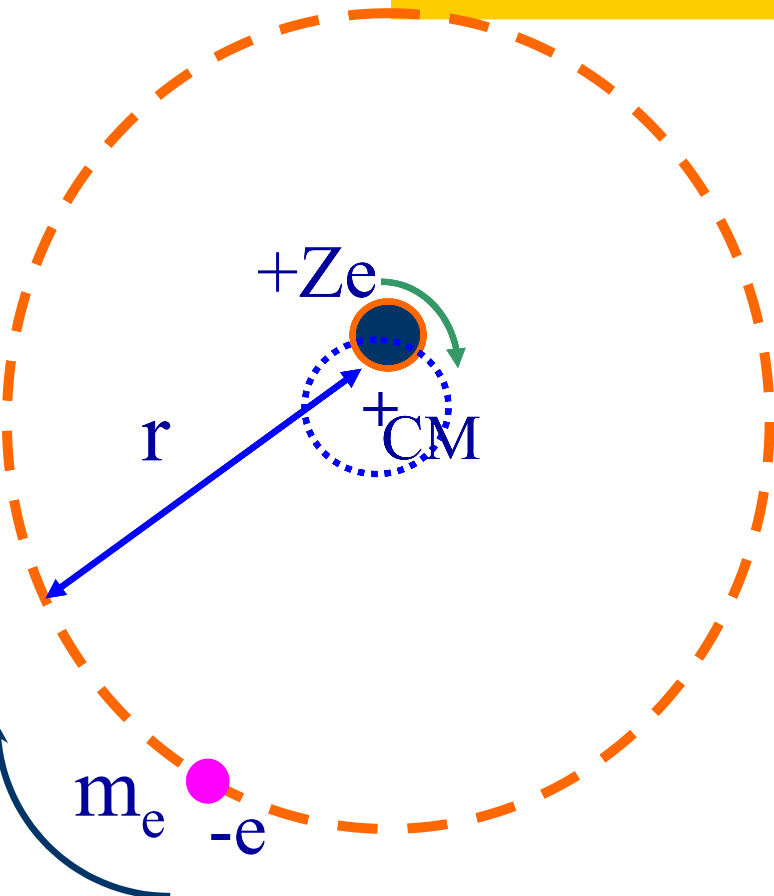


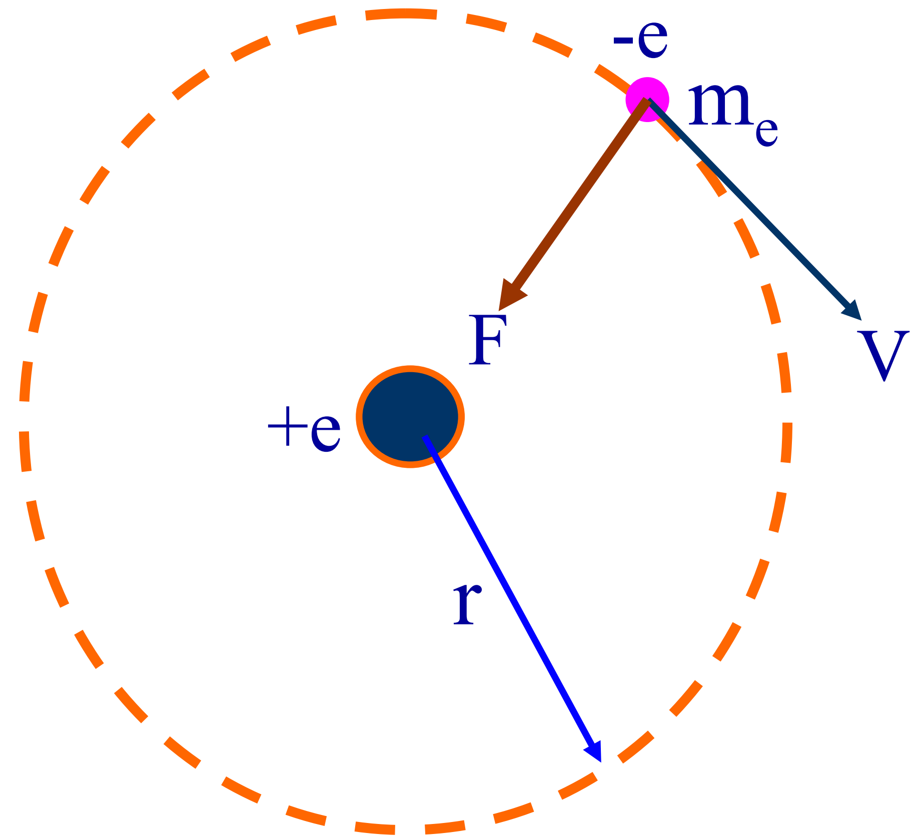
$$U(r) = -k\frac{e^2}{r}$$

$$KE = \frac{1}{2} m_e v^2$$

1. Electron in circular orbit around proton with vel=v
2. Only stationary orbits allowed . Electron does not radiate when in these stable (stationary) orbits
3. Orbits quantized:
   - $M_e v\, r = n\, h/2\pi$ (n=1,2,3…)
4. Radiation emitted when electron "jumps" from a stable orbit of higher energy → stable orbit of lower energy $E_f - E_i = hf = hc/\lambda$
5. Energy change quantized
   - f = frequency of radiation

Reduced Mass of 2-body system





- Both Nucleus & e^- revolve around their common center of mass (CM)
- Such a system is equivalent to single particle of "reduced mass" μ that revolves around position of Nucleus at a distance of (e^- -N) separation
  - $\mu = (m_e M)/(m_e + M)$, when $M >> m$, $\mu = m$ (Hydrogen atom)
  - Not so when calculating Muon ($m_\mu = 207\ m_e$) or equal mass charges rotating around each other (similar to what you saw in gravitation)

Allowed Energy Levels & Orbit Radii in Bohr Model

$$\text{E=KE+U} = \frac{1}{2} m_e v^2 - k\frac{e^2}{r}$$

Force Equality for Stable Orbit

$\Rightarrow$ Coulomb attraction = CP Force

$$k\frac{e^2}{r^2} = \frac{m_e v^2}{r}$$

$$\Rightarrow KE = \frac{m_e v^2}{2} = k\frac{e^2}{2r}$$

Total Energy $\boxed{\text{E} = \text{KE+U} = -k\frac{e^2}{2r}}$

Negative E $\Rightarrow$ Bound system

This much energy must be added to the system to break up the bound atom

Radius of Electron Orbit :

$$mvr = n\hbar$$

$$\Rightarrow v = \frac{n\hbar}{mr},$$

substitute in $\text{KE} = \frac{1}{2} m_e v^2 = \frac{ke^2}{2r}$

$$\Rightarrow r_n = \frac{n^2\hbar^2}{mke^2},\ n = 1, 2, \ldots \infty$$

$n = 1 \Rightarrow$ Bohr Radius a_0

$$a_0 = \frac{1^2\hbar^2}{mke^2} = 0.529\times 10^{-10}\,m$$

In general $r_n = n^2 a_0; n = 1, 2, \ldots \infty$

Quantized orbits of rotation

Energy Level Diagram and Atomic Transitions

$$E_n = K + U = \frac{-ke^2}{2r}$$

since $r_n = a_0 n^2$, n = quantum number

$$E_n = \frac{-ke^2}{2a_0 n^2} = -\frac{13.6}{n^2} eV, \quad n = 1, 2, 3..\infty$$

Interstate transition: $n_i \rightarrow n_f$

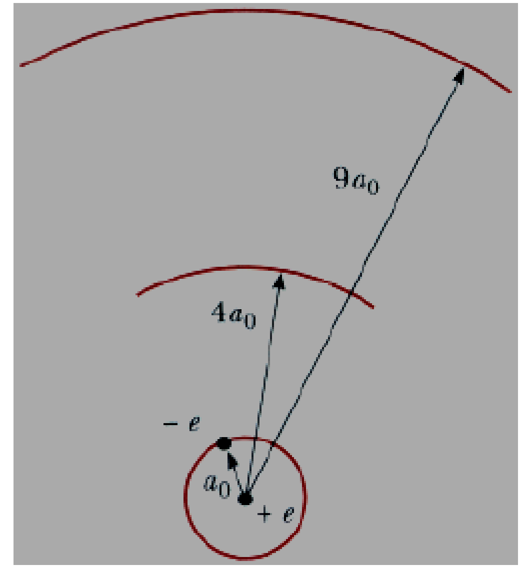
$$\Delta E = hf = E_i - E_f$$

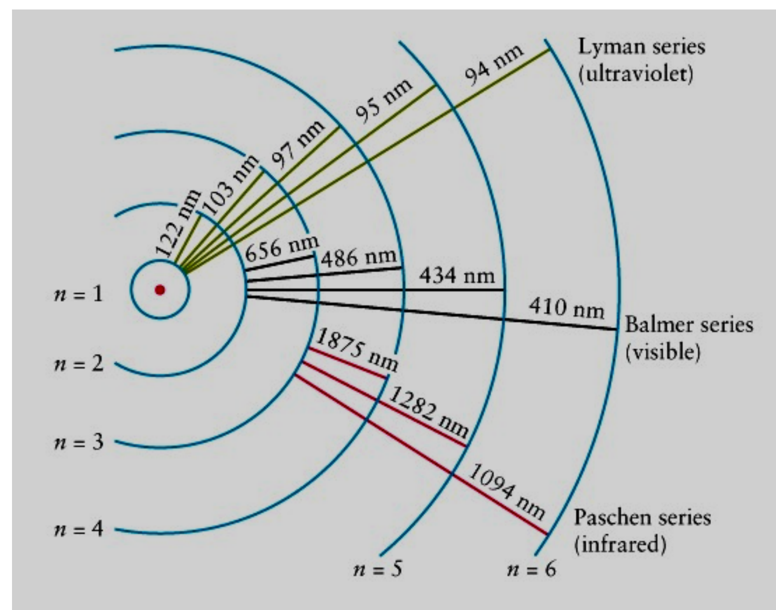
$$= \frac{-ke^2}{2a_0}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$$

$$f = \frac{ke^2}{2ha_0}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

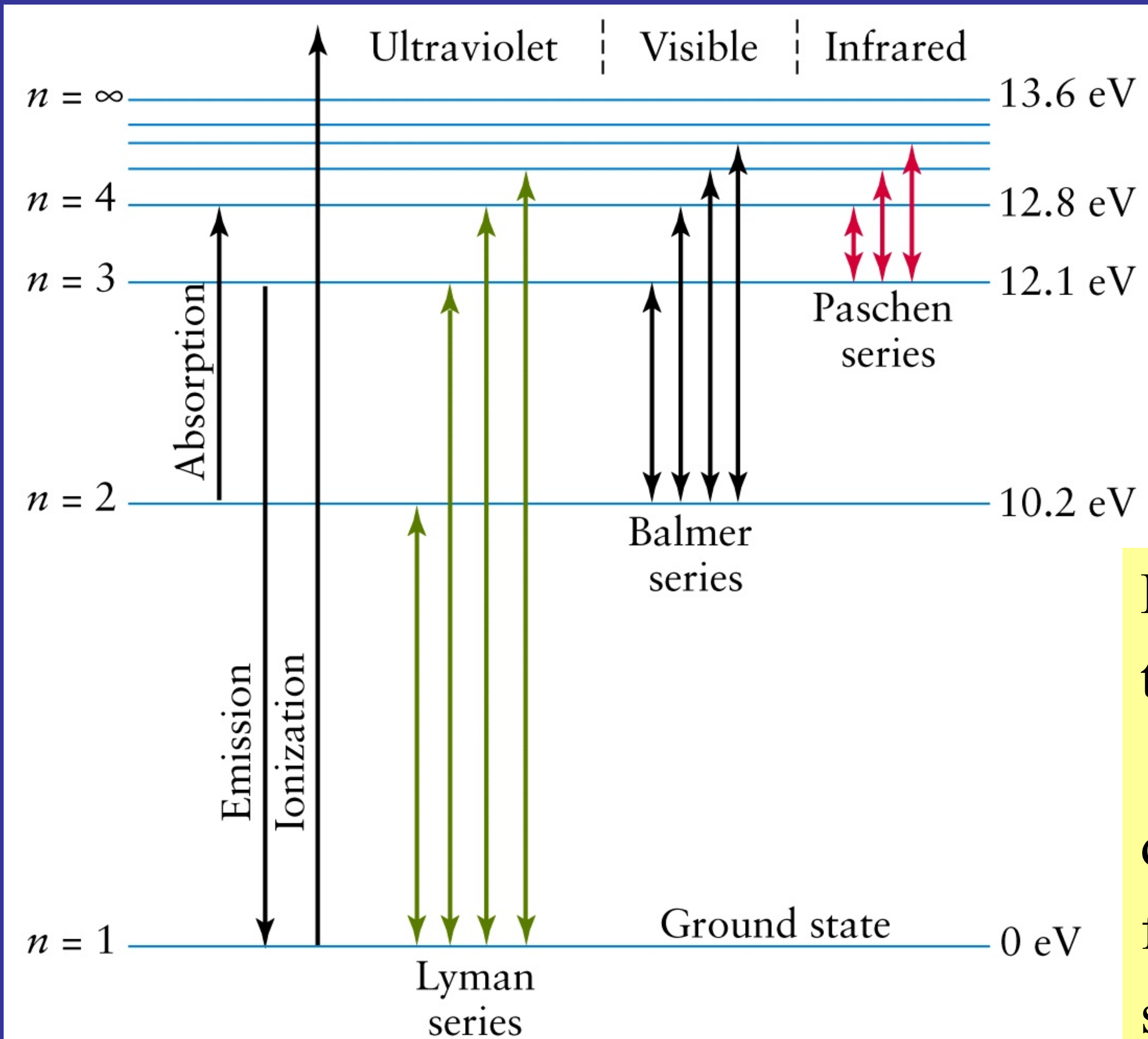
$$\frac{1}{\lambda} = \frac{f}{c} = \frac{ke^2}{2hca_0}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$= R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$





Hydrogen Spectrum: as explained by Bohr



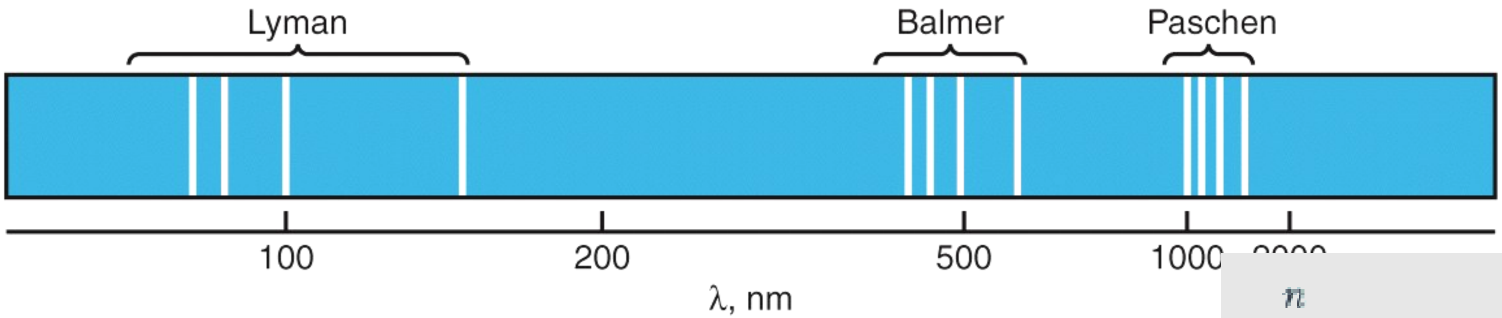
$$E_n = -\left(\frac{ke^2}{2a_0}\right)\frac{Z^2}{n^2}$$

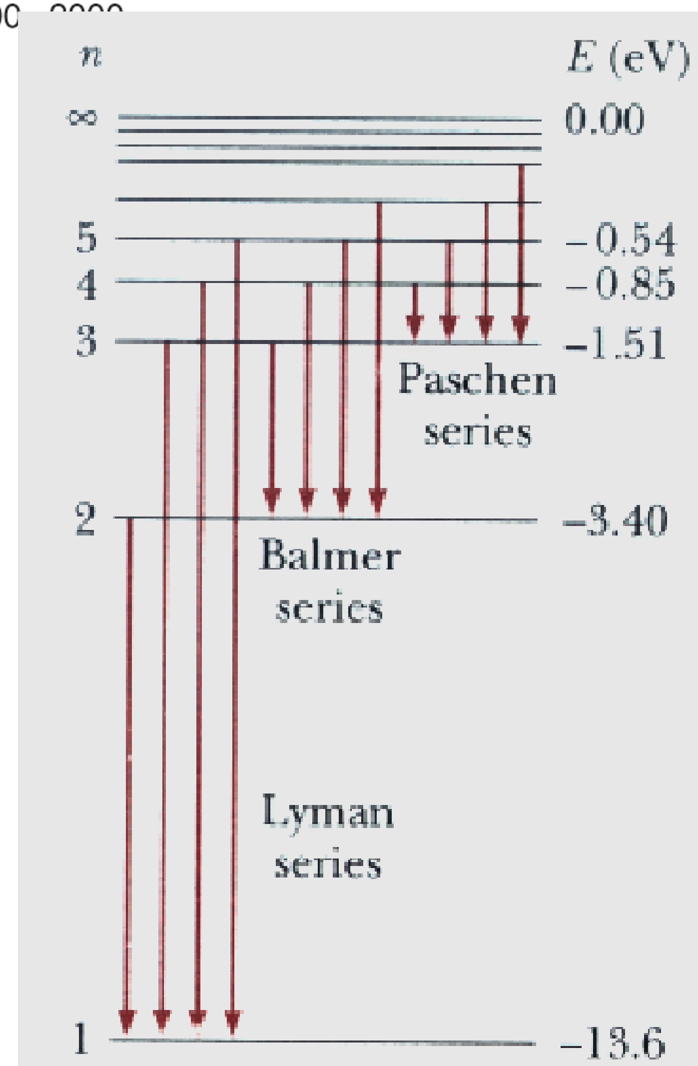
Bohr's "R" same as the Rydberg Constant

R

derived emperically from photographs of the spectral series

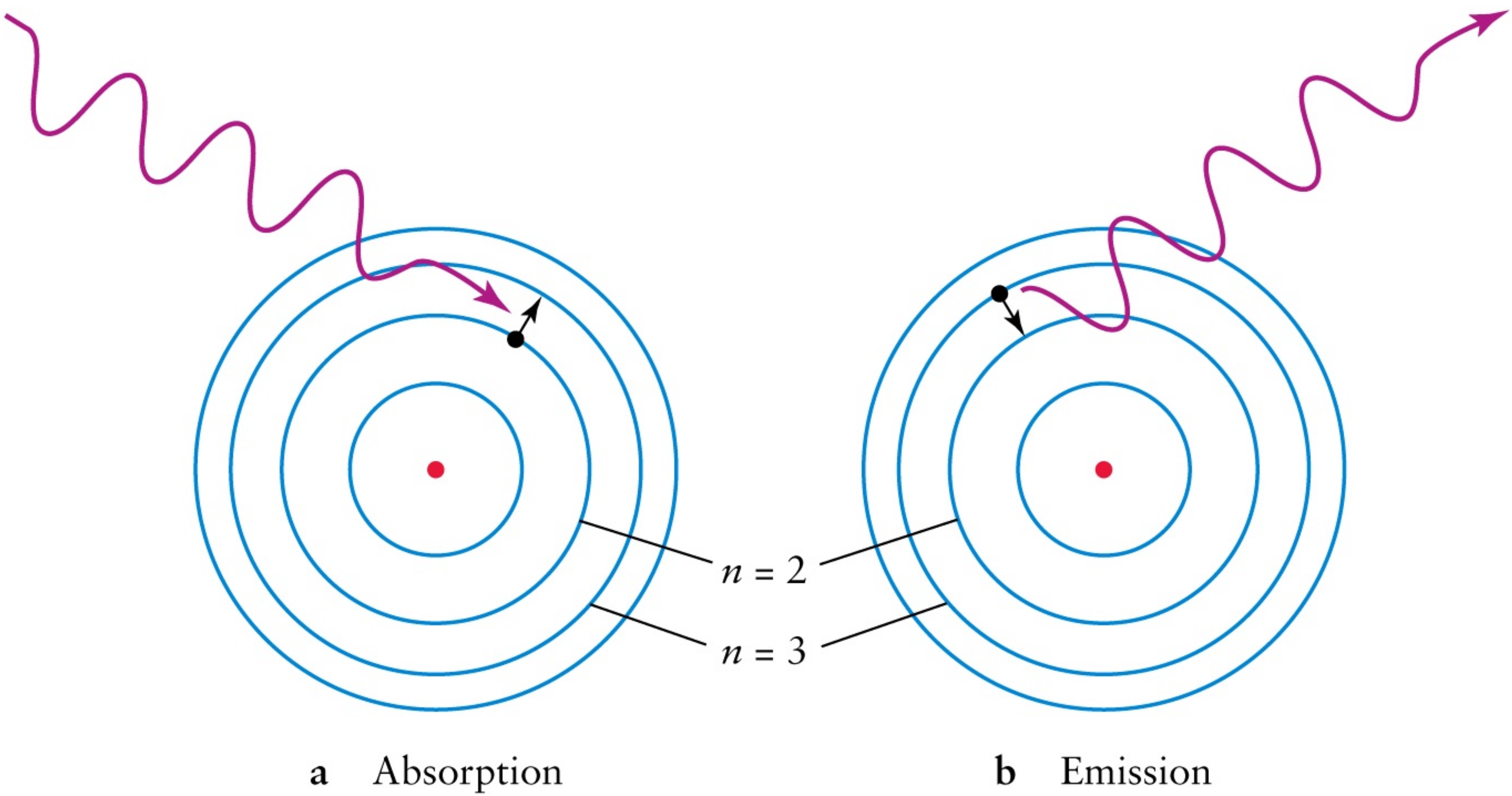
Another Look at the Energy levels





$$E_n = -\left(\frac{ke^2}{2a_0}\right)\frac{Z^2}{n^2}$$

Bohr's Atom: Emission & Absorption Spectra



Some Notes About Bohr Like Atoms

- Ground state of Hydrogen atom (n=1) $E_0 = -13.6$ eV
- Method for calculating energy levels etc applies to all Hydrogen-like atoms → -1e around +Ze
  - Examples : He^+, Li^{++}
- Energy levels would be different if replace electron with Muons
- Bohr's method can be applied in general to all systems under a central force (e.g. gravitational instead of Coulombic)

If change $U(r) = k\frac{Q_1 Q_2}{r} \rightarrow G\frac{M_1 M_2}{r}$

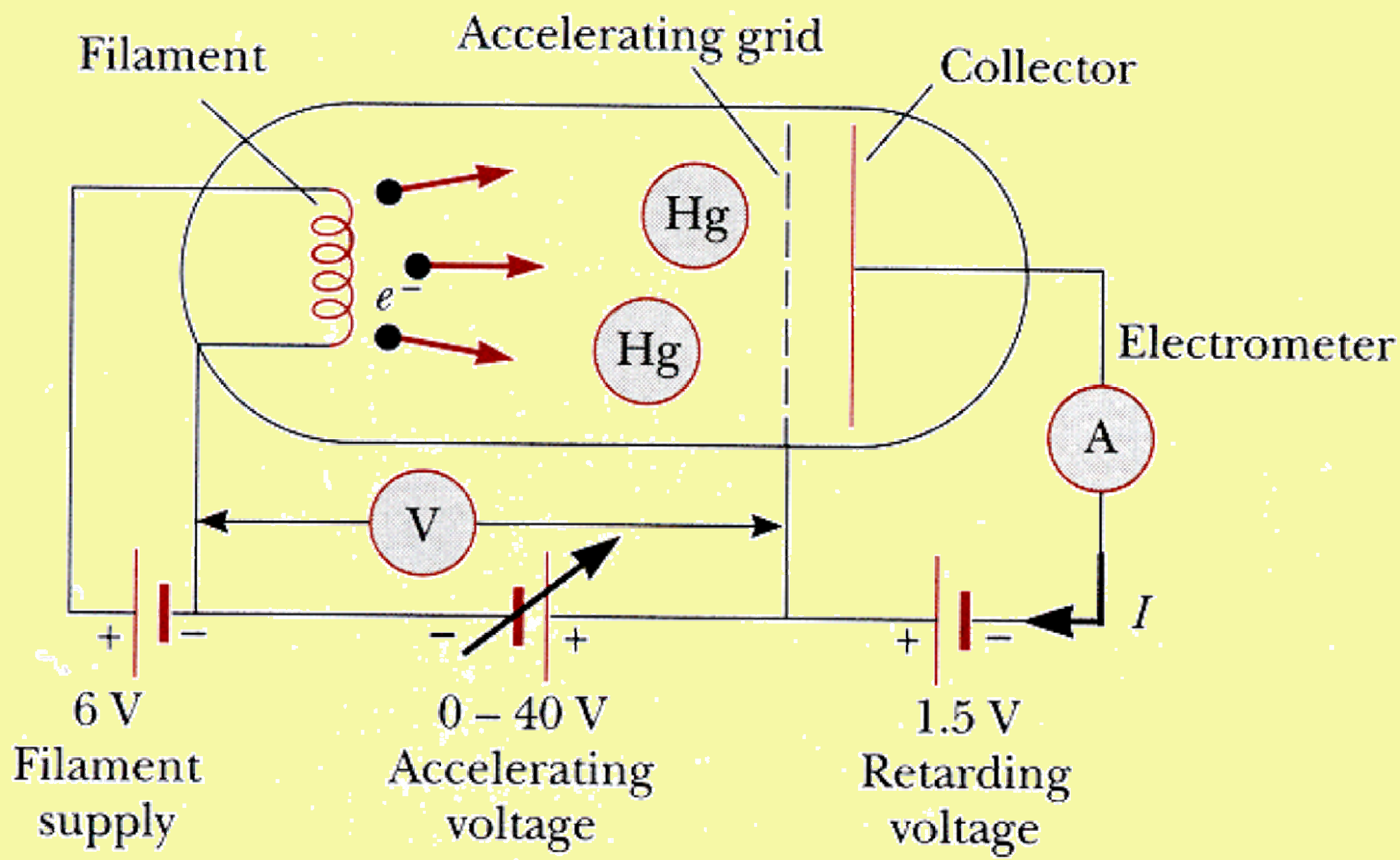
Changes every thing: E, r , f etc

"Importance of constants in your life"

Atomic Excitation by Electrons: Franck-Hertz Expt

Other ways of Energy exchange are also quantized ! Example:

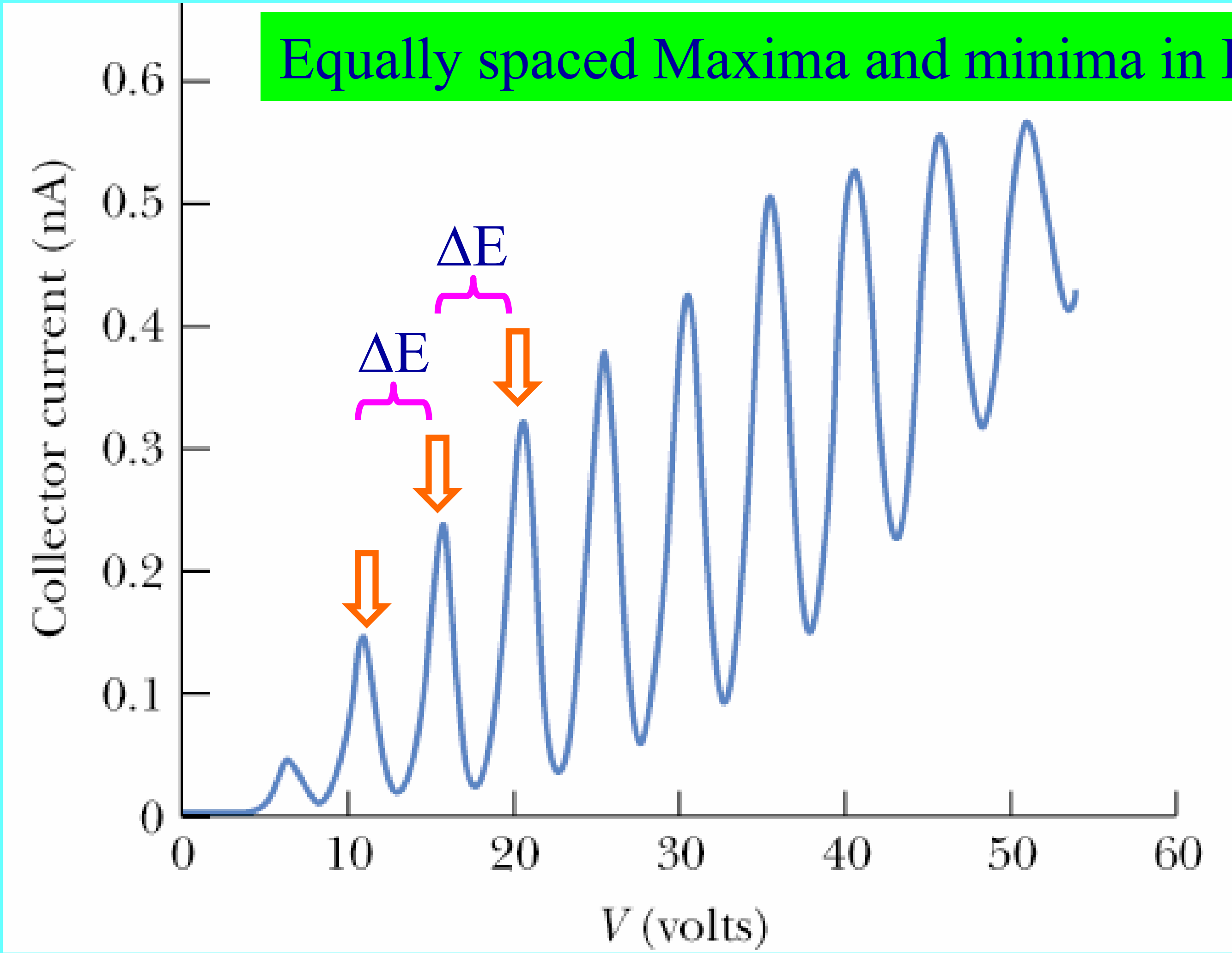
- Transfer energy to atom by colliding electrons on it
- Accelerate electrons, collide with Hg atoms, measure energy transfer in inelastic collision (retarding voltage)



Atomic Excitation by Electrons: Franck-Hertz Expt

Plot # of electrons/time (current) overcoming the retarding potential (V)

Equally spaced Maxima and minima in I-V curve



Atoms accept only discrete amount of Energy,
no matter the fashion in which energy is transffered