PHYS 3313 – Section 001
Lecture #10

Wednesday, Feb. 25, 2015
Dr. Jaehoon Yu

- Blackbody Radiation
- Photoelectric Effect
- Compton Effect
- Pair production/Pair annihilation

Announcements

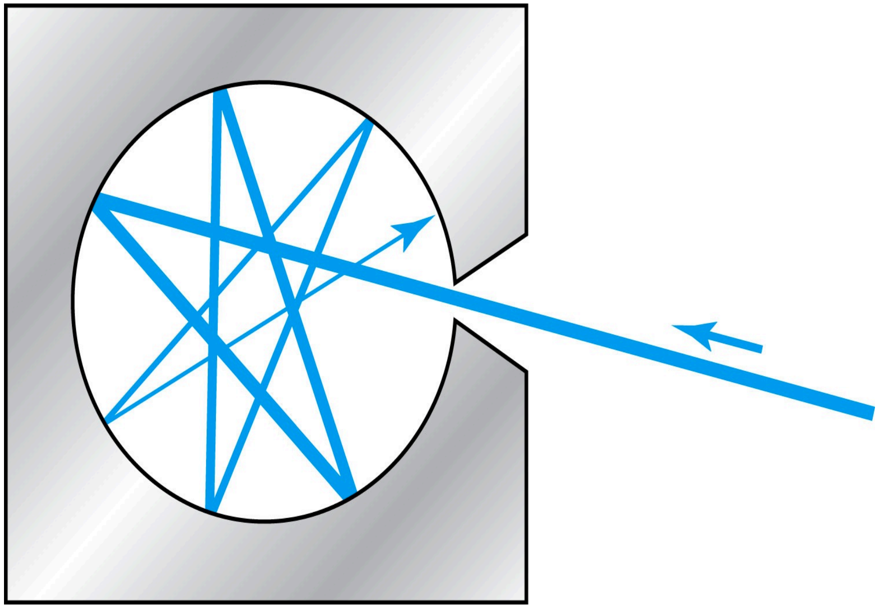
- Midterm Exam
  - In class next Wednesday, March. 4
  - Covers from CH1.1 through what we learn March 2 plus the math refresher in the appendices
  - Mid-term exam constitutes 20% of the total
  - **Please do NOT miss the exam! You will get an F if you miss it.**
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of handwritten formulae and values of constants for the exam
  - No derivations, word definitions or solutions of any problems !
  - No additional formulae or values of constants will be provided!
- Colloquium at 4pm today in SH101
  - Dr. Wallace from UTD on 2D devices

Special Project #3

- A total of N_i incident projectile particle of atomic number Z_1 kinetic energy KE scatter on a target of thickness t and atomic number Z_2 and has n atoms per volume. What is the total number of scattered projectile particles at an angle θ? (20 points)
- Please be sure to clearly define all the variables used in your derivation! Points will be deducted for missing variable definitions.
- This derivation must be done on your own. Please do not copy the book, internet or your friends'.
- Due is Wednesday, March 18

Blackbody Radiation

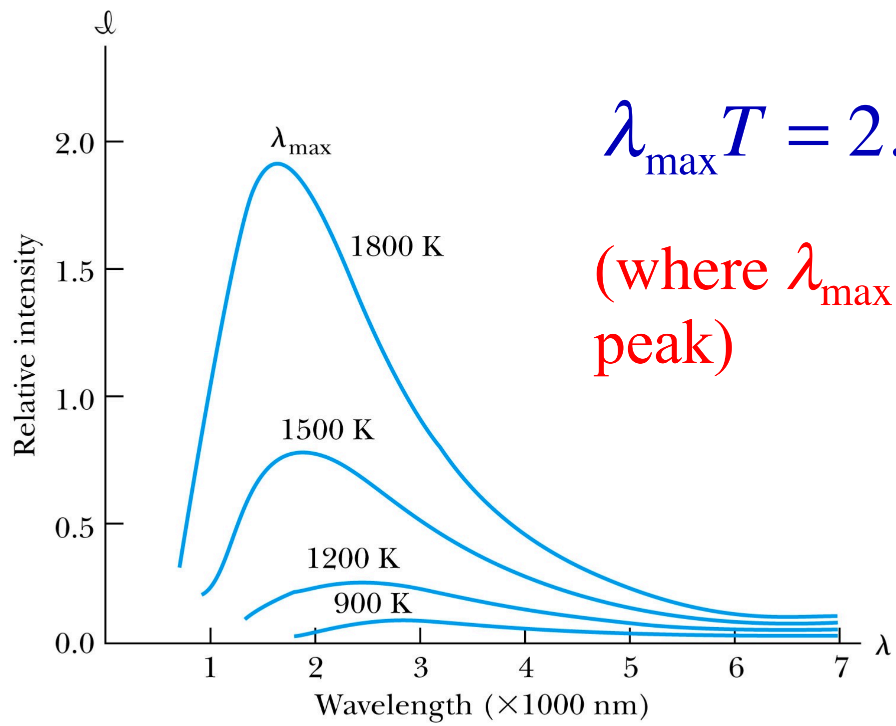
- When matter is heated, it emits radiation.
- A blackbody is an ideal object that has 100% absorption and 100% emission without a loss of energy
- A cavity in a material that only emits thermal radiation can be considered as a black-body. Incoming radiation is fully absorbed in the cavity.



- Blackbody radiation is theoretically interesting because
  - Radiation properties are independent of the particular material.
  - Properties of intensity versus wavelength at fixed temperatures can be studied

Wien's Displacement Law

- The intensity $\mathscr{l}(\lambda, T)$ is the total power radiated per unit area per unit wavelength at the given temperature.
- **Wien's displacement law**: The peak of $\mathscr{l}(\lambda, T)$ distribution shifts to smaller wavelengths as the temperature increases.



$$\lambda_{max} T = 2.898 \times 10^{-3} m \cdot K$$

(where λ_{max} = wavelength of the peak)

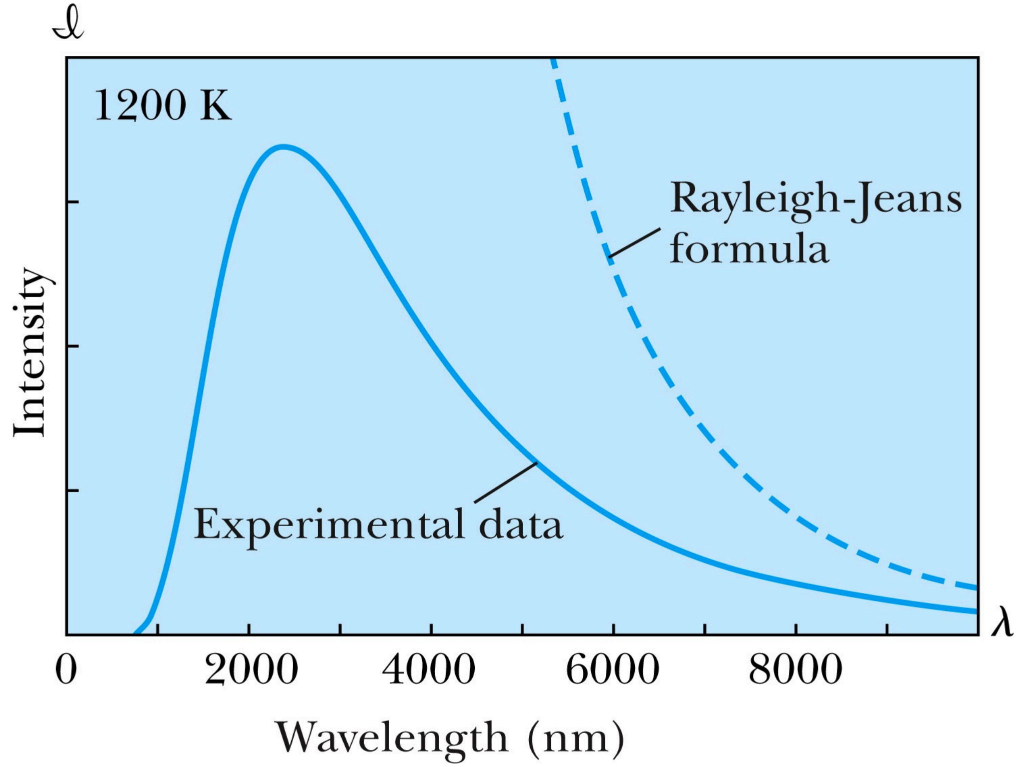
Stefan-Boltzmann Law

- The total power radiated increases with the temperature: $$R(T)=\int_0^\infty \ell(\lambda,T)\,d\lambda=\varepsilon\sigma T^4$$
- This is known as the **Stefan-Boltzmann law**, with the constant σ experimentally measured to be σ $=5.6705\times10^{-8}$ W / (m^2 · K^4).
- The **emissivity** ε (ε = 1 for an idealized blackbody) is the ratio of the emissive power of an object to that of an ideal blackbody and is always less than 1.

Rayleigh-Jeans Formula

- Lord Rayleigh used the classical theories of electromagnetism and thermodynamics to show that the blackbody spectral distribution should be

$$\ell(\lambda, T) = \frac{2\pi ckT}{\lambda^4}$$



- Worked reasonably well at longer wavelengths but..
- it deviates badly at short wavelengths.
- ➔ "the ultraviolet catastrophe" a serious issue that couldn't be explained

Planck's Radiation Law

- Planck assumed that the radiation in the cavity was emitted (and absorbed) by some sort of "oscillators" that were contained in the walls. He used Boltzman's statistical methods to arrive at the following formula that fit the blackbody radiation data.

$$\ell(\lambda,T)=\frac{2\pi c^2 h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}$$ Planck's radiation law

- Planck made two modifications to classical theory:
  1) The oscillators (of electromagnetic origin) can only have certain discrete energies determined by $E_n = nhf$, where n is an integer, f is the frequency, and h is called Planck's constant. $h = 6.6261 \times 10^{-34}$ J·s.
  2) **<u>The oscillators can absorb or emit energy ONLY in discrete multiples of the fundamental quantum of energy</u>** given by

$$\Delta E = hf = \frac{hc}{\lambda}$$

Photoelectric Effect

Definition: Incident electromagnetic radiation shining on a metal transfers energy to the electrons, allowing them to escape the surface of the metal. Ejected electrons are called photoelectrons.

Other methods of electron emission:

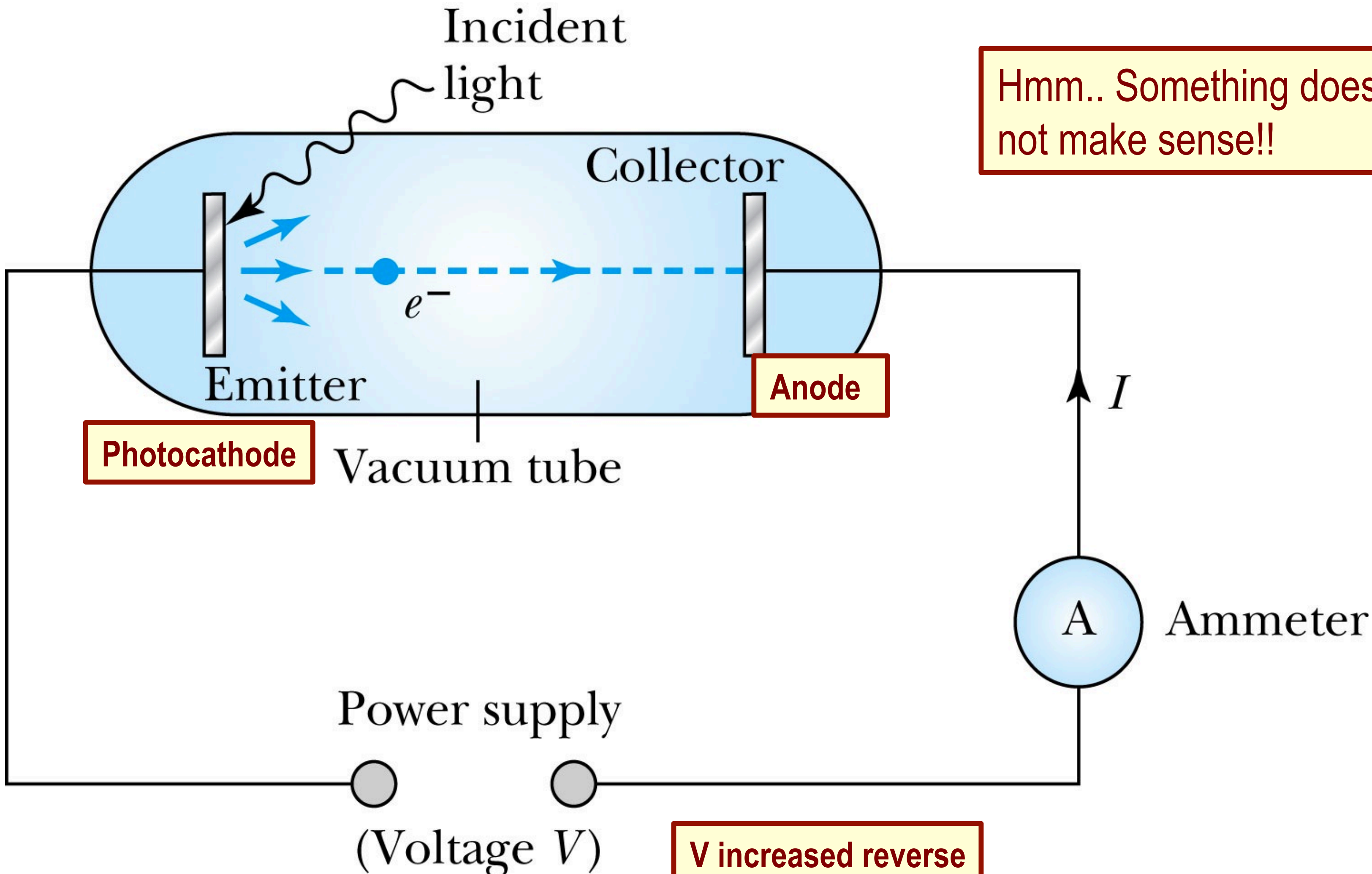
- **Thermionic emission**: Application of heat allows electrons to gain enough energy to escape.
- **Secondary emission**: The electron gains enough energy by transfer from another high-speed particle that strikes the material from outside.
- **Field emission**: A strong external electric field pulls the electron out of the material. (an example?)

Classical Interpretation of Photoelectric Effect

- Classical theory allows EM radiation to eject photoelectrons from matter
- Classical theory predicts the energy of the photoelectrons increase in proportion to the radiation intensity
- Thus, KE of the photoelectrons must be proportional to the intensity of light not the current
- Time for an experiment!

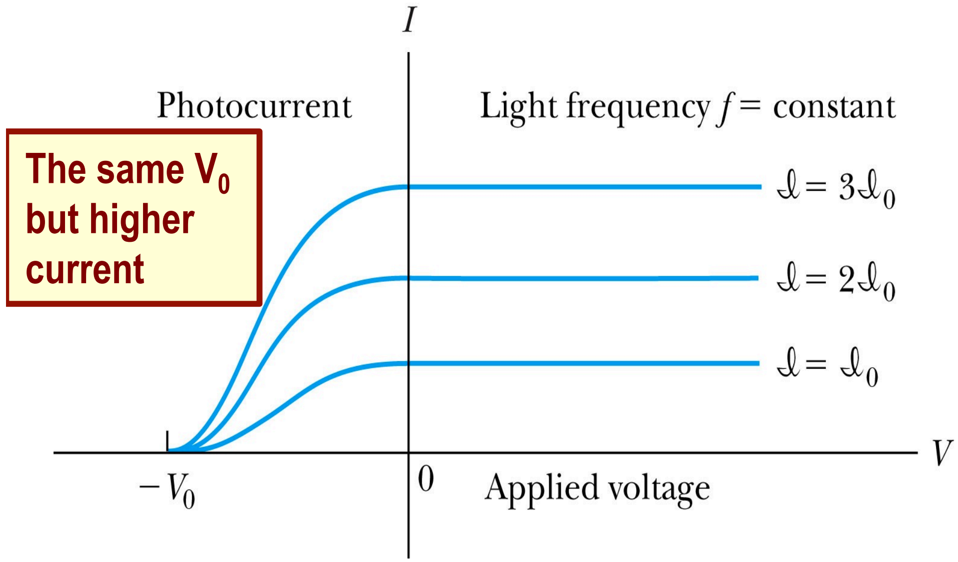
Photoelectric Effect Experimental Setup

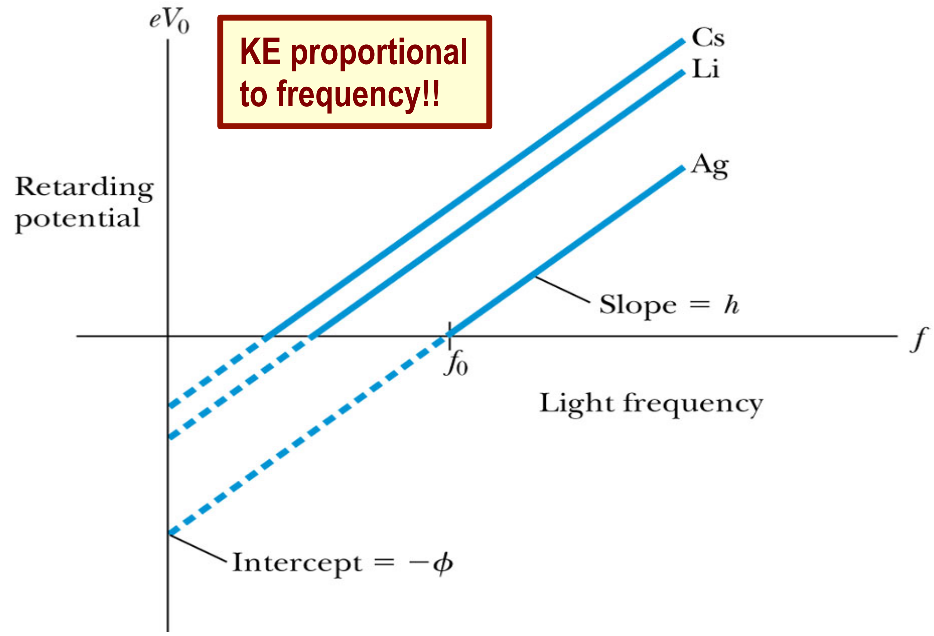
Hmm.. Something does not make sense!!

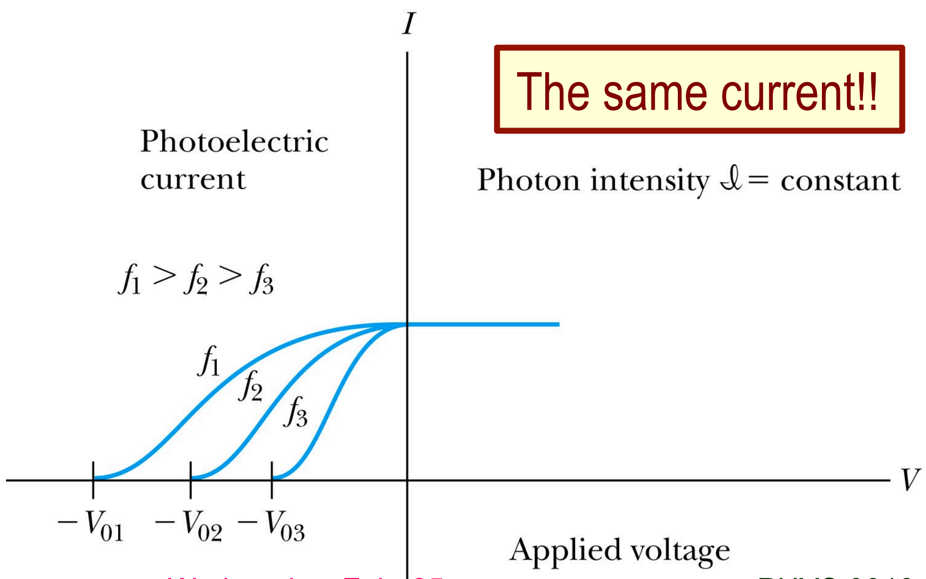


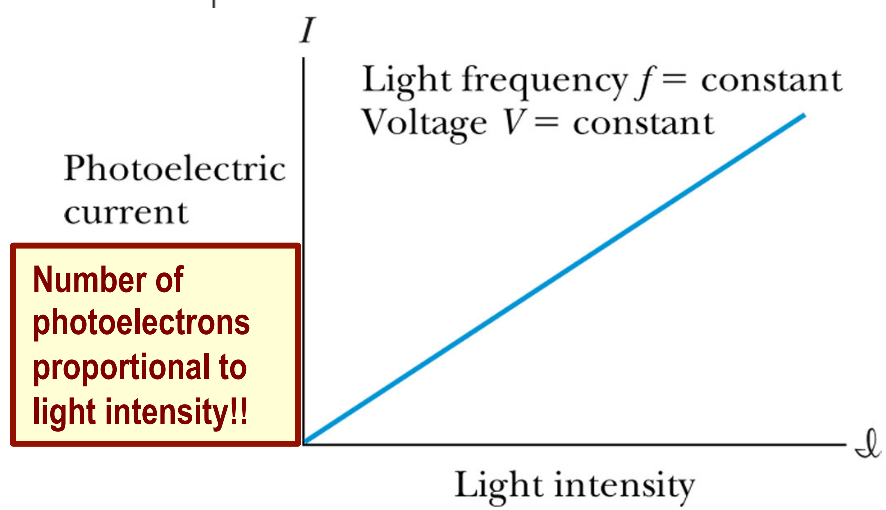
V increased reverse direction to stop I

Experimental Observations









Summary of Experimental Observations

- Light intensity does not affect the KE of the photoelectrons
- The max KE of the photoelectrons for a given emitter material depends only on the frequency of the light
- The smaller the work function ϕ of the emitter material, the smaller is the threshold frequency of the light that can eject photoelectrons.
- When the photoelectrons are produced, their number is proportional to the intensity of light.
- The photoelectrons are emitted almost instantly following the illumination of the photocathode, independent of the intensity of the light. ➔ Totally unexplained by classical physics

Einstein's Theory of Photoelectric Effect

- Einstein suggested that the electromagnetic radiation field of the light is quantized into particles called **photons**. Each photon has the energy quantum:

$$E = hf$$

- where f is the frequency of the light and h is Planck's constant.
- The photon travels at the speed of light in a vacuum, and its wavelength is given by

$$\lambda f = c$$

Einstein's Theory

- Conservation of energy yields:

$$\text{Energy Before(photon)=Energy After (electron)}$$

$$hf = \phi + KE(photoelectron)$$

where ϕ is the work function of the metal

The photon energy can then be written

$$hf = \phi + \frac{1}{2}mv_{\max}^2$$

- The retarding potentials measure the KE of the most energetic photoelectrons.

$$eV_0 = \frac{1}{2}mv_{\max}^2$$

Quantum Interpretation

- KE of the electron depends only on the light frequency and the work function ϕ of the material not the light intensity at all

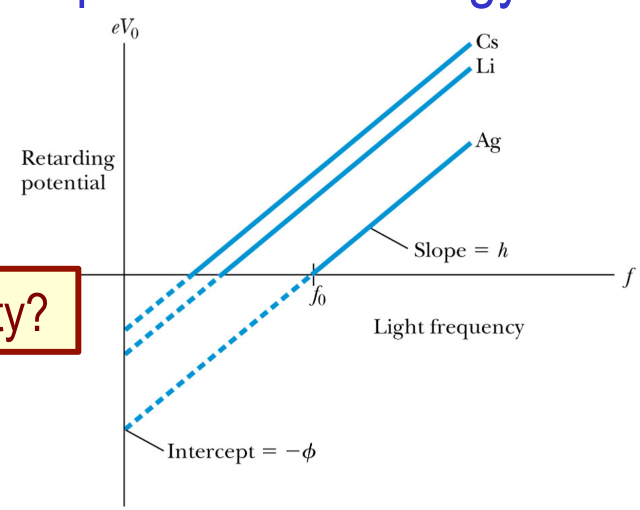
$$\frac{1}{2}mv_{\max}^2 = eV_0 = hf - \phi$$

- Einstein in 1905 predicted that the stopping potential was linearly proportional to the light frequency, with a slope *h*, the same constant found by Planck.

$$eV_0 = \frac{1}{2}mv_{\max}^2 = hf - hf_0 = h\left(f - f_0\right)$$

- From this, Einstein concluded that light is a particle with energy:

$$E = hf = \frac{hc}{\lambda}$$



Was he already thinking about particle/wave duality?

Ex 3.11: Photoelectric Effect

- Light of wavelength 400nm is incident upon lithium (ϕ=2.93eV). Calculate (a) the photon energy (eV) and (b) the stopping potential V_0.
- Since the wavelength is known, we use plank's formula:

$$E = hf = \frac{hc}{\lambda} = \frac{\left(1.626\times10^{-34}J\cdot s\right)\left(3\times10^{8}\,m/s\right)}{400\times10^{-9}m} = 3.10eV$$

- The stopping potential can be obtained using Einstein's formula for photoelectron energy

$$eV_0 = hf - \phi = E - \phi$$

$$V_0 = \frac{E-\phi}{e} = \frac{\left(3.10-2.93\right)eV}{e} = 0.17V$$