PHYS 3313 – Section 001
Lecture #11

Wednesday, Feb. 22, 2017
Dr. Jaehoon Yu

- Determination of Electron Charge
- Line Spectra
- Blackbody Radiation
- Photoelectric Effect

Announcements

- Midterm Exam
  - In class Wednesday, March. 8
  - Covers from CH1.1 through what we learn March 1 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!
    - Eg., Lorentz velocity transformation NOT allowed!
  - No additional formulae or values of constants will be provided!
- Colloquium at 4pm today in SH103
  - Drs. Park, Jones and Asaadi of UTA Physics department

Physics Department
The University of Texas at Arlington
<u>COLLOQUIUM</u>

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The 30th Anniversary of Supernova 1987A and Extra-Solar Neutrino Detection

Sangwook Park

Core collapse supernovae and the light of SN1987A

Ben Jones

The birth of neutrino astronomy with the neutrinos of SN1987A

Jonathan Asaadi

The future of supernova neutrino detection

University of Texas at Arlington

Wednesday February 22, 2017

4:00 Room 103 Science Hall

Abstract:

On February 23 1987, approximately 168,000 light years away, the blue supergiant star (named "Sanduleak -69° 202") exploded, liberating tremendous quantities of gravitational energy into light and matter. This produced th e brightest supernova explosion observed since the year 1604. This event, called SN1987A, has provided astronomers with an unprecedented opportunity to test the physics of stellar explosions.

As well as light, supernova 1987A emitted $10^{\wedge 46}$ Joules of energy in the form of neutrinos. Some of these neutrinos were detected by a new generation of large nucleon decay experiments (which, due to a pernicious background soon became known as neutrino detectors), Kamiokande and IMB. The handful of detected neutrinos provided vast information about neutrino physics, and validated the basic theory of core collapse supernovae.

In this mini-symposium, UTA faculty members will discuss the light and neutrinos of SN1987A and what they have contributed to our respective fields.

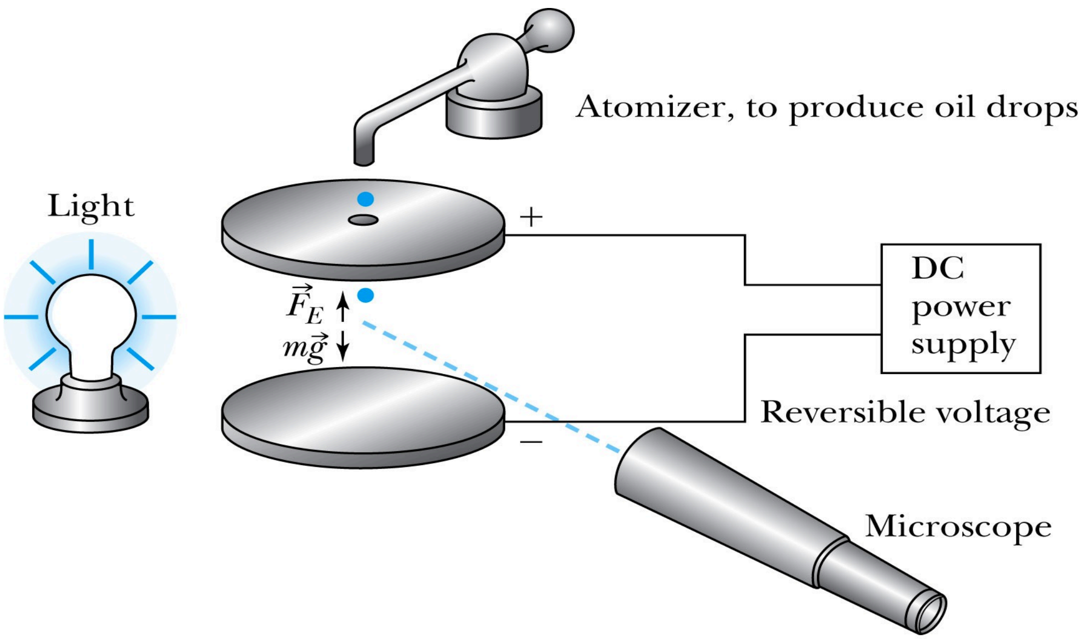
Refreshments will be served at 3:30 p.m. in the Physics Library

Special Project #4

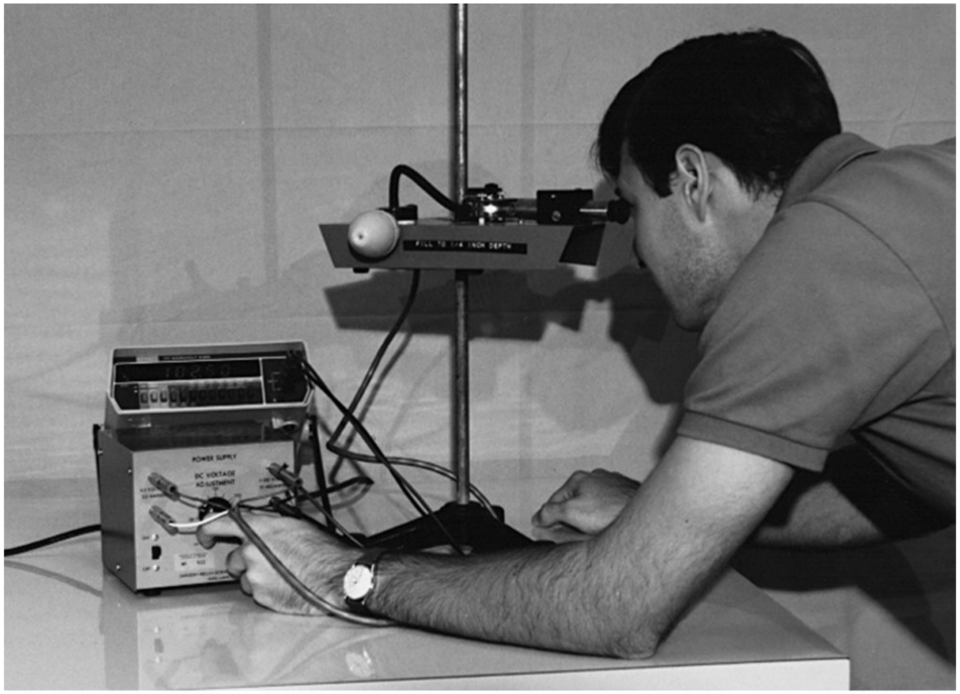
- A total of N_i incident projectile particle of atomic number Z_1 kinetic energy KE scatter on a target of thickness t and atomic number Z_2 and has n atoms per volume. What is the total number of scattered projectile particles at an angle θ? (20 points)
- Please be sure to clearly define all the variables 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 next Wednesday, March 1

Determination of Electron Charge

- Millikan (and Fletcher) in 1909 measured the charge of electron and showed that the free electric charge is in multiples of the basic charge of an electron



(a)



Calculation of the oil drop charge

- Used an electric field and gravity to suspend a charged oil drop $\vec{F}_E = q\vec{E} = -m\vec{g} \Rightarrow qV/d = mg$
- So the magnitude of the charge on the oil drop $$q = \frac{mgd}{V}$$
- Mass is determined from Stokes' relationship of the terminal velocity to the radius, the medium viscosity and density $$r = 3\sqrt{\eta v_t / 2g\rho}$$
$$m = \frac{4}{3}\pi r^3 \rho = \frac{4}{3}\pi \cdot 3\left(\frac{\eta v_t}{2g\rho}\right)^{\frac{3}{2}} \rho = \frac{4\pi}{\sqrt{\rho}}\left(\frac{\eta v_t}{2g}\right)^{\frac{3}{2}}$$
- Thousands of experiments showed that there is a basic quantized electron charge $$q = 1.602 \times 10^{-19}\ C$$

Line Spectra

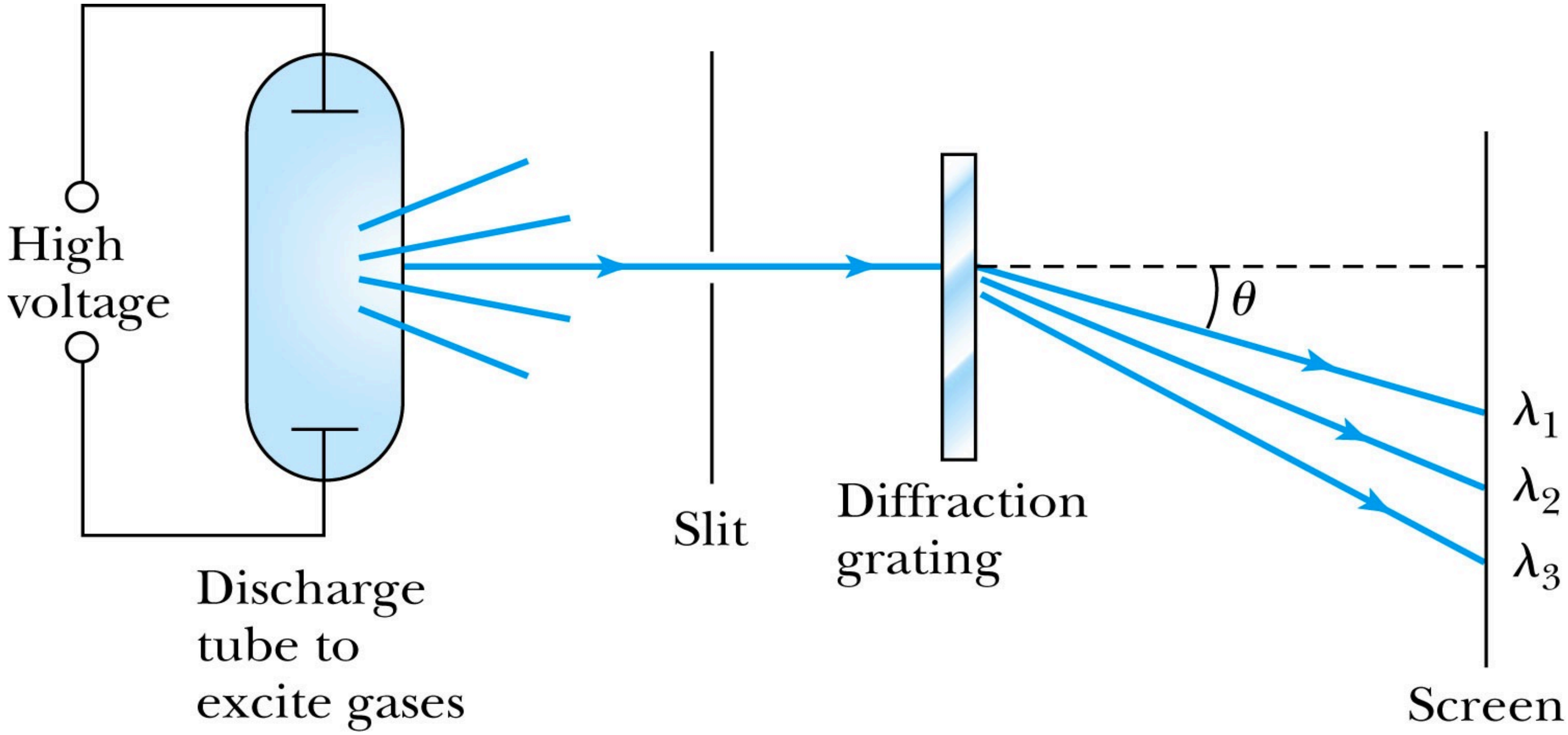
- Chemical elements produce unique wavelengths of light when burned or excited in an electrical discharge.
- Collimated light is passed through a diffraction grating with thousands of gratings per centimeter.
  - The diffracted light is separated at an angle θ according to its wavelength λ by the equation:

$$d \sin\theta = n\lambda$$

Diffraction maxima

where *d* is the distance between gratings and *n* is an integer called the order number (n=1 strongest)

Optical Spectrometer

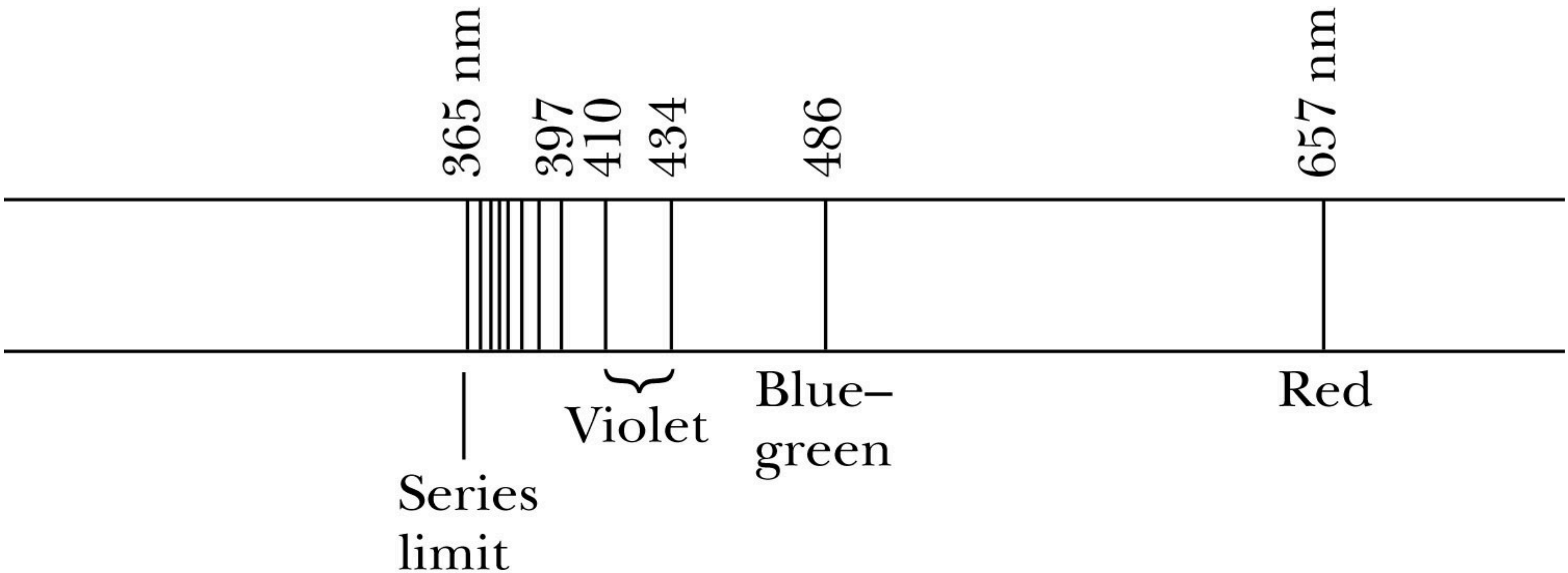


- Diffraction creates a *line spectrum* pattern of light bands and dark areas on the screen.
- Chemical elements and the composition of materials can be identified through the wavelengths of these line spectra

Balmer Series

- In 1885, Johann Balmer found an empirical formula for wavelength of the visible hydrogen line spectra in nm:

$$\lambda = 364.56 \frac{k^2}{k^2 - 4} \; nm$$ (where k = 3,4,5… and $k > 2$)



Rydberg Equation

- Several more series of hydrogen emission lines at infrared and ultraviolet wavelengths were discovered, the Balmer series equation was extended to the Rydberg equation:

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n^2} - \frac{1}{k^2} \right) \quad R_H = 1.096776 \times 10^7 m^{-1}$$

(Balmer series: n = 2, k>n)

Table 3.2 Hydrogen Series of Spectral Lines

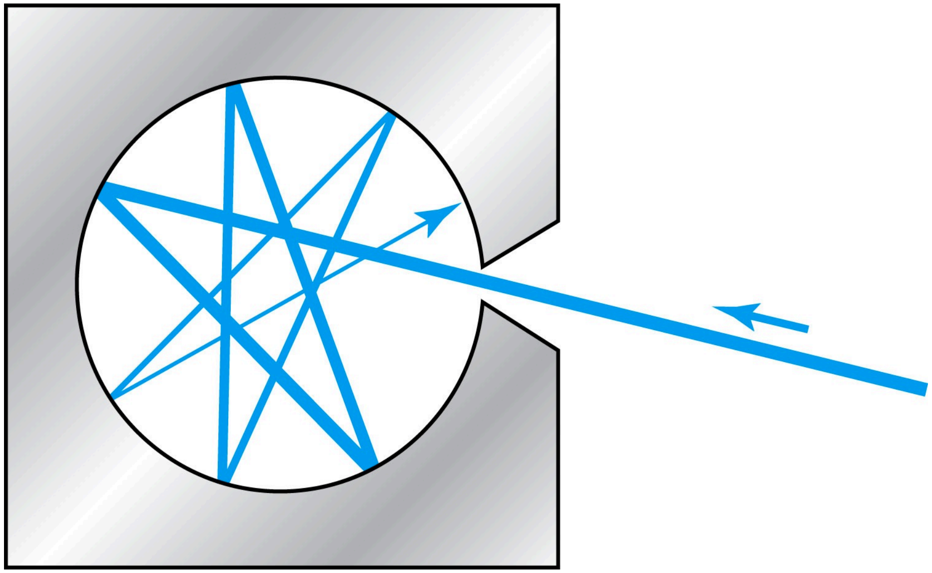
Discoverer (year)	Wavelength	*n*	*k*
Lyman (1916)	Ultraviolet	1	>1
Balmer (1885)	Visible, ultraviolet	2	>2
Paschen (1908)	Infrared	3	>3
Brackett (1922)	Infrared	4	>4
Pfund (1924)	Infrared	5	>5

More Quantization

- Current theories predict that charges are quantized in units (**quarks**) of $\pm e/3$ and $\pm 2e/3$, but quarks are not directly observed experimentally.
- The charges of particles that have been directly observed are always quantized in units of $\pm e$.
- The measured atomic weights are not continuous—they have only discrete values, which are close to integral multiples of a unit mass.

Blackbody Radiation

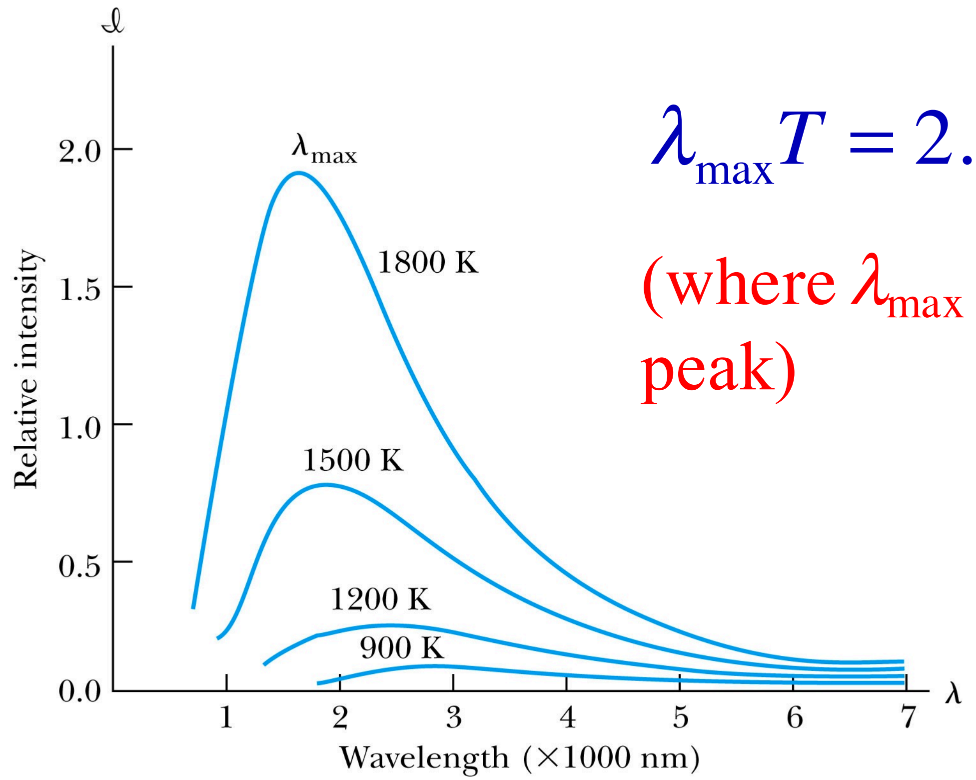
- When a matter is heated, it emits radiation.
- A blackbody is an ideal object that has 100% absorption and 100% emission without a loss of energy
- A cavity in a material that only emits thermal radiation can be considered as a black-body. Incoming radiation is fully absorbed in the cavity.



- 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 $\mathscr{I}(\lambda, T)$ is the total power radiated per unit area per unit wavelength at the given temperature. (Nobel 1911)
- **Wien's displacement law**: The peak of $\mathscr{I}(\lambda, T)$ 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)

Ex 3.4: Using Wien's Law

- A furnace has a wall of temperature 1600 °C. What is the wave length of maximum intensity emitted when a small door is opened?
- Since it has a small door open, we treat the furnace as if it is a blackbody.
- Using Wien's displacement law, we obtain

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

$$\lambda_{Max} = \frac{2.898 \times 10^{-3} m \cdot K}{T} = \frac{2.898 \times 10^{-3} m \cdot K}{273 + 1600} = 1.55 \times 10^{-6} m = 1550 nm$$

Stefan-Boltzmann Law

- The total power per unit area radiated from a blackbody increases with the temperature:

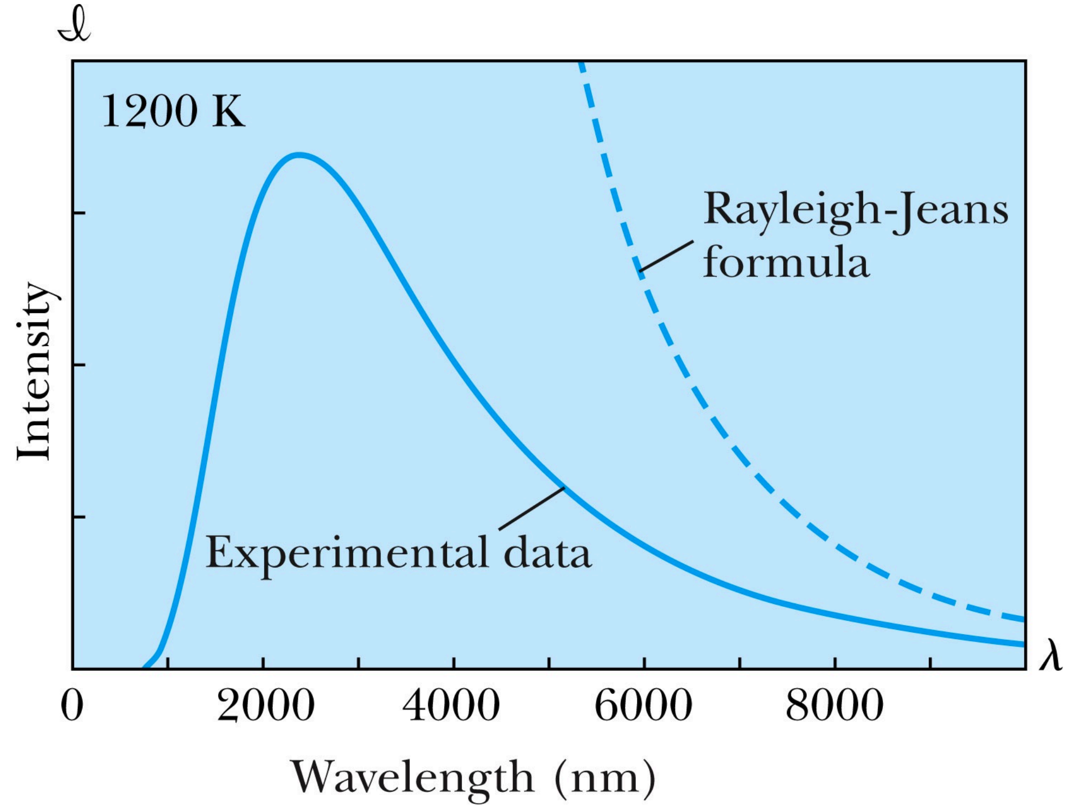
$$R(T) = \int_0^\infty \ell(\lambda, T)\, d\lambda = \varepsilon\sigma T^4$$

- This is known as the **Stefan-Boltzmann law**, with the constant value of σ experimentally measured to be
  - $\sigma = 5.6705 \times 10^{-8}\ \mathrm{W/(m^2 \cdot K^4)}$.
- The **emissivity** ε ($\varepsilon = 1$ 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 important 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) **The oscillators can absorb or emit energy ONLY in discrete multiples of the fundamental quantum of energy** given by

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

Photoelectric Effect

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

Hertz noticed during his experiment in 1887 that when ultraviolet light falls on metal surface charge gets ejected ➔ Left it to Philip Lenard to study further

Other methods of electron emission:

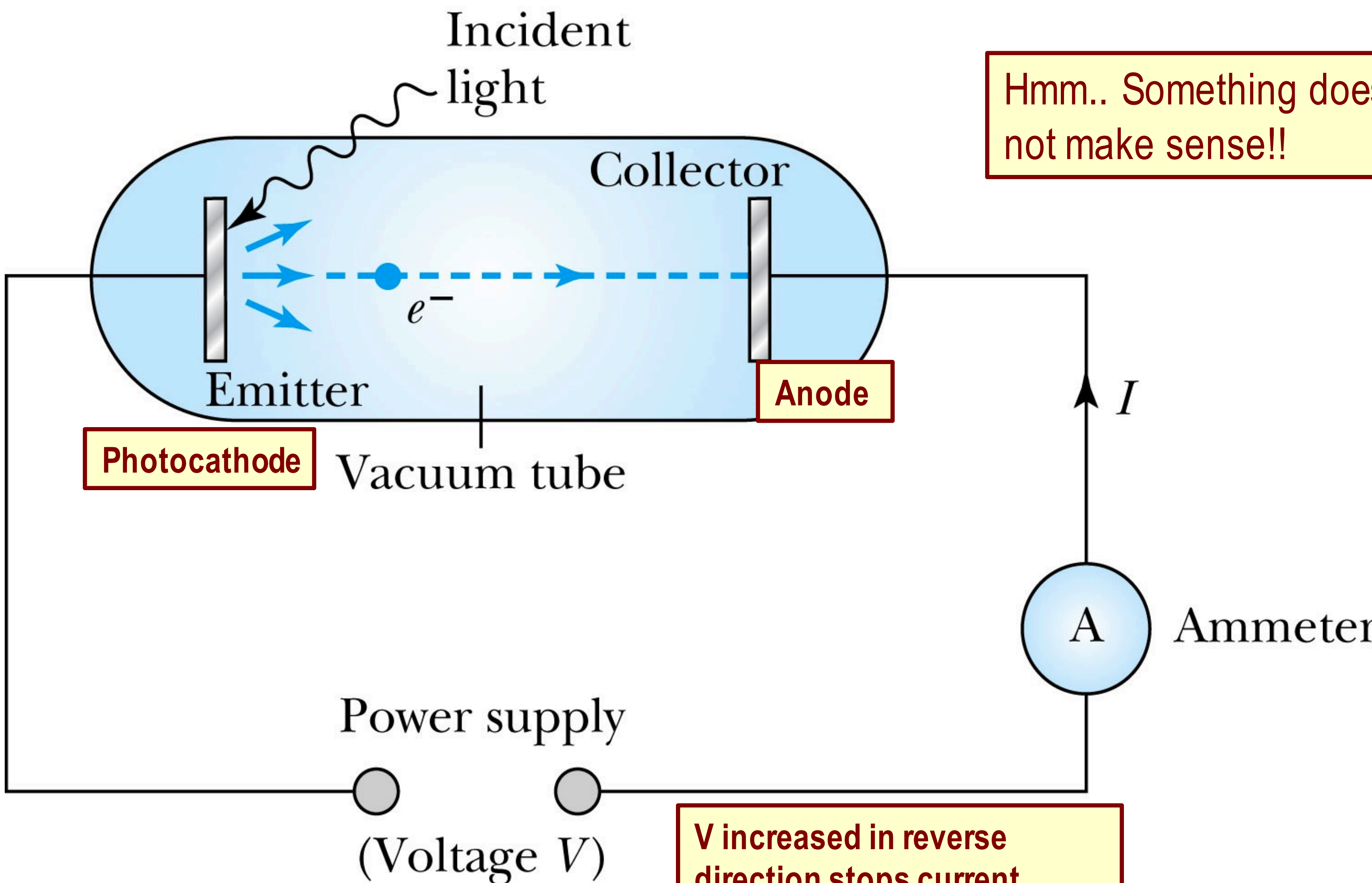
- **Thermionic emission**: Application of heat allows electrons to gain enough energy to escape.
- **Secondary emission**: The electron gains enough energy by transfer from another high-speed particle that strikes the material from outside.
- **Field emission**: A strong external electric field pulls 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, the KE of the photoelectrons must be proportional to the intensity of light not the current
- Time for an experiment!

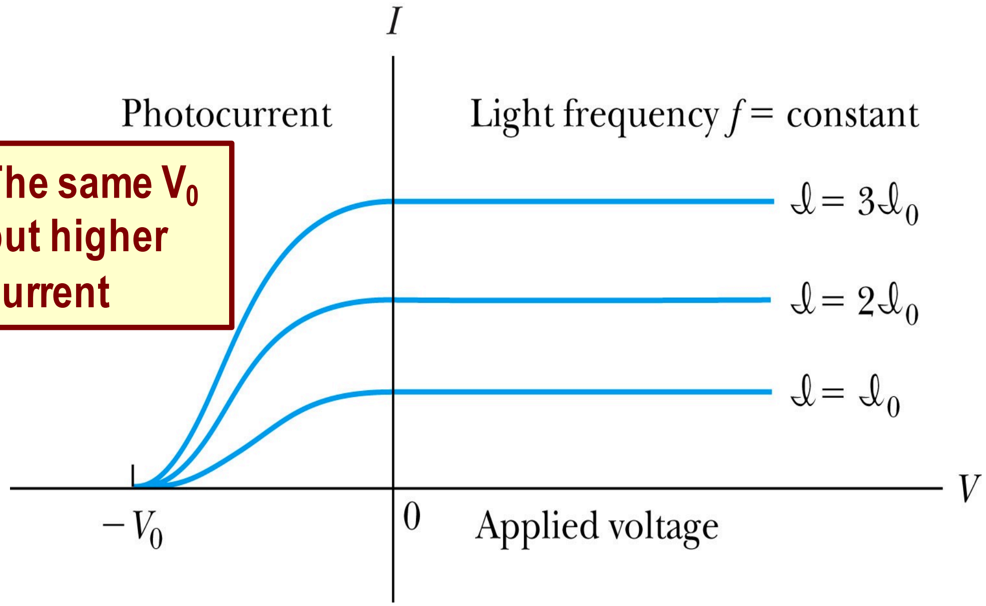
Photoelectric Effect Experimental Setup

Hmm.. Something does not make sense!!

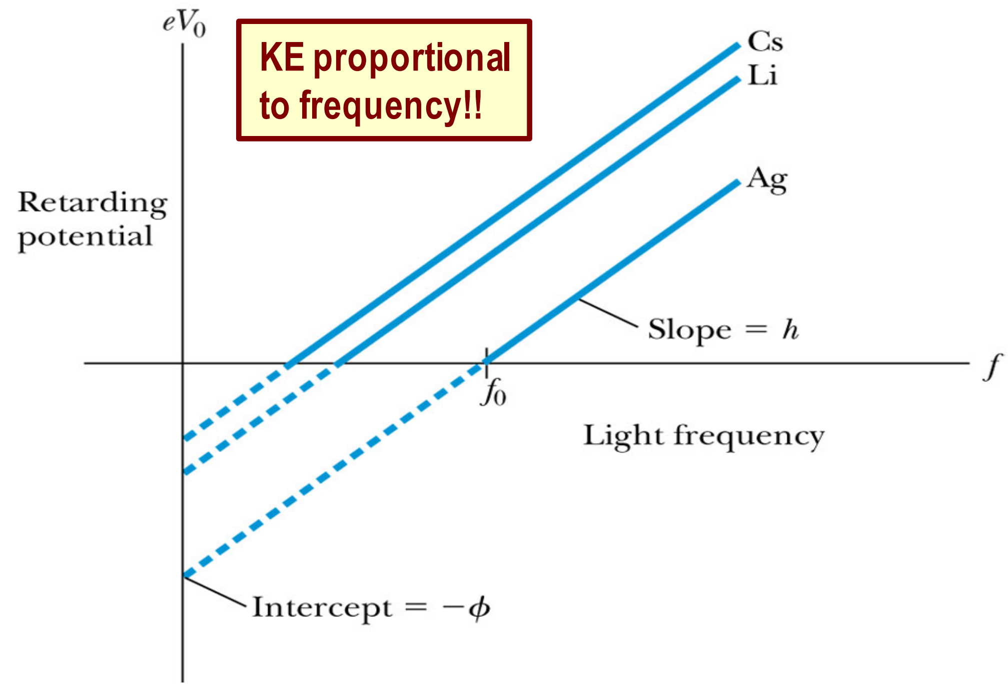


V increased in reverse direction stops current independent of light intensity

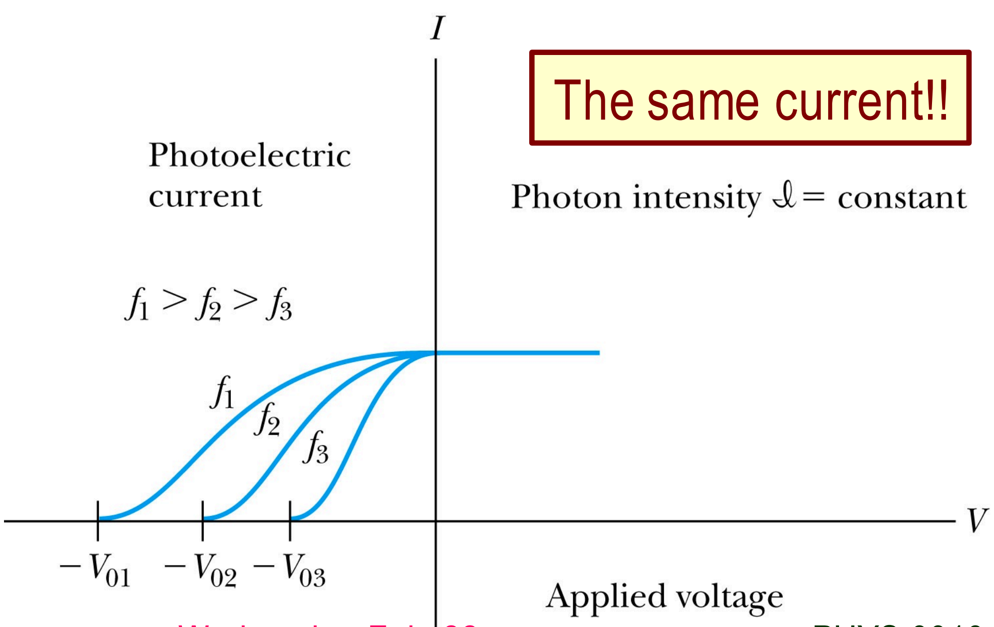
Experimental Observations



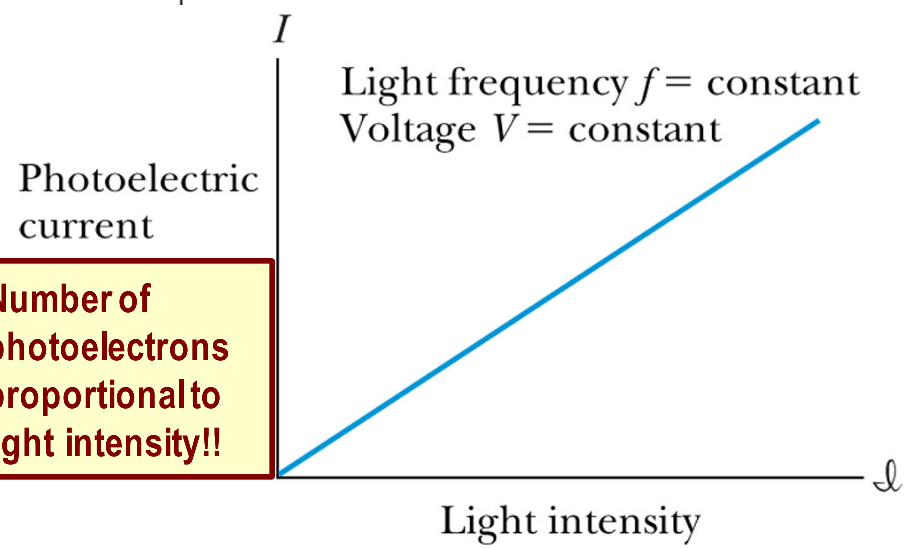
The same V_0 but higher current



KE proportional to frequency!!



The same current!!



Number of photoelectrons proportional to light intensity!!

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