PHYS 3313 – Section 001
Lecture #9

Wednesday, Feb. 12, 2014
Dr. Jaehoon Yu

- Determination of Electron Charge
- Line Spectra
- Blackbody Radiation

Announcements

- Reminder: Homework #2
  - CH3 end of the chapter problems: 2, 19, 27, 36, 41, 47 and 57
  - Due Wednesday, Feb. 19
- Quiz #2 Wednesday, Feb. 19
  - Beginning of the class
  - Covers CH1.1 – what we finish Monday, Feb. 17
  - 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 or solutions of any problems allowed!
  - No additional formulae or values of constants will be provided!
- Colloquium today→ Dr. C. B. Jackson of UTA

Physics Department
The University of Texas at Arlington

COLLOQUIUM

"Dark Matter(s): Twisted But True"

Dr. Christopher Jackson

Department of Physics, University of Texas at Arlington

4:00 pm Wednesday February 12, 2014 room 101 SH

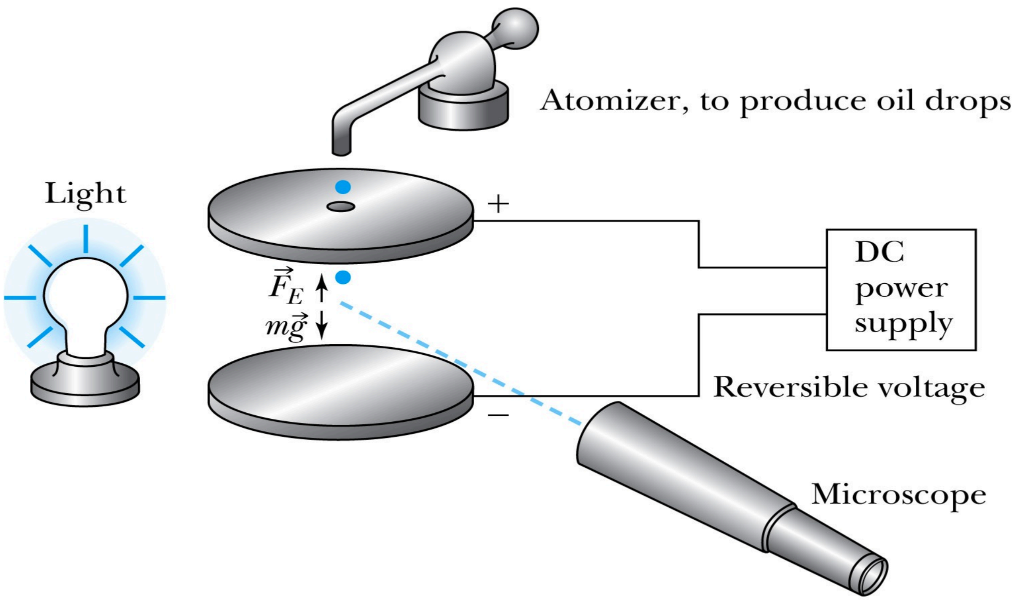
Abstract:

Over eighty percent of the matter in the Universe is made up of a mysterious and yet undetected substance called "dark matter". In this talk, I will motivate the existence of dark matter and highlight some of our best guesses as to what it could be. I will also discuss current attempts to detect dark matter and the most recent results of those searches. Finally, I will outline some recent proposals which put forth new ways in which we can try to detect dark matter (including the weird and wacky).

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

Determination of Electron Charge

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



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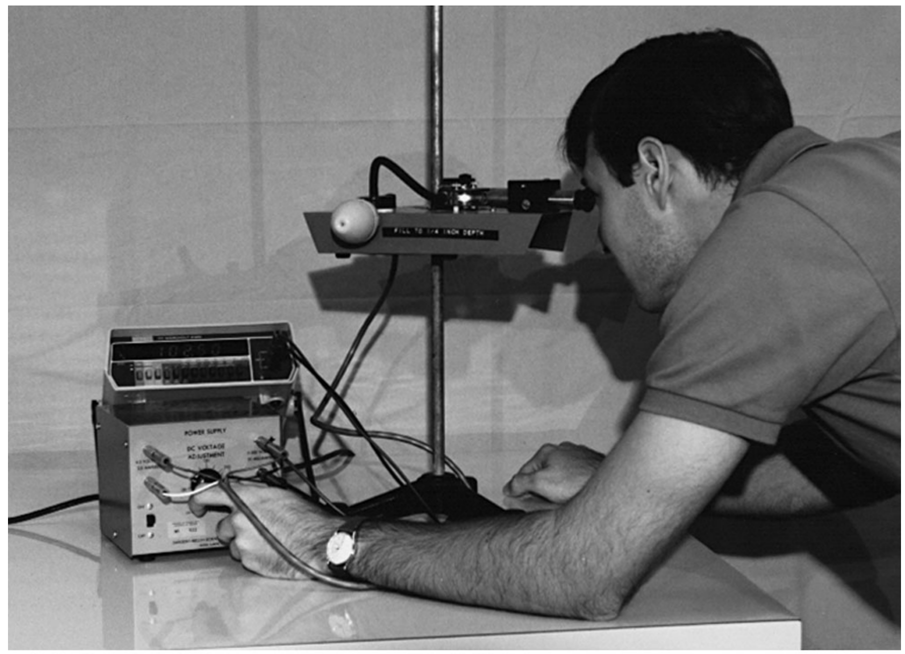


Calculation of the oil drop charge

- 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 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

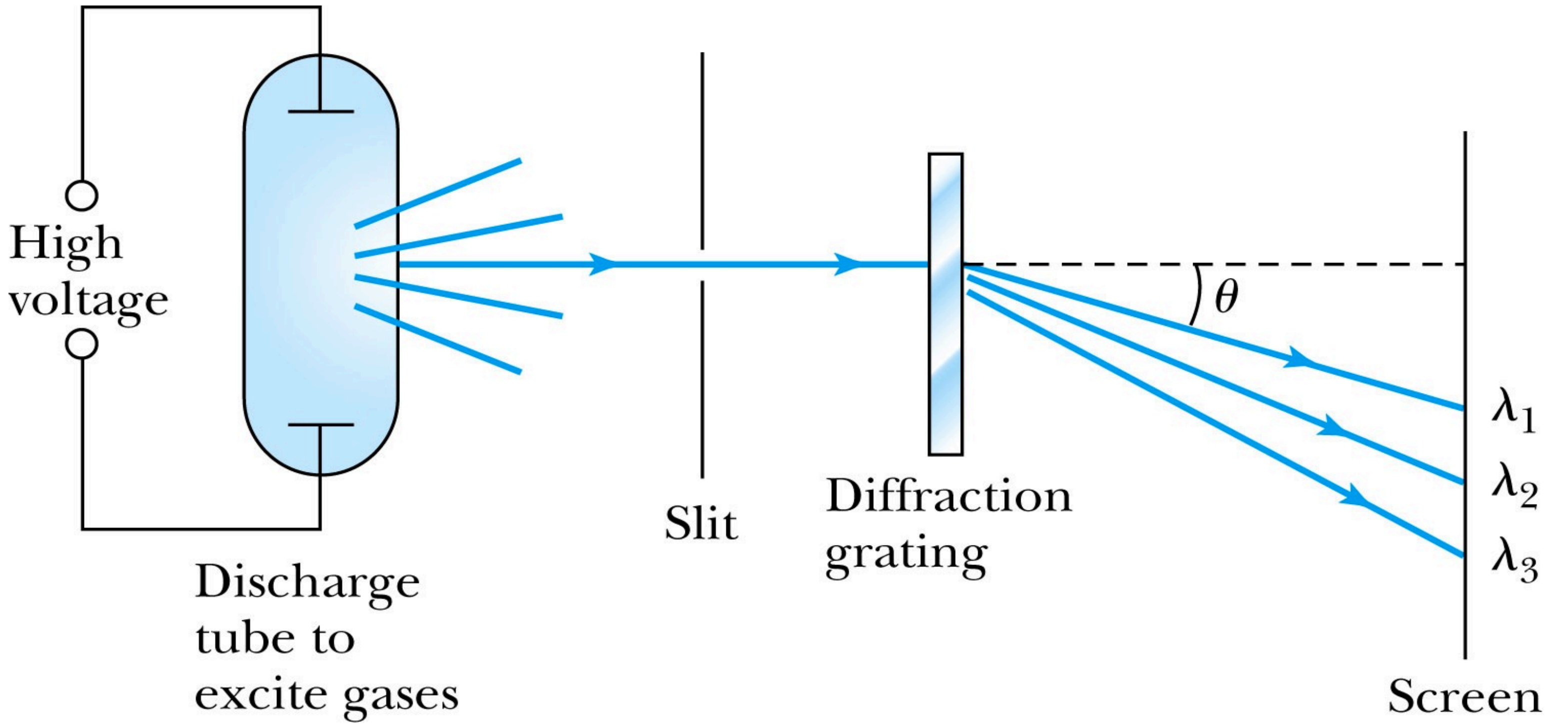
- Chemical elements produce unique wavelengths of light when burned or excited in an electrical discharge.
- Collimated light is passed through a diffraction grating with thousands of ruling lines per centimeter.
  - The diffracted light is separated at an angle θ according to its wavelength λ by the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

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

Diffraction maxima

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

Optical Spectrometer

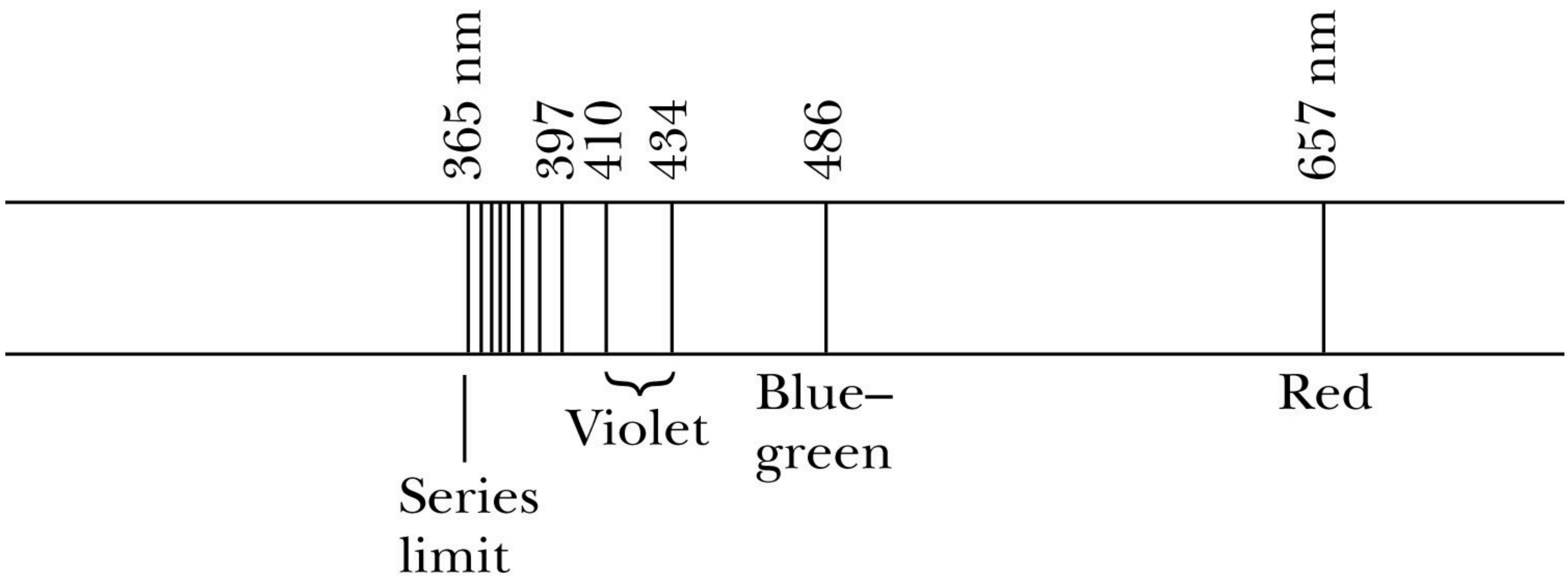


- Diffraction creates a *line spectrum* pattern of light bands and dark areas on the screen.
- Chemical elements and the composition of materials can be identified through the wavelengths of these line spectra

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:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n^2} - \frac{1}{k^2}\right) \quad R_H = 1.096776\times10^7 m^{-1} \quad (n = 2, n>K)$$

Table 3.2 Hydrogen Series of Spectral Lines

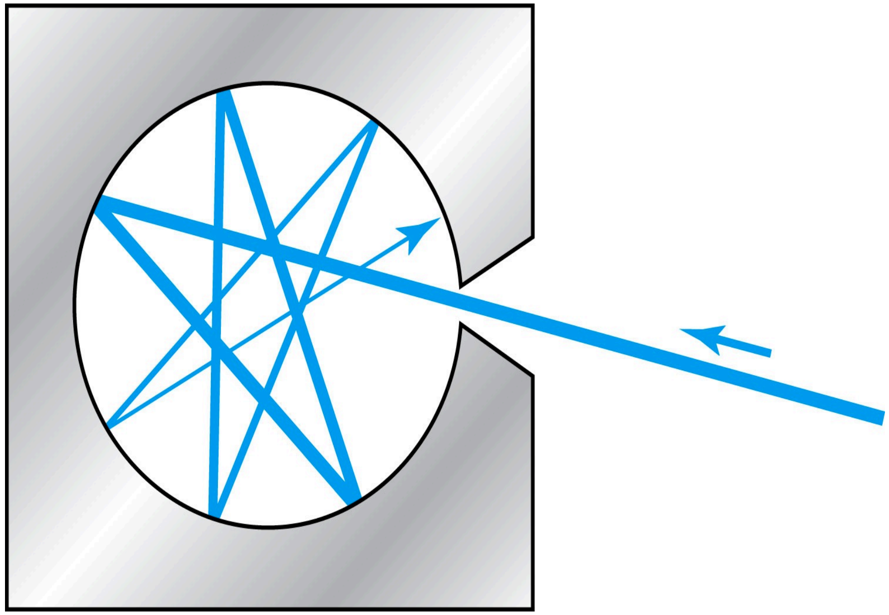
Discoverer (year)	Wavelength	*n*	*k*
Lyman (1916)	Ultraviolet	1	>1
Balmer (1885)	Visible, ultraviolet	2	>2
Paschen (1908)	Infrared	3	>3
Brackett (1922)	Infrared	4	>4
Pfund (1924)	Infrared	5	>5

Quantization

- Current theories predict that charges are quantized in units (**quarks**) of ±*e*/3 and ±2*e*/3, but quarks are not directly observed experimentally.
- The charges of particles that have been directly observed are always quantized in units of ±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

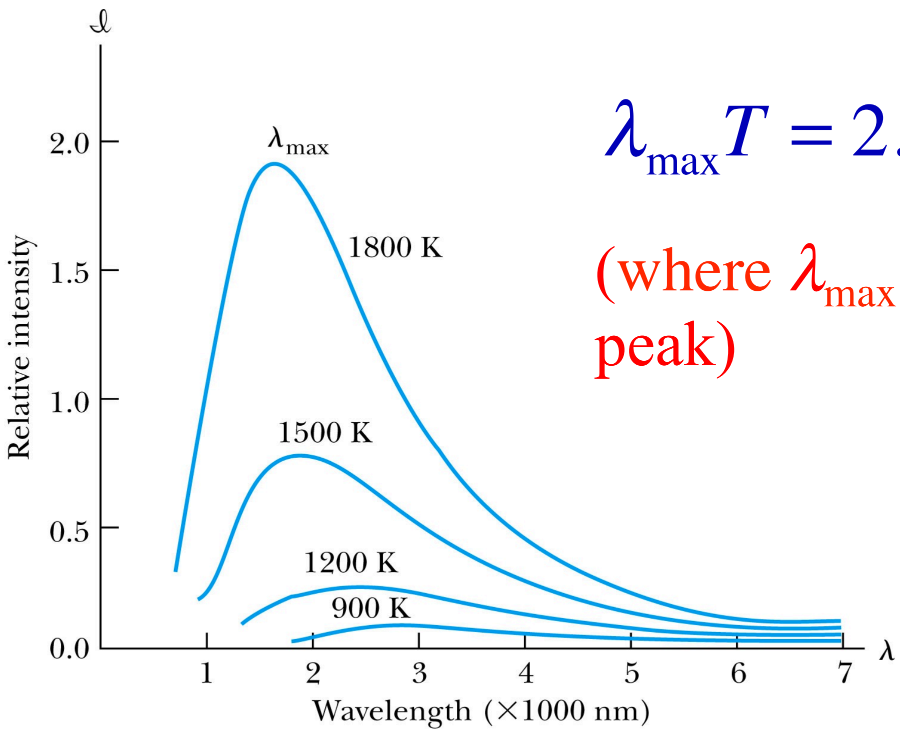
- When matter is heated, it emits radiation.
- A blackbody is an ideal object that has 100% absorption and 100% emission without a loss of energy
- A cavity in a material that only emits thermal radiation can be considered as a black-body. Incoming radiation is fully absorbed in the cavity.



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

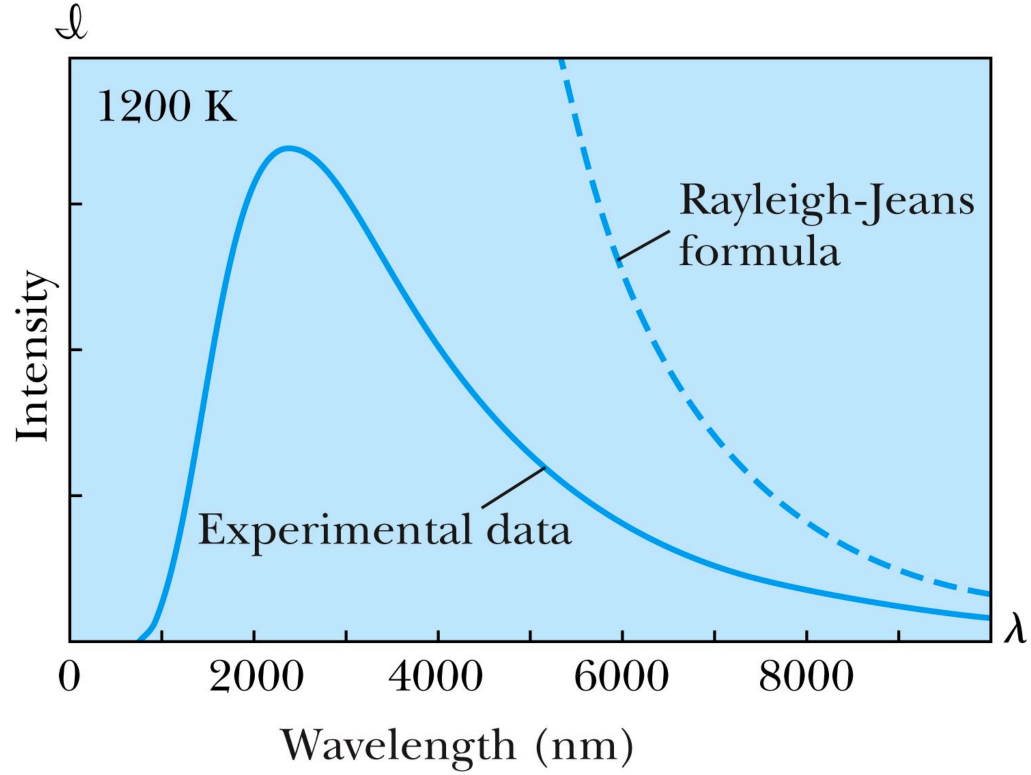
$$R(T) = \int_0^\infty \ell(\lambda, T)\, d\lambda = \varepsilon \sigma T^4$$

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

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