PHYS 3313 – Section 001
Lecture #9

Wednesday, Feb. 18, 2015
Dr. Jaehoon Yu

- Quantization
- Discovery of the X-ray and the Electron
- Determination of Electron Charge
- Line Spectra
- Blackbody Radiation
- Photoelectric Effect

Announcements

- Reminder: Homework #2
  - CH3 end of the chapter problems: 2, 19, 27, 36, 41, 47 and 57
  - Due Wednesday, Feb. 25
- Reminder: Quiz #2 Monday, Feb. 23
  - Beginning of the class
  - Covers CH1.1 – what we finish today
  - You can bring your calculator but it must not have any relevant formula pre-input
  - 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 today on Wind Energy…

What does the word "Quantize" mean?

- Dictionary: To restrict to discrete values
- To consist of indivisible discrete quantities instead of continuous quantities
  - Integer is a quantized set with respect to real numbers
- Some examples of quantization?
  - Digital photos
  - Lego blocks
  - Electric charge
  - Photon (a quanta of light) energy
  - Angular momentum
  - Etc…

Discovery of the X Ray and the Electron

- X rays were discovered by Wilhelm Röntgen in 1895.
  - Observed X rays emitted by cathode rays bombarding glass

- Electrons were discovered by J. J. Thomson.
  - Observed that cathode rays were charged particles

Cathode Ray Experiments

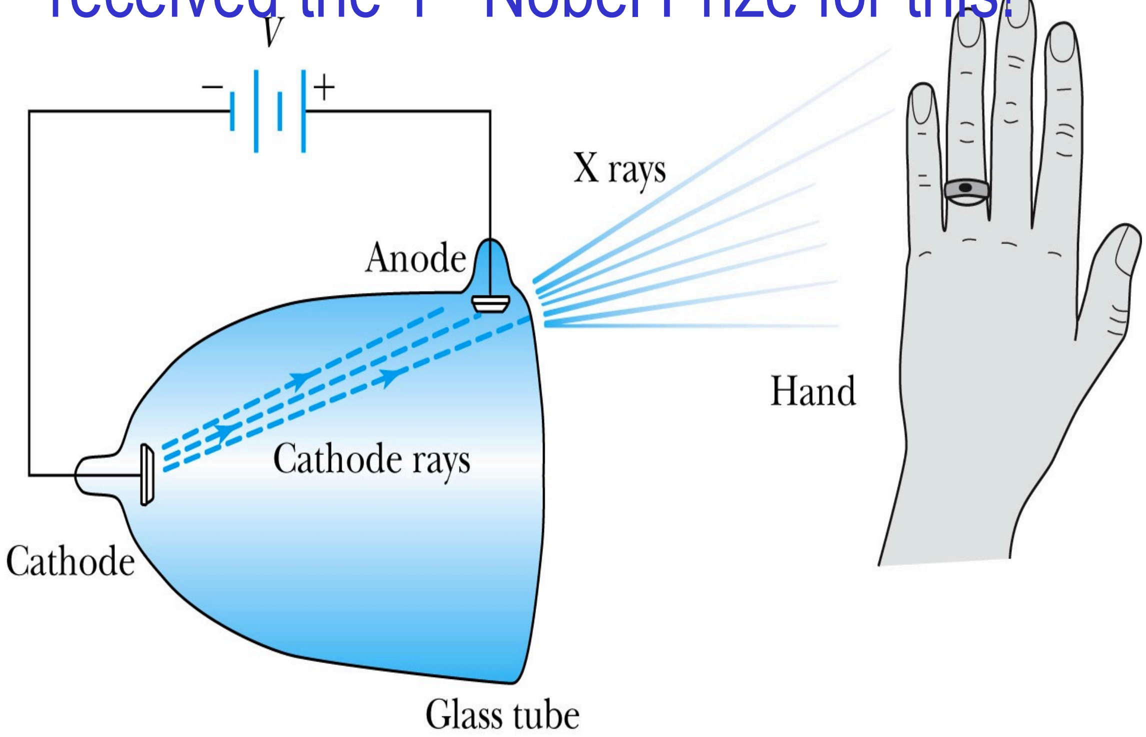
- In the 1890's scientists and engineers were familiar with cathode rays, generated from one of the metal plates in an evacuated tube across a large electric potential
- People thought cathode rays had something to do with atoms.
- It was known that cathode rays could penetrate matter and their properties were under intense investigation during the 1890's.

Observation of x Rays

- Wilhelm Röntgen studied the effect of cathode rays passing through various materials.
- He noticed that a nearby phosphorescent screen glowed during some of these experiments.
- These rays were unaffected by magnetic fields and penetrated materials more than cathode rays.
- He called them **x rays** and deduced that they were produced by the cathode rays bombarding the glass walls of his vacuum tube

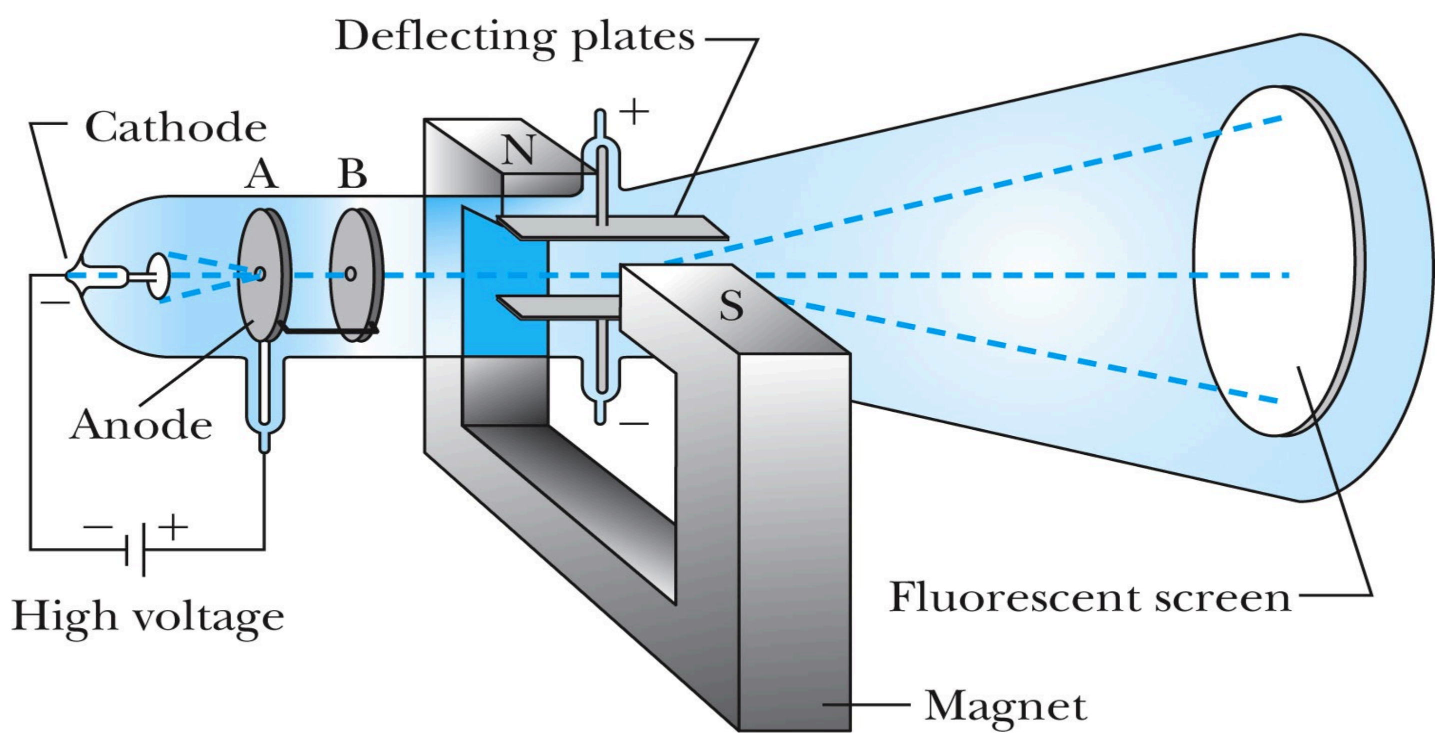
Röntgen's X Ray Tube

- Röntgen produced the X-ray by allowing cathode rays to impact the glass wall of the tube.
- Took image the bones of a hand on a phosphorescent screen.
- Tremendous contribution to medical imaging, and Röntgen received the 1st Nobel Prize for this!



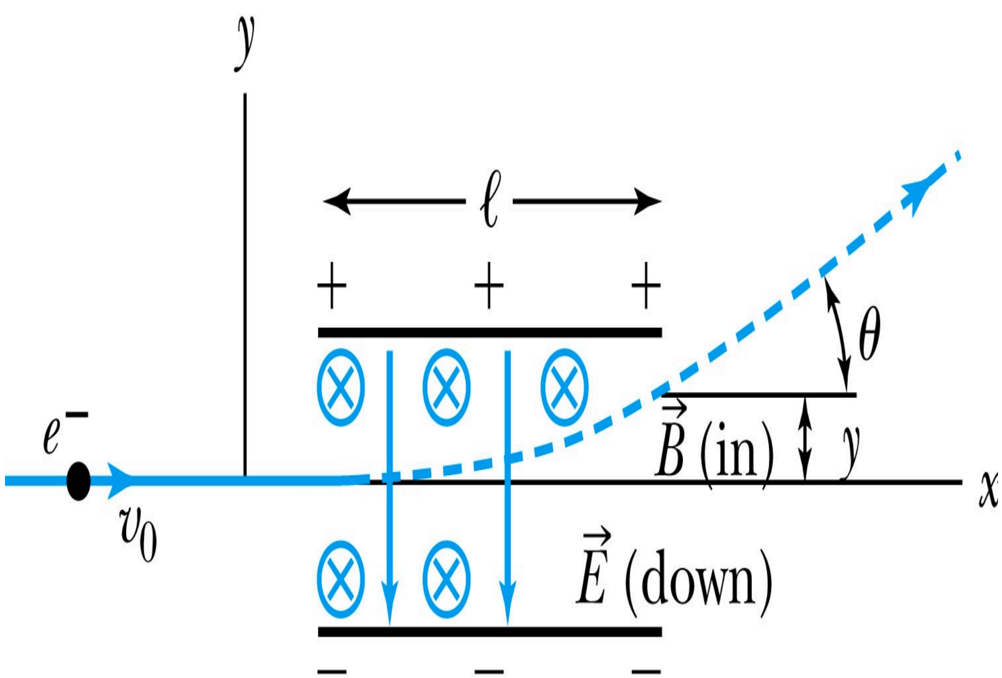
J.J. Thomson's Cathode-Ray Experiment

- Thomson showed that the cathode rays were negatively charged particles (electrons)! How?
  - By deflecting them in electric and magnetic fields.



Thomson's Experiment

- Thomson measured the ratio of the electron's charge to mass by sending electrons through a region containing a magnetic field perpendicular to an electric field.



- Measure the deflection angle with only E!
- Turn on and adjust B field till no deflection!
- What do we know?
  - ℓ, B, E and θ
- What do we not know?
  - v_0, q and m

Calculation of *q/m*

- An electron moving through the electric field w/o magnetic field is accelerated by the force: $F_y = ma_y = qE$
- Electron angle of deflection: $\tan\theta = \frac{v_y}{v_x} = \frac{a_y t}{v_0} = \frac{qE}{m}\frac{l/v_0}{v_0} = \frac{qE}{m}\frac{l}{v_0^2}$
- Adjust the perpendicular magnetic field until it balances E and keeps electrons from deflecting in y-direction

$$\vec{F} = q\vec{E} + q\vec{v}\times\vec{B} = 0$$

$$F_y = -qE + qv_xB = 0 \quad \Rightarrow qE = qv_xB \quad \Rightarrow v_x = \frac{E}{B} = v_0$$

- Charge to mass ratio:

$$\tan\theta = \frac{qE}{m}\frac{l}{v_0^2} \Rightarrow \quad \frac{q}{m} = \frac{v_0^2\tan\theta}{El} = \frac{(E/B)^2\tan\theta}{El} = \frac{E\tan\theta}{B^2 l}$$

Ex 3.1: Thomson's experiment

- In an experiment similar to Thomson's, we use deflecting plates 5.0cm in length with an electric field of 1.2×10^{4}V/m. Without the magnetic field, we find an angular deflection of 30^{o}, and with a magnetic field of 8.8×10^{-4}T we find no deflection. What is the initial velocity of the electron and its q/m?

- First v_0 using E and B, we obtain:

$$v_0 = v_x = \frac{E}{B} = \frac{1.2\times10^{4}}{8.8\times10^{-4}} = 1.4\times10^{7}\, m/s$$

- q/m is then

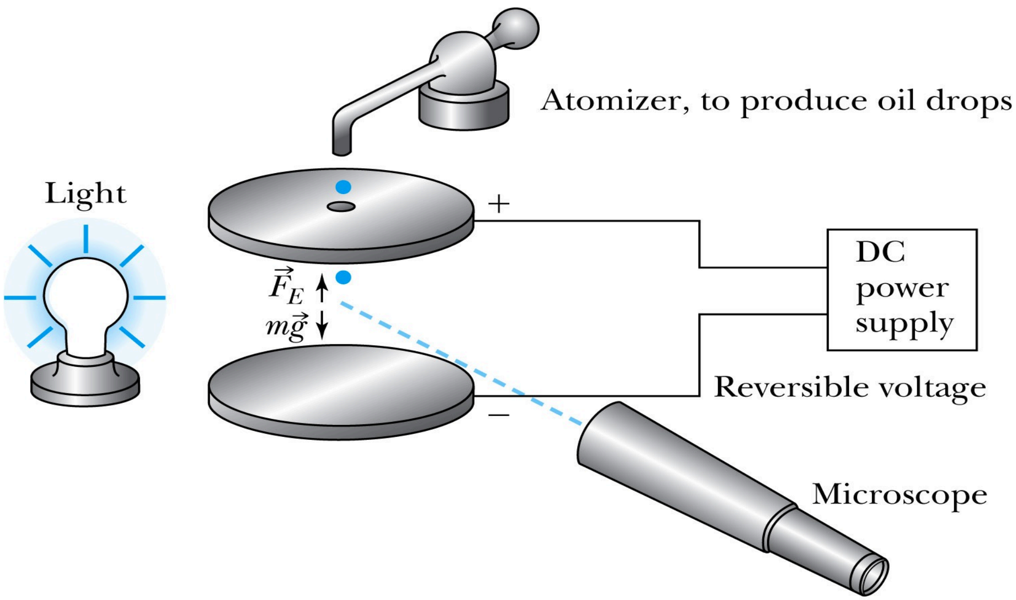
$$\frac{q}{m} = \frac{E\tan\theta}{B^2 l} = \frac{1.2\times10^{4}\tan 30^\circ}{\left(8.8\times10^{-4}\right)^2\cdot 0.5} = 1.8\times10^{11}\, C/kg$$

- What is the actual value of q/m using the known quantities?

$$\frac{q}{m} = \frac{1.6022\times10^{-19}}{9.1094\times10^{-31}} = 1.759\times10^{11}\, C/kg$$

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



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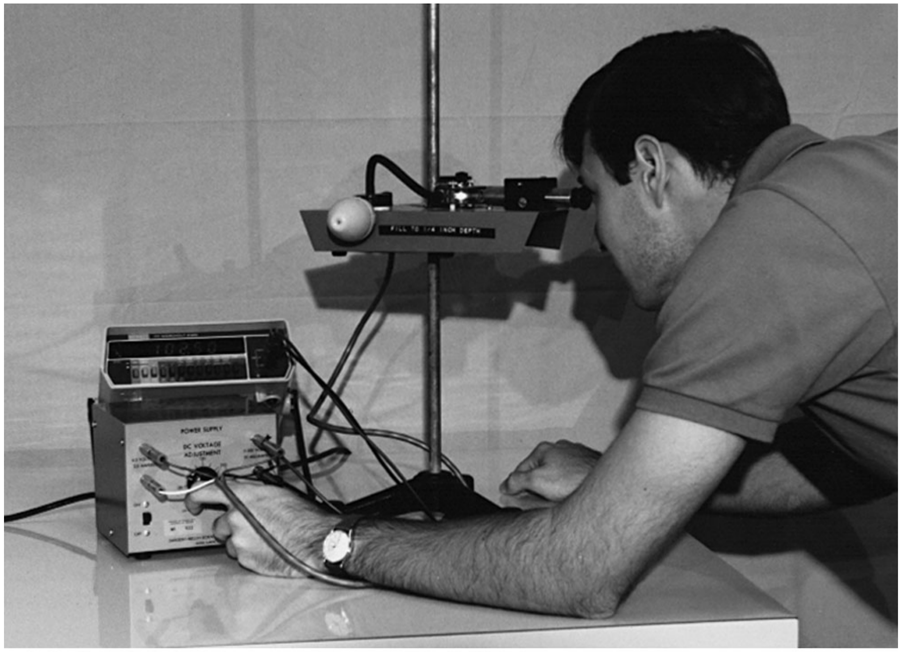


Calculation of the oil drop charge

- 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, 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

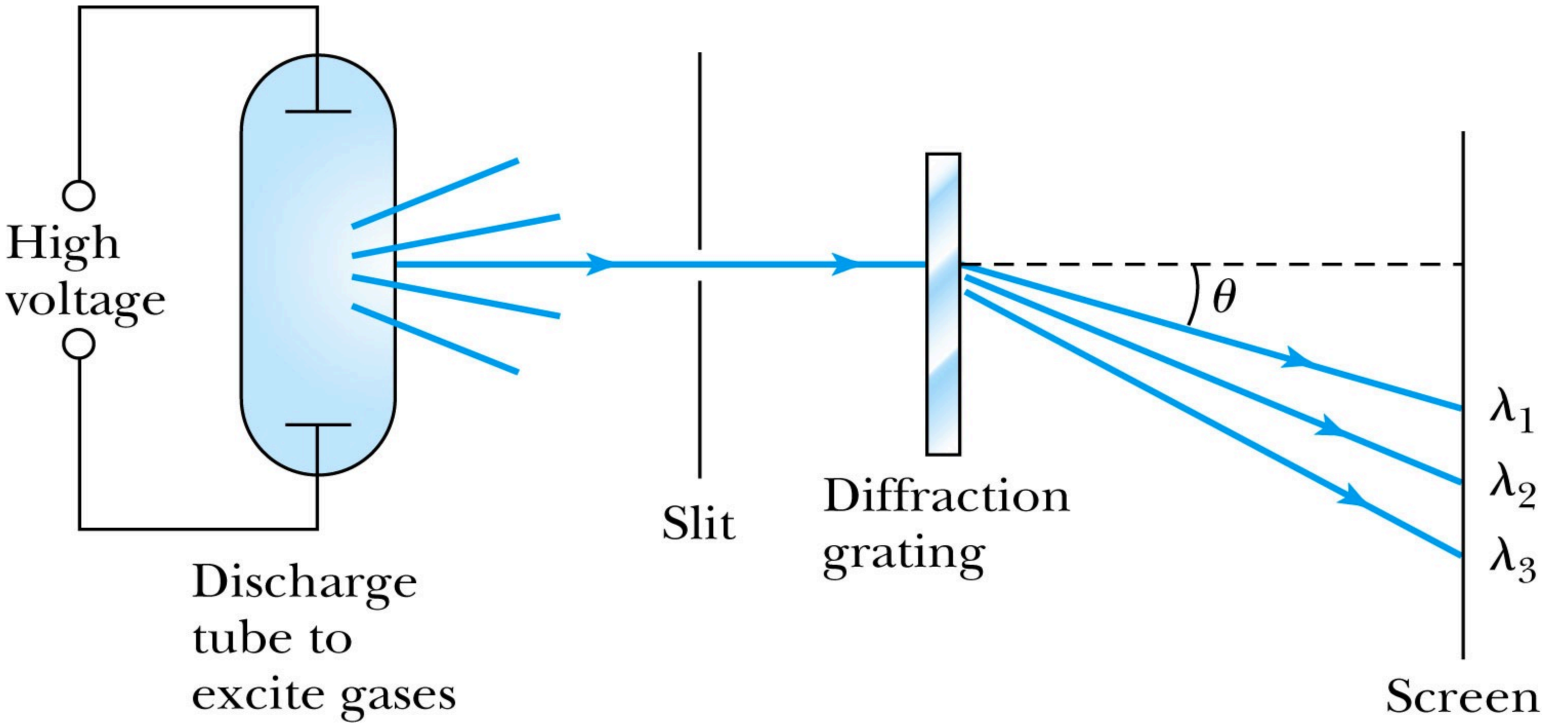
- Chemical elements produce unique wavelengths of light when burned or excited in an electrical discharge.
- Collimated light is passed through a diffraction grating with thousands of ruling lines per centimeter.
  - The diffracted light is separated at an angle θ according to its wavelength λ by the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

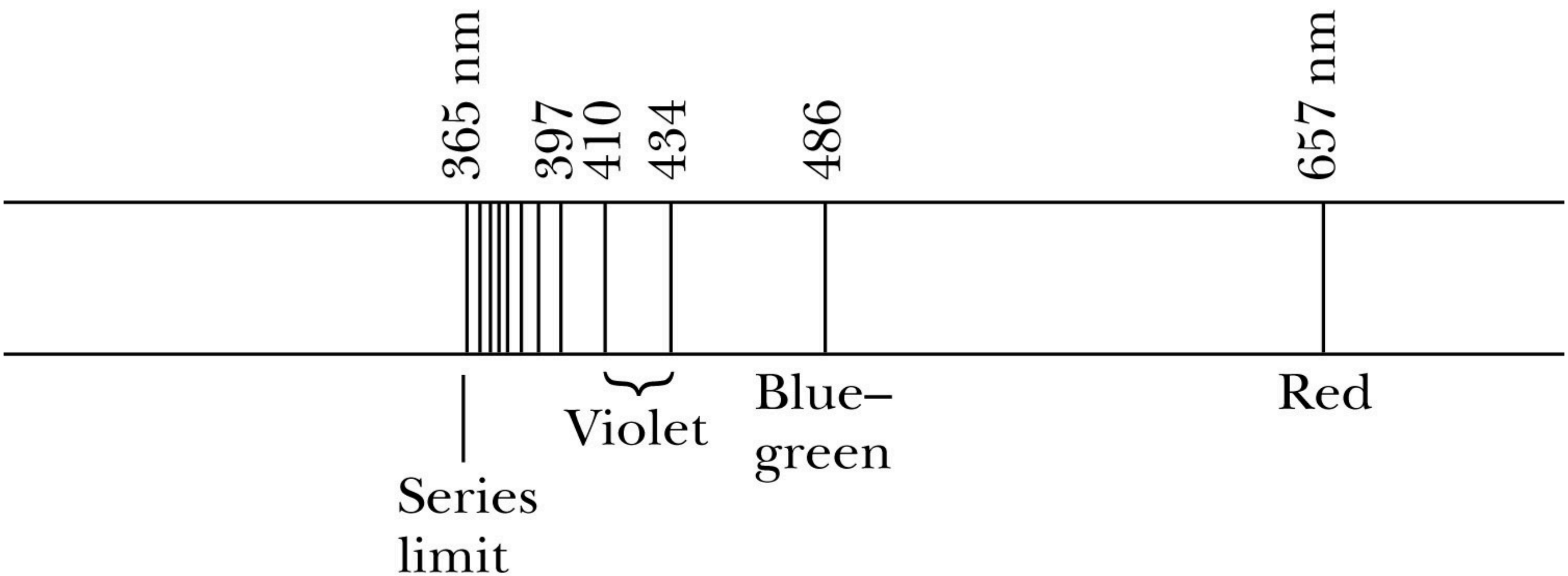


- Diffraction creates a *line spectrum* pattern of light bands and dark areas on the screen.
- Chemical elements and the composition of materials can be identified through the wavelengths of these line spectra

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:

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

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 $\pm e/3$ 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.