PHYS 3313 – Section 001
Lecture #8

Monday, Feb. 10, 2014
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- Binding Energy
- Quantization
- Discovery of the X-ray and the Electron
- Determination of Electron Charge
- Line Spectra
- Blackbody Radiation
- Photoelectric Effect

Announcements

- Reading assignments: CH3.9
- 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 this Monday, Feb. 17

Binding Energy

- The potential energy associated with the force keeping a system together ➔ E_B.
- The difference between the rest energy of the individual particles and the rest energy of the combined bound system.

$$M_{\text{bound system}}c^2 + E_B = \sum_i m_i c^2$$

$$E_B = \sum_i m_i c^2 - M_{\text{bound system}}c^2$$

Examples 2.13 and 2.15

- Ex. 2.13: A 2-GeV proton hits another 2-GeV proton in a head on collision. (proton rest mass = 938MeV/c^2)
  - Compute v, β, p, K and E for each of the initial protons
  - What happens to the kinetic energy?
- Ex. 2.15: What is the minimum kinetic energy the protons must have in the head-on collision in the reaction $p+p \rightarrow \pi^+ + d$, in order to produce the positively charged pion and a deuteron. The mass of pion is 139.6MeV/c^2.

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

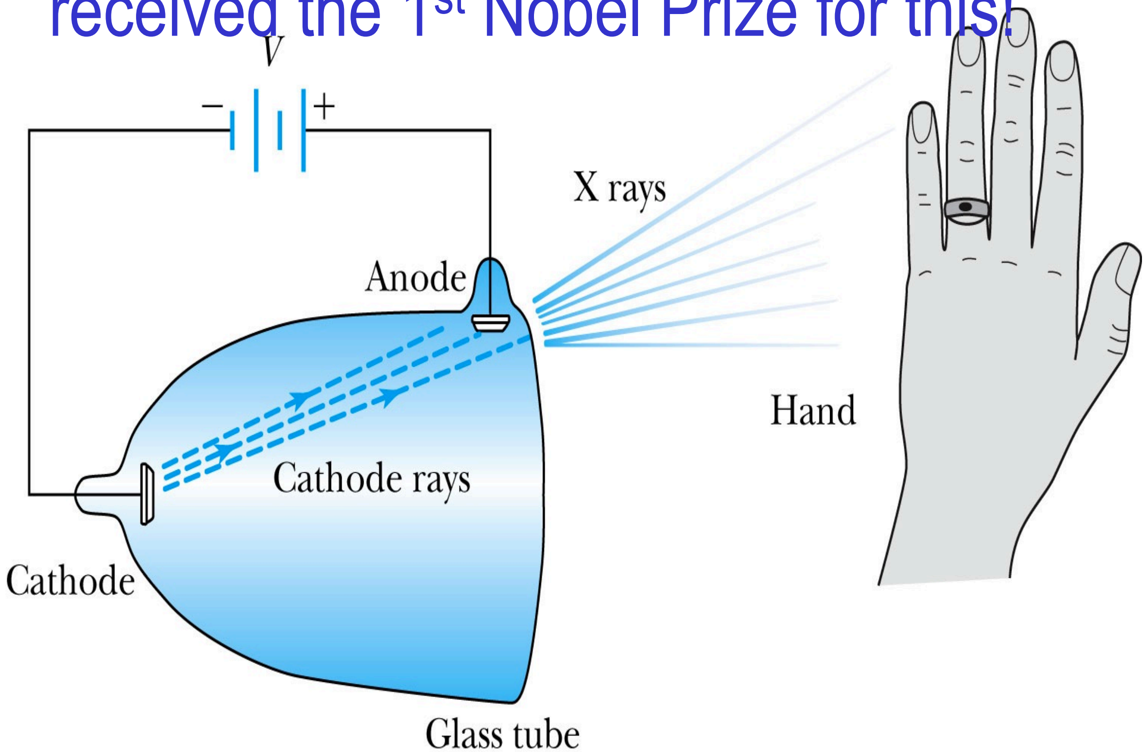
- In the 1890's scientists and engineers were familiar with cathode rays, generated from one of the metal plates in an evacuated tube across a large electric potential
- People thought cathode rays had something to do with atoms.
- It was known that cathode rays could penetrate matter and their properties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

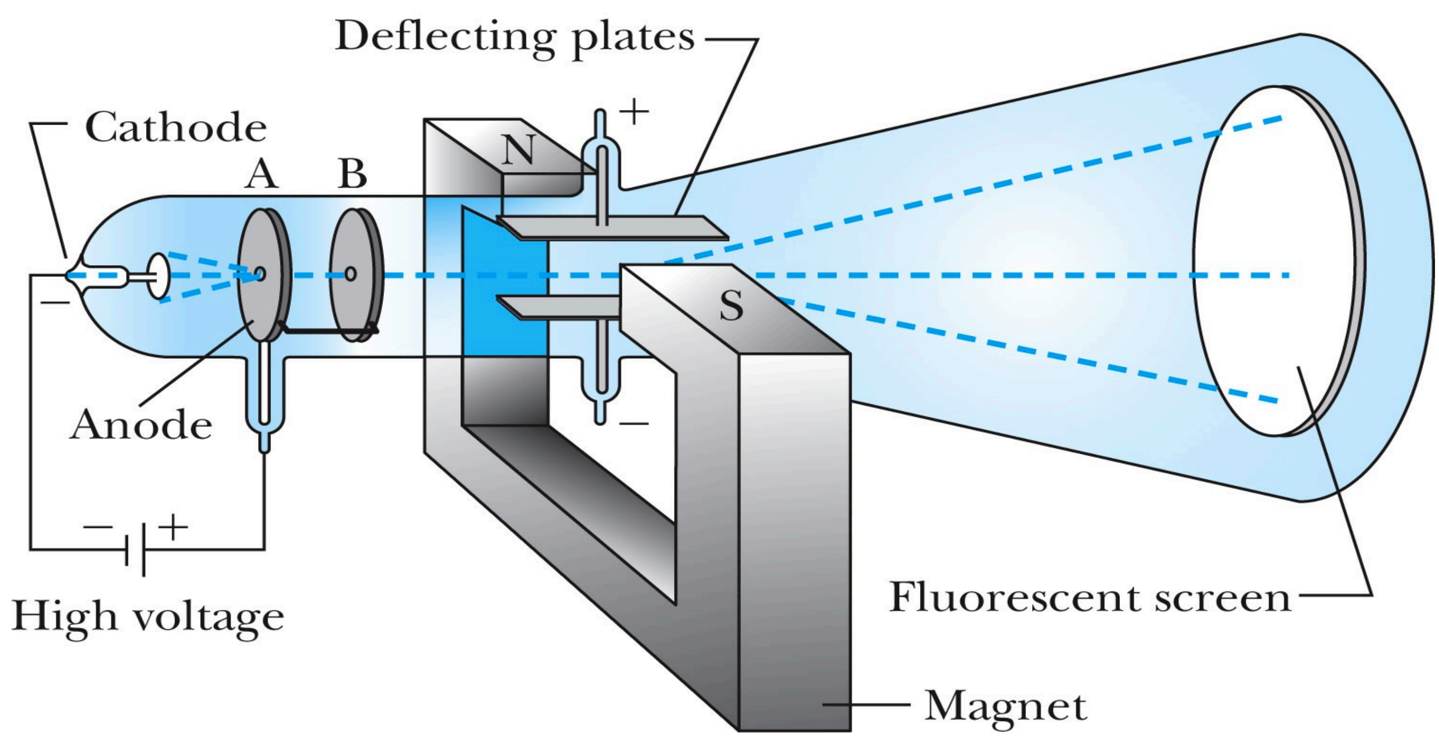
Röntgen's X Ray Tube

- Röntgen produced 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!



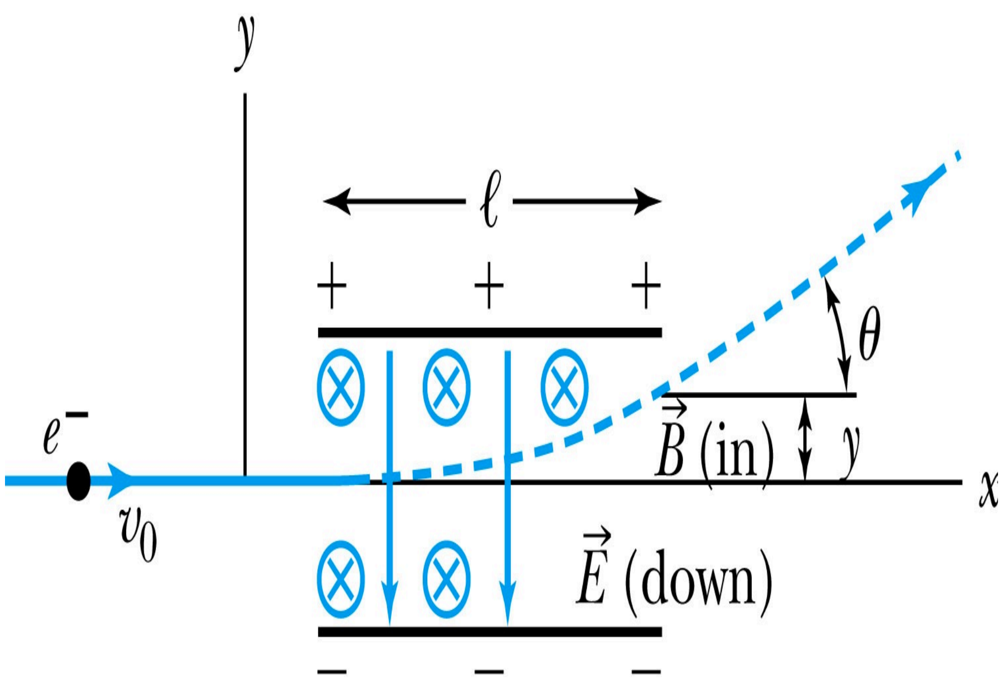
J.J. Thomson's Cathode-Ray Experiment

- 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

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

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

- 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 $1.2\text{x}10^4$V/m. Without the magnetic field, we find an angular deflection of 30^o, and with a magnetic field of $8.8\text{x}10^{-4}$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?

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