PHYS 3313 – Section 001
Lecture #10

Monday, Oct. 1, 2012
Dr. Jaehoon Yu

- Importance of Bohr's Model
- X-ray Scattering
- Bragg's Law
- De Broglie Waves
- Bohr's Quantization
- Electron Scattering
- Wave Properties

Announcements

- Reading assignments: CH4.6 and CH4.7
- Mid-term exam
  - In class on Wednesday, Oct. 10, in PKH107
  - Covers: CH1.1 to what we finish this Wednesday, Oct. 3
  - Style: Mixture of multiple choices and free response problems which are more heavily weighted
  - Mid-term exam constitutes 20% of the total
- Homework #3
  - End of chapter problems on CH4: 5, 14, 17, 21, 23 and 45
  - Due: Monday, Oct. 8
- Colloquium this week
  - 4pm, Wednesday, Oct. 3, SH101
  - Dr. Hongxing Jiang of Texas Tech

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Nitride semiconductors for lighting, solar cells, and microdisplays

Dr. Hongxing Jiang

Texas Tech University

4:00 pm Wednesday October 3, 2012 room 101 SH

Abstract:

This talk will highlight several innovative device architectures pioneered by our group for solid state lighting (SSL) to reduce the cost and enhance the performance, including micro-LED array based high voltage AC- and DC-LEDs, photonic crystals LEDs, and large LED wafers grown on Si substrates. Recent progress on the realization of nitride energy conversion devices including solar cells and thermoelectric (TE) devices will be presented. Our recent achievement of an active-driving blue/green full VGA microdisplay (640 x 480 pixels with 12 μm pixel size) and its advantages over other technologies will also be discussed.

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

Special Project #3

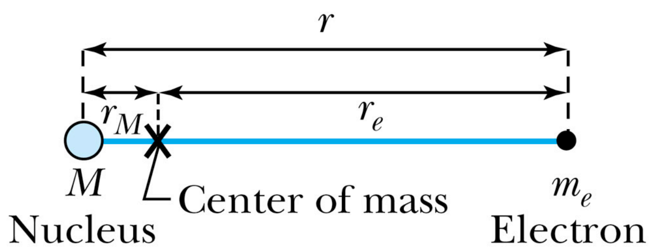
- A total of N_i incident projectile particles of atomic number Z_1 kinetic energy KE scatter on a target of thickness t, atomic number Z_2 and with n atoms per volume. What is the total number of scattered projectile particles at an angle θ? (20 points)
- Please be sure to define all the variables used 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 or your friends'.
- Due is Monday, Oct. 8.

Importance of Bohr's Model

- Demonstrated the need for Plank's constant in understanding atomic structure
- Assumption of quantized angular momentum which led to quantization of other quantities, r, v and E as follows
- Orbital Radius: $$r_n = \frac{4\pi\varepsilon_0\hbar^2}{m_e e^2} n^2 = a_0 n^2$$
- Orbital Speed: $$v = \frac{n\hbar}{mr_n} = \frac{\hbar}{ma_0}\frac{1}{n}$$
- Energy levels: $$E_n = \frac{e^2}{8\pi\varepsilon_0 a_0 n^2} = \frac{E_0}{n^2}$$

Successes and Failures of the Bohr Model

- The electron and hydrogen nucleus actually revolved about their mutual center of mass ➔ reduced mass correction!!



- All we need is to replace m_e with atom's **reduced mass**.

$$\mu_e = \frac{m_e M}{m_e + M} = \frac{m_e}{1 + m_e / M}$$

- The Rydberg constant for infinite nuclear mass, R_∞ is replaced by *R*.

$$R = \frac{\mu_e}{m_e} R_\infty = \frac{1}{1 + m_e / M} R_\infty = \frac{\mu_e e^4}{4\pi c \hbar^3 \left(4\pi\varepsilon_0\right)^2}$$

For H: $R_H = 1.096776 \times 10^7 \, m^{-1}$

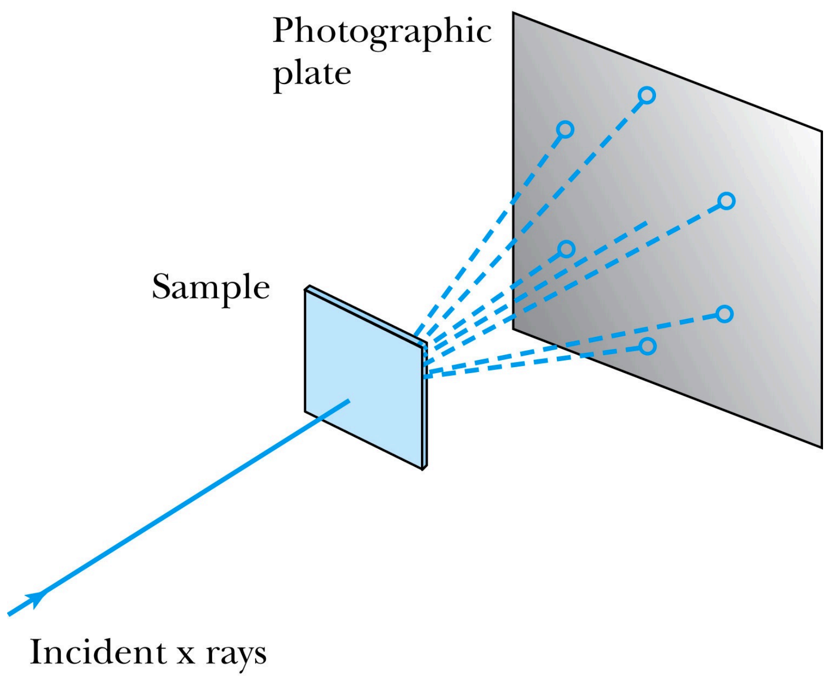
Limitations of the Bohr Model

The Bohr model was a great step of the new quantum theory, but it had its limitations.

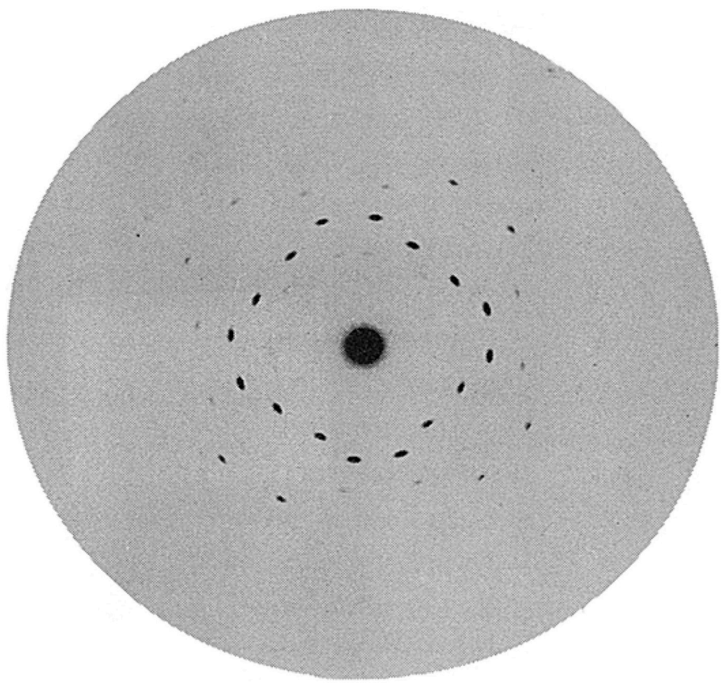
1) Works only to single-electron atoms
   - Even for ions ➔ What would change?
   - The charge of the nucleus $\frac{1}{\lambda} = Z^2 R\left(\frac{1}{n_l^2} - \frac{1}{n_u^2}\right)$
2) Could not account for the intensities or the fine structure of the spectral lines
   - Fine structure is caused by the electron spin
   - When a magnetic field is applied, spectral lines split
3) Could not explain the binding of atoms into molecules

X-Ray Scattering

- Max von Laue suggested that if x rays were a form of electromagnetic radiation, interference effects should be observed. (Wave property!!)
- Crystals act as three-dimensional gratings, scattering the waves and producing observable interference effects.



(a)



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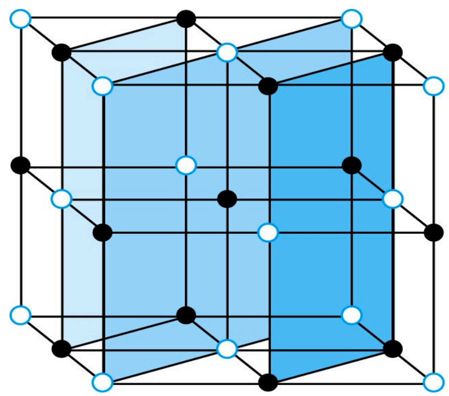
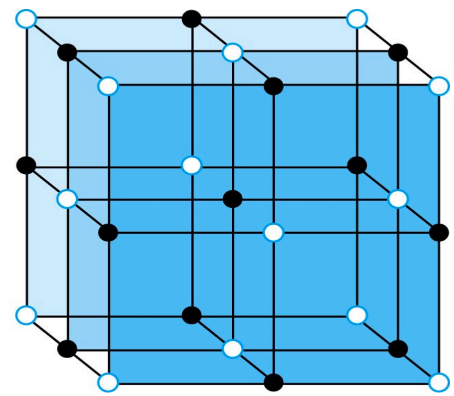
Bragg's Law

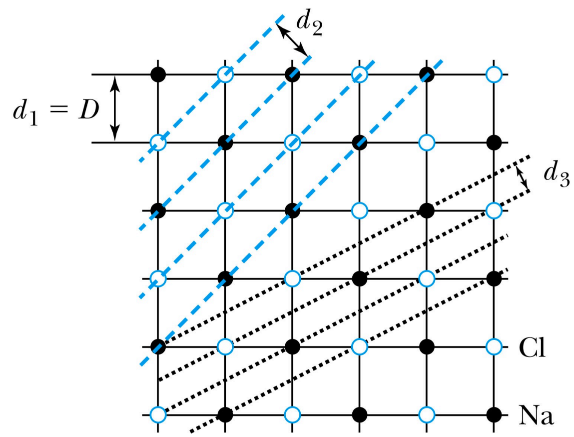
- William Lawrence Bragg interpreted the x-ray scattering as the reflection of the incident x-ray beam from a unique set of planes of atoms within the crystal.
- There are two conditions for constructive interference of the scattered x rays:

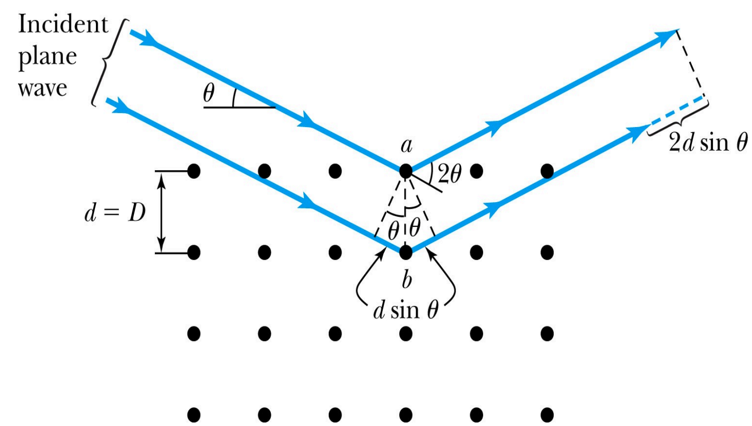
1) The angle of incidence must equal the angle of reflection of the outgoing wave. (total reflection)
2) The difference in path lengths between two rays must be an integral number of wavelengths.





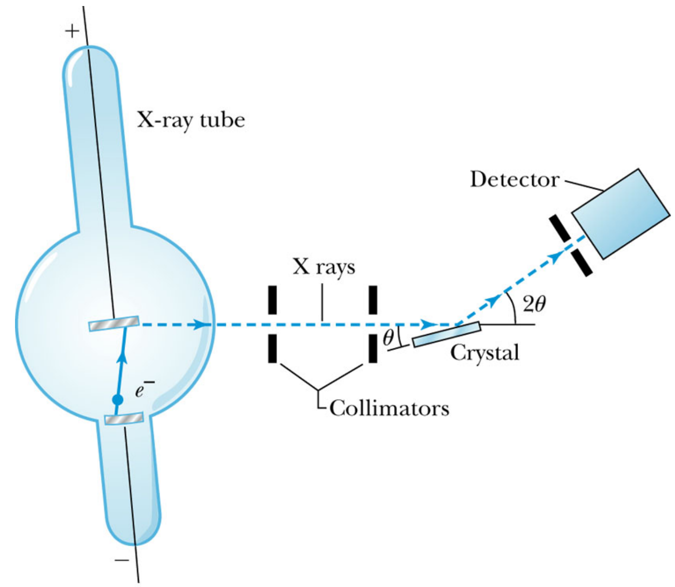
- **Bragg's Law:**
- $n\lambda = 2d \sin\theta$
- (n = integer)

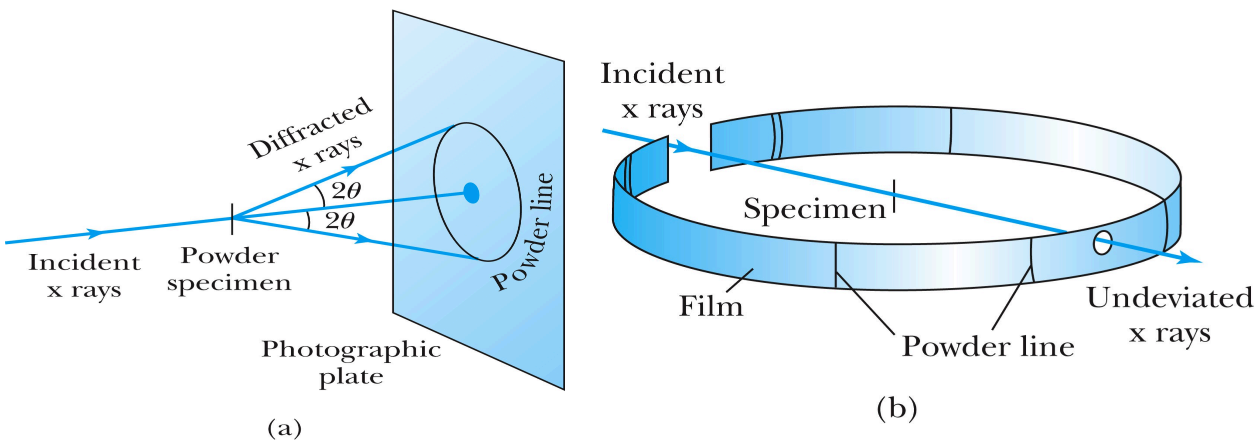


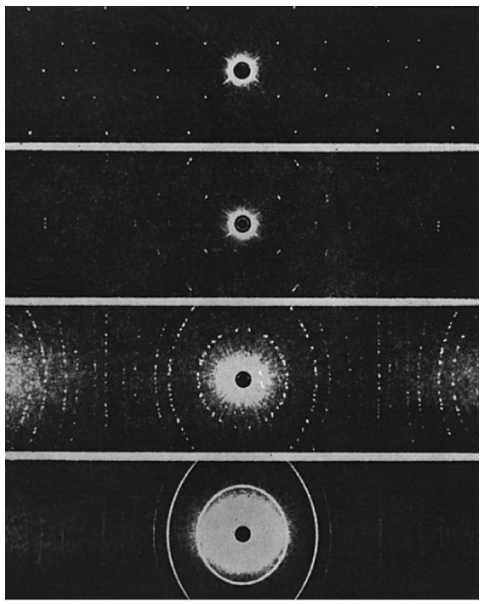


The Bragg Spectrometer

- A Bragg spectrometer scatters x rays from several crystals. The intensity of the diffracted beam is determined as a function of scattering angle by rotating the crystal and the detector.
- When a beam of x rays passes through the powdered crystal, the dots become a series of rings due to random arrangement.







(c)

Ex 5.1: Bragg's Law

X rays scattered from rock salt (NaCl) are observed to have an intense maximum at an angle of 20° from the incident direction. Assuming n=1 (from the intensity), what must be the wavelength of the incident radiation?

- Bragg's law: $n\lambda = 2d \sin\theta$
- *What do we need to know to use this? The lattice spacing d!*
- *We know n=1 and 2θ=20°.*
- *We use the density of NaCl to find out what d is.*

$$\frac{N_{molecules}}{V} = \frac{N_A \rho_{NaCl}}{M} = \frac{\left(6.02\times10^{23}\, molecules/mol\right)\cdot\left(2.16\, g/cm^3\right)}{58.5\, g/mol} =$$

$$= 2.22\times10^{22}\frac{molecules}{cm^3} = 4.45\times10^{22}\frac{atoms}{cm^3} = 4.45\times10^{28}\frac{atoms}{m^3}$$

$$\frac{1}{d^3} = 4.45\times10^{28}\frac{atoms}{m^3} \Rightarrow d = \frac{1}{\sqrt[3]{4.45\times10^{28}}} = 0.282nm$$

$$\lambda = 2d\sin\theta = 2\cdot 0.282\cdot\sin 10^o = 0.098nm$$

De Broglie Waves

- Prince Louis V. de Broglie suggested that mass particles should have wave properties similar to electromagnetic radiation → many experiments supported this!
- Thus the wavelength of a matter wave is called the de Broglie wavelength:

$$\lambda = \frac{h}{p}$$

- Since for a photon, $E = pc$ and $E = hf$, the energy can be written as

$$E = hf = pc = p\lambda f$$

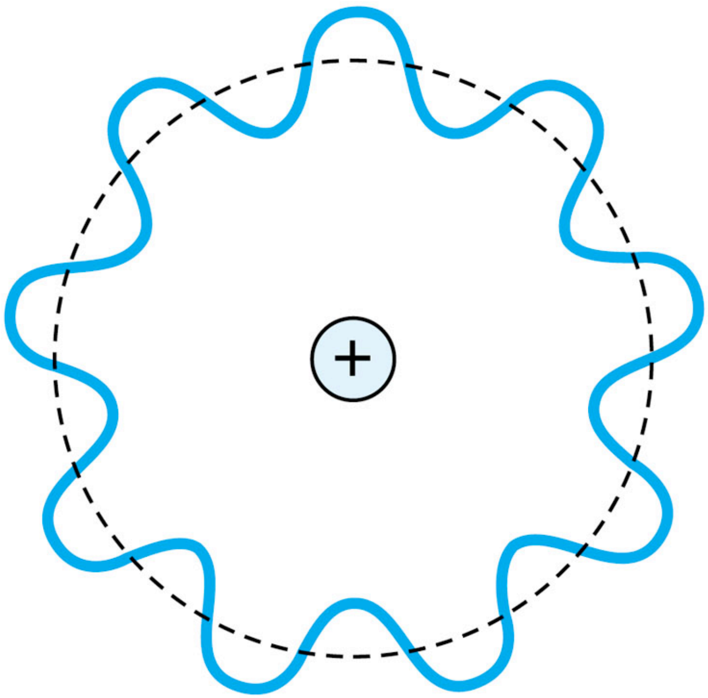
Bohr's Quantization Condition

- One of Bohr's assumptions concerning his hydrogen atom model was that the angular momentum of the electron-nucleus system in a stationary state is an integral multiple of $h/2\pi$.
- The electron is a standing wave in an orbit around the proton. This standing wave will have nodes and be an integral number of wavelengths.

$$2\pi r = n\lambda = n\frac{h}{p}$$

- The angular momentum becomes:

$$L = rp = \frac{nh}{2\pi p}p = n\frac{h}{2\pi} = n\hbar$$



Ex 5.2: De Broglie Wavelength

Calculate the De Broglie wavelength of (a) a tennis ball of mass 57g traveling 25m/s (about 56mph) and (b) an electron with kinetic energy 50eV.

- What is the formula for De Broglie Wavelength? $\lambda = \frac{h}{p}$
- (a) for a tennis ball, m=0.057kg.

$$\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{0.057\cdot 25} = 4.7\times10^{-34}\,m$$

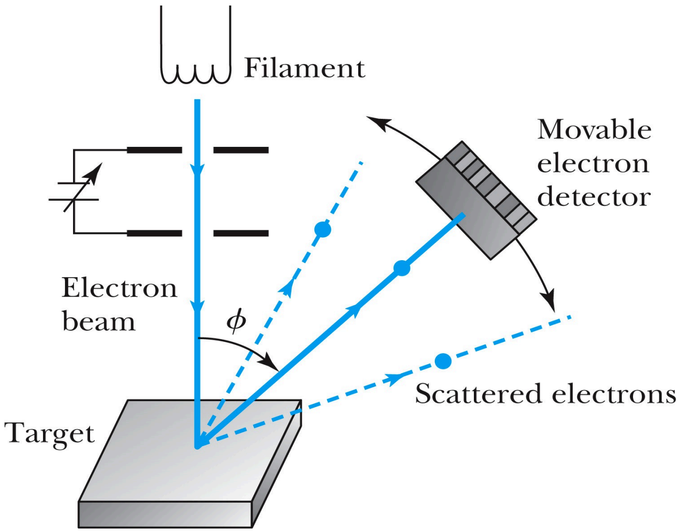
- (b) for electron with 50eV KE, since KE is small, we can use non-relativistic expression of electron momentum!

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m_eK}} = \frac{hc}{\sqrt{2m_ec^2K}} = \frac{1240eV\cdot nm}{\sqrt{2\cdot 0.511MeV\cdot 50eV}} = 0.17nm$$

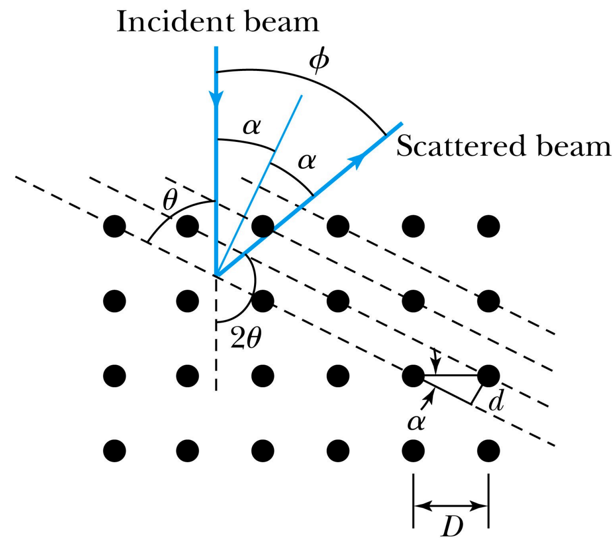
- What are the wavelengths of you running at the speed of 2m/s? What about your car of 2 metric tons at 100mph? How about the proton with 14TeV kinetic energy?
- What is the momentum of the photon from a green laser?

Electron Scattering

- Davisson and Germer experimentally observed that electrons were diffracted much like x rays in nickel crystals. ➔ direct proof of De Broglie wave!



$$\lambda = \frac{D\sin\phi}{n}$$



- George P. Thomson (1892–1975), son of J. J. Thomson, reported seeing the effects of electron diffraction in transmission experiments. The first target was celluloid, and soon after that gold, aluminum, and platinum were used. The randomly oriented polycrystalline sample of SnO_2 produces rings as shown in the figure at right.