PHYS 3313 – Section 001
Lecture #16

Monday, March 27, 2017
Dr. Jaehoon Yu

- X-ray Scattering
- Bragg's Law
- de Broglie Waves
- Bohr's Quantization Conditions
- Electron Scattering

Announcements

- Reminder: Quadruple extra credit
  - Colloquium on April 19, 2017
  - Speaker: Dr. Nigel Lockyer, Director of Fermilab
  - Title: Particle Physics: Science without Borders; Neutrinos Go Global
  - Make your arrangements to take advantage of this opportunity
  - Seats may be limited
- I strongly encourage you to start the writing process ASAP
  - Deadline for report submission: April 26, 2017

Research Projects

1. Each of the 9 research groups has an assigned research topic

Research Topics

1. Blackbody radiation
2. Michelson–Morley Experiment
3. The Photoelectric Effect
4. The Brownian Motion
5. Compton Effect
6. Discovery of Electron
7. Rutherford Scattering
8. Super-conductivity
9. The Discovery of Radioactivity

Research Projects

1. Each of the 9 research groups has an assigned research topic
2. Study the topic as a group, looking up references
   - Original theory or Original observation
   - Experimental proofs or Theoretical prediction + subsequent experimental proofs
   - Importance and the impact of the theory/experiment
3. Each member of the group writes a 5 – 7 page report, including figures (must not copy!!)
   - 10% of the total grade
   - Can share the theme and facts but you must write your own!
   - Due beginning of the class Wed. Apr. 26, 2017
4. Each group presents a 10+2min power point talk
   - 5% of the total grade
   - Date and time will be announced close to the end of the semester

Reminder: Research Project Report

1. Must contain the following at the minimum
   – Original theory or Original observation
   – Experimental proofs or Theoretical prediction + subsequent experimental proofs
   – Importance and the impact of the theory/experiment
   – Conclusions and future prospects
   – The reference to the original paper must be included!
   – Bibliography referring to web site must be minimized (<20%)

Project Report Template

Title Goes Here Like This with The First Letter of Each Word Capital

PHYS-3313, Spring 2017
MM DD, 2017

Author Name
Department of XYZ
The University of Texas at Arlington

Abstract

Describe briefly and to the point the content of the note in about a paragraph or so, including the brief conclusion. The font of the main body must be Times New Roman 12pt. Tables and figures must be numbered in sequence as they appear as Table 1 or Figure 1. Each has its own numbering system. They must be placed as close to the text in which they are referred. They must have associated captions attached to them. These explain what the contents of the figure or table are. Captions must be Times New Roman 11pt. References must be placed to where the reference is relevant in a square bracket with a number counted in sequence as they appear but only in the main body not in the abstract.

1. **Introduction**
   Describe what this paper is all about and how this note is organized [1] and motivate the readers.

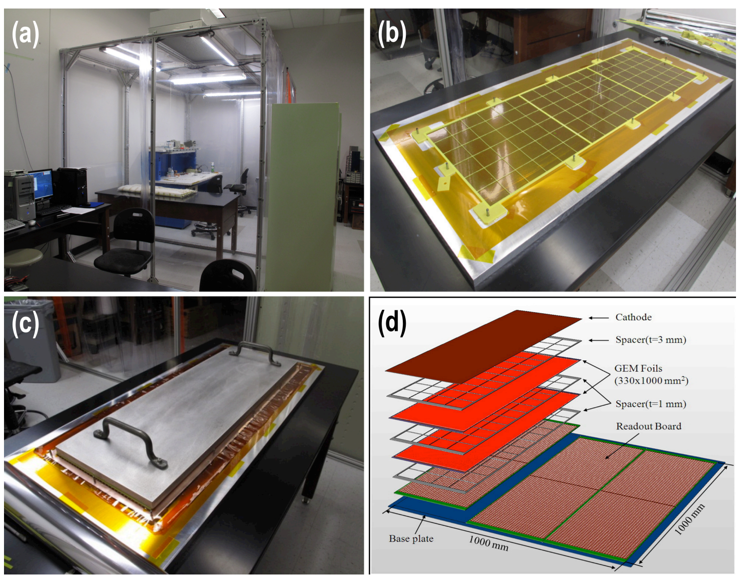


Figure. 1 (a) 12'x8' clean room for LGEM construction (b) An LGEM layer on an assembly jig held by alignment pins throughout the sides (c) glue curing process with heavy flattening pressing plane (d) Layout of a full $100\text{cm} \times 100\text{cm}$ GEM DHCAL active layer.

2. **Original Theory or Experiment**
   Describe the original theory or experiment that prompted this particular paper here.
3. **Theoretical predictions and/or experimental proofs**
   Describe the subsequent experimental proof of the theory or of the paper.
4. **Importance and the impact of the theory/experiment of the paper**
   Describe in detail the importance and impact of the paper. What did we do with the knowledge of the paper?
5. **Conclusions and Future Work**
   Describe what your conclusions are on this paper and what can be done more.

Bibliography← your references go here and in the text with the same reference numbers in order as they appear in the paper. They get assigned the ref. number just once. You then use them throughout the paper.

1. D. Decamp et al., ALEPH Collaboration, Nucl. Inst. Meth. **A360**, 481 (1995).
2. R. Bouclier, *et al.*, "The Gas Electron Multiplier (GEM)," IEEE Trans. Nucl. Sci. **NS-44**, 646[1] (1997).

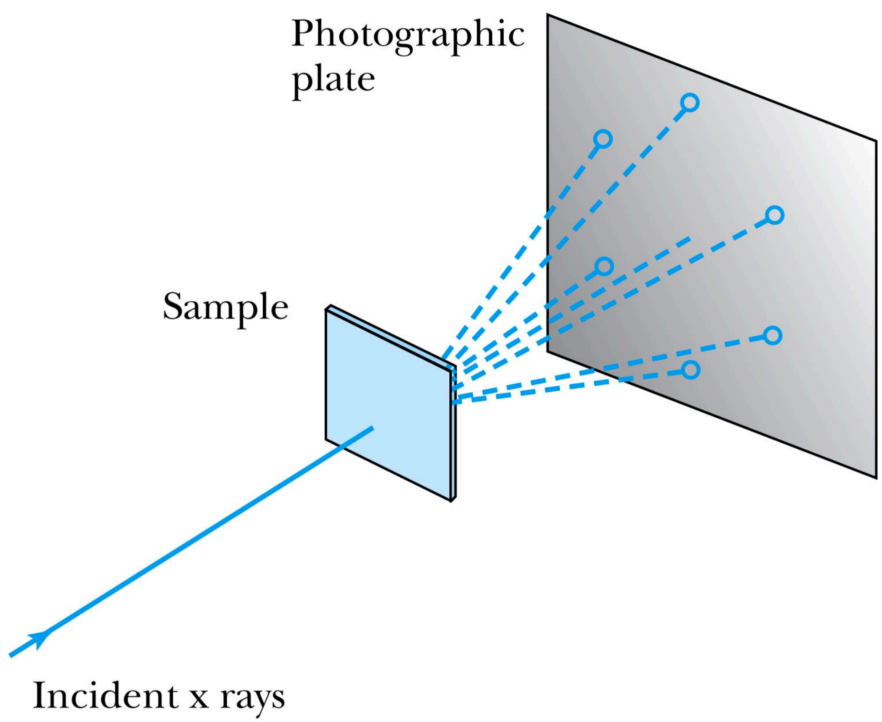
[1]

Research Presentations

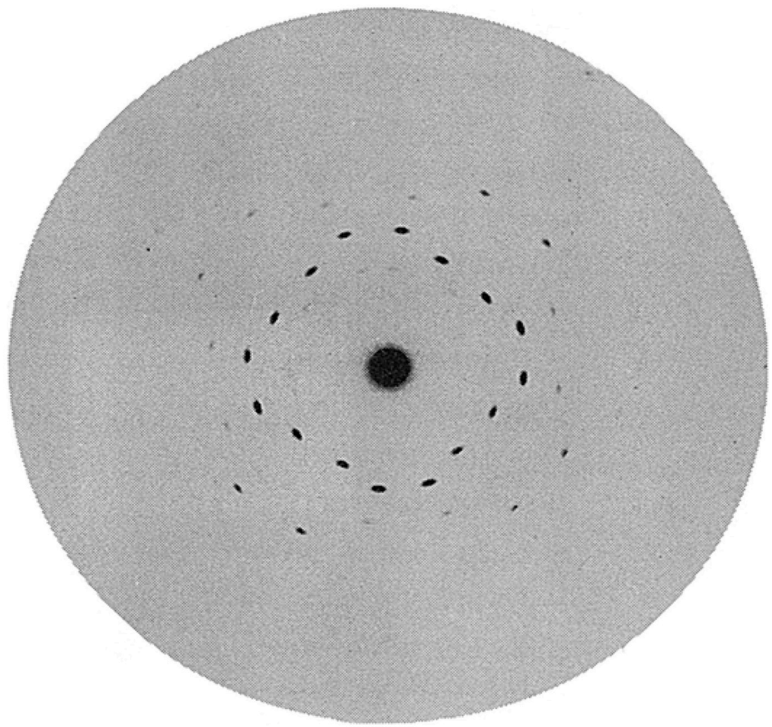
- Each of the 9 research groups makes a 10+2min presentation
  - 10min presentation + 2min Q&A
  - All presentations must be in power point
  - I must receive all final presentation files by 8pm, Sunday, Apr. 23, 2017
    - No changes are allowed afterward
  - The representative of the group makes the presentation followed by all group members' participation in the Q&A session
- Date and time:
  - In class Monday and Wednesday, Apr. 24 and 26, 2017
- Important metrics
  - Contents of the presentation: 60%
    - Inclusion of all important points as mentioned in the report
    - The quality of the research and making the right points
  - Quality of the presentation itself: 15%
  - Presentation manner: 10%
  - Q&A handling: 10%
  - Staying in the allotted presentation time: 5%
  - Judging participation and sincerity: 5%

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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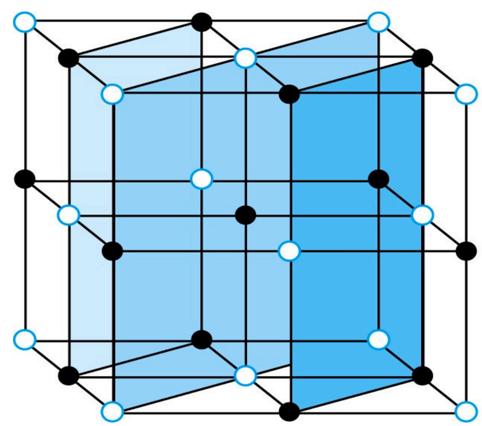
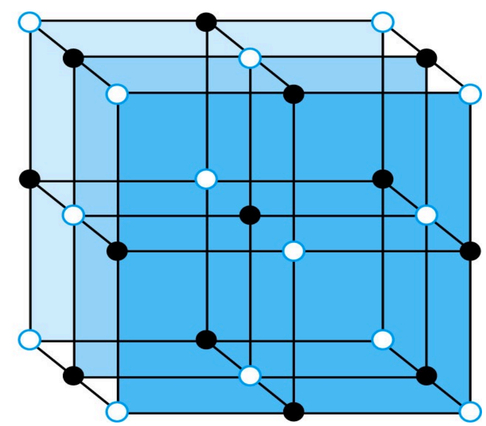
Bragg's Law

- 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 a 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.

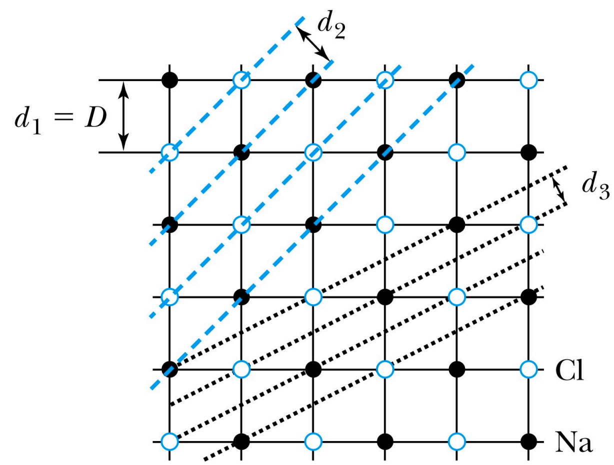


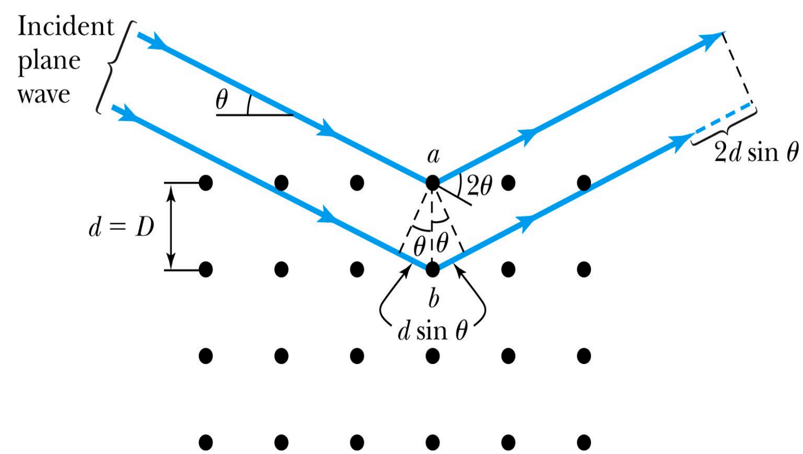


- **Bragg's Law:**

  $n\lambda = 2d \sin \theta$

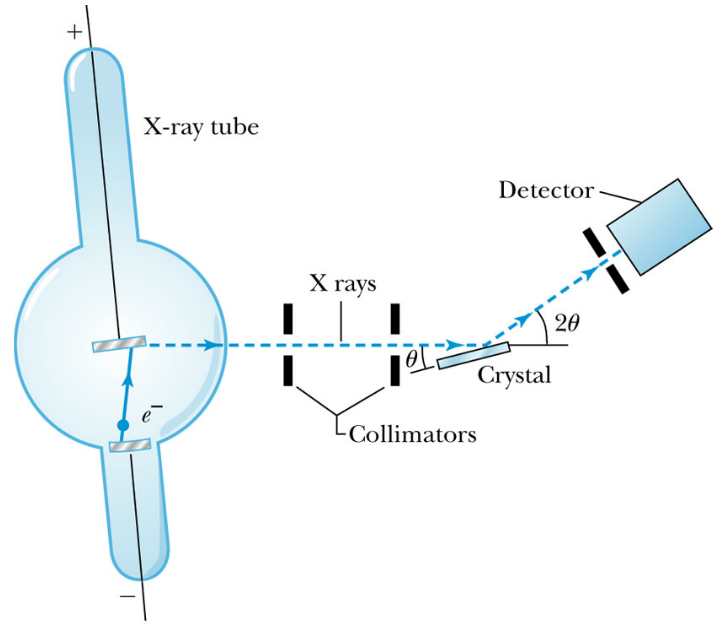
  (n = integer)

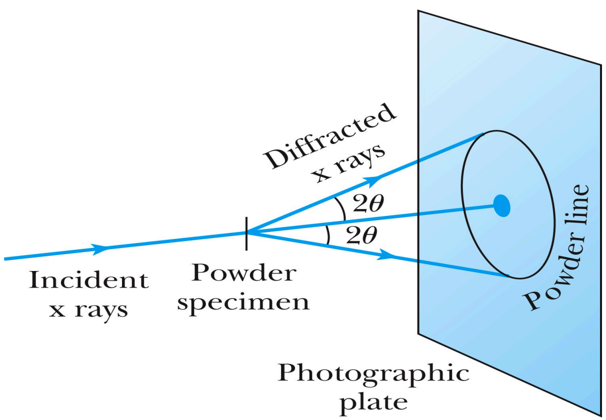




The Bragg Spectrometer

- 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.





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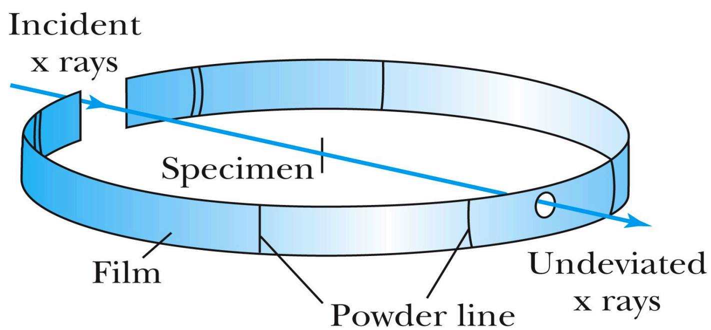

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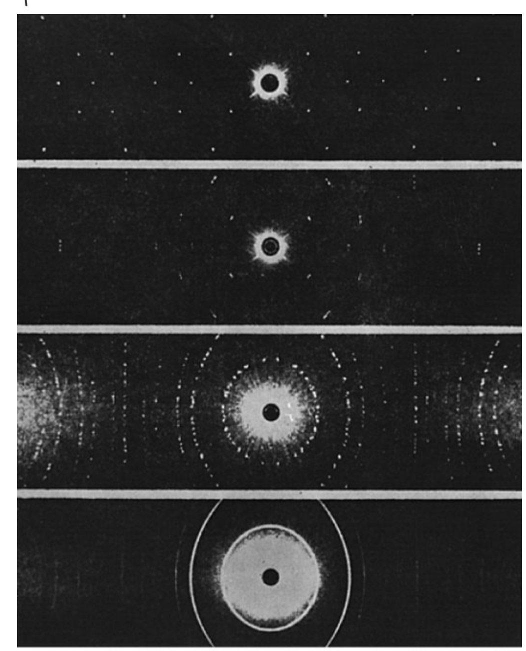


(c)

Ex 5.1: Bragg's Law

X rays scattered from rock salt (NaCl) are observed to have an intense maximum at an angle of 20º 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=20º.*
- *We use the density of NaCl to find out what d is.*

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

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

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

$$\lambda = 2d\sin\theta = 2\cdot0.282\cdot\sin10^o = 0.098nm$$

De Broglie Waves

- Louis V. de Broglie suggested that matter 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:

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

- This can be considered as the probing beam length scale
- Since for a photon, $E = pc$ and $E = hf$, the energy can be written as

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

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 (λ=532nm)?

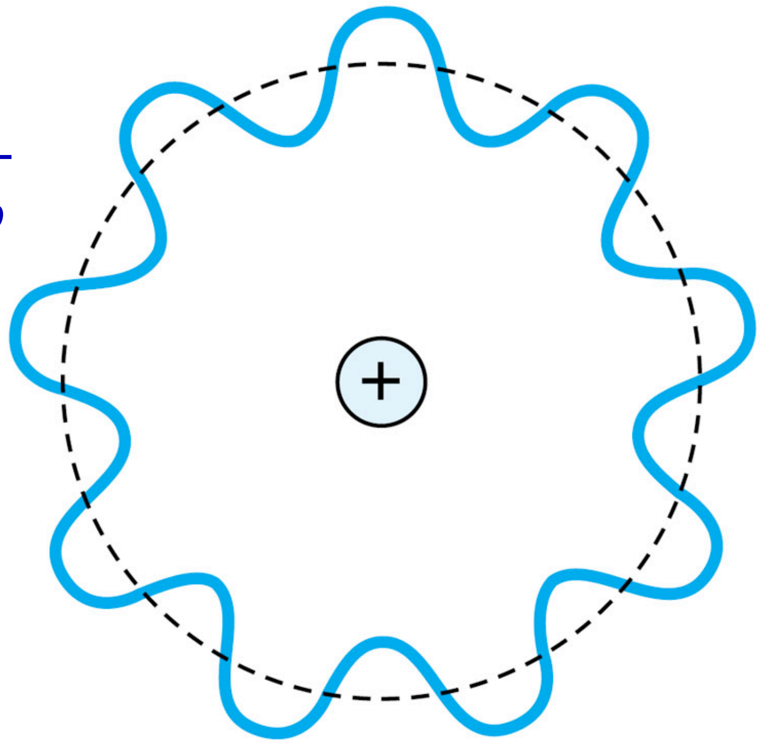
Bohr's Quantization Condition

- 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 in an integral number of wavelengths.

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

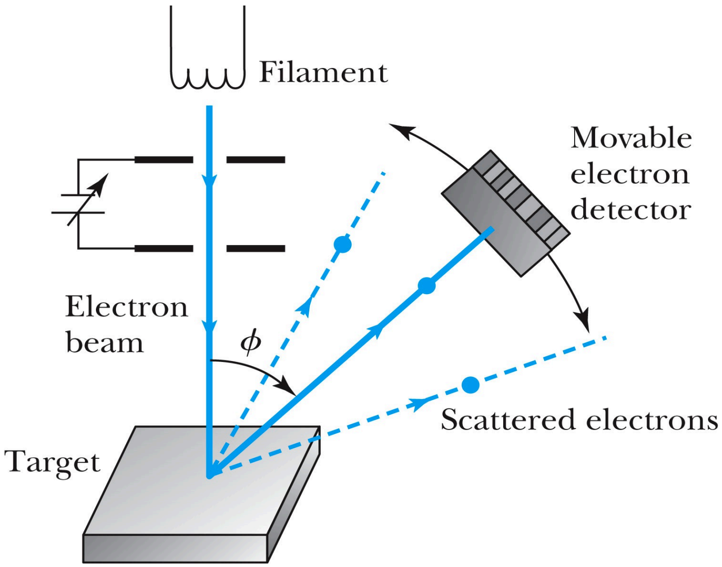
- The angular momentum becomes:

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

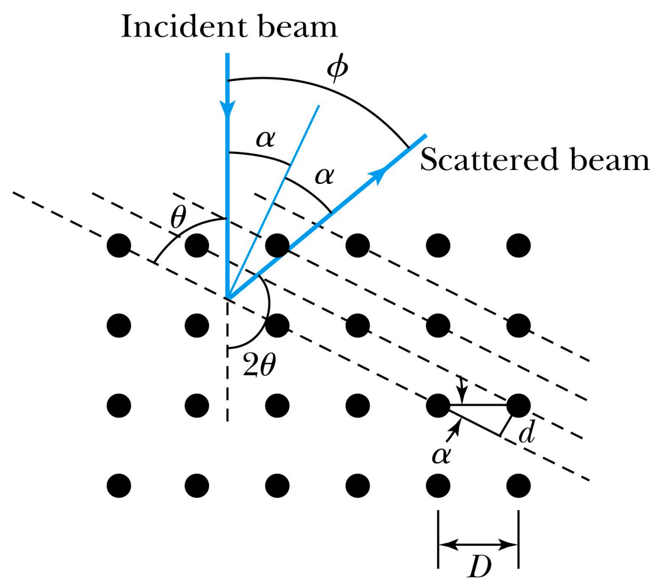


Electron Scattering

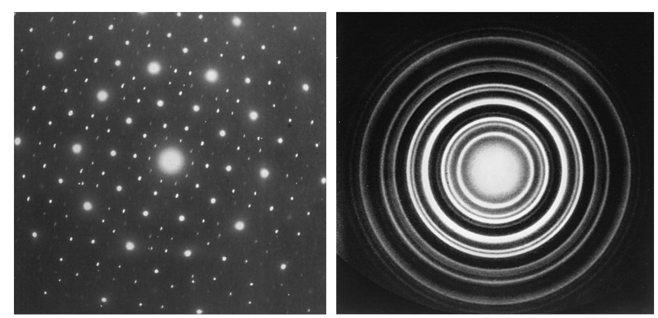
- Davisson and Germer experimentally observed that electrons were diffracted much like X rays in nickel crystals. ➔ direct proof of de Broglie wave!



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



- 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.



(a) (b)

So particle/wave properties?

- Photons, which we thought were waves, act particle like (eg Photoelectric effect or Compton Scattering)
- Electrons, which we thought were particles, act wave particle like (eg electron scattering)
- de Broglie: All matter has an intrinsic wavelength
  - Wavelength is inversely proportional to momentum
  - The more massive… the smaller the wavelength… the harder to observe the wavelike properties
  - So while photons appear mostly wavelike, electrons (next lightest particle!) appear mostly particle like.
- How can we reconcile the wave/particle views?