Physics 2D Lecture Slides
Week of May 4, 2009
part 1

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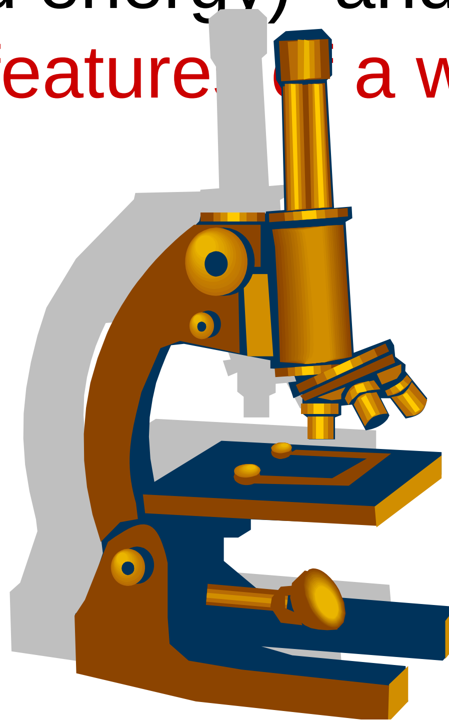
UCSD Physics

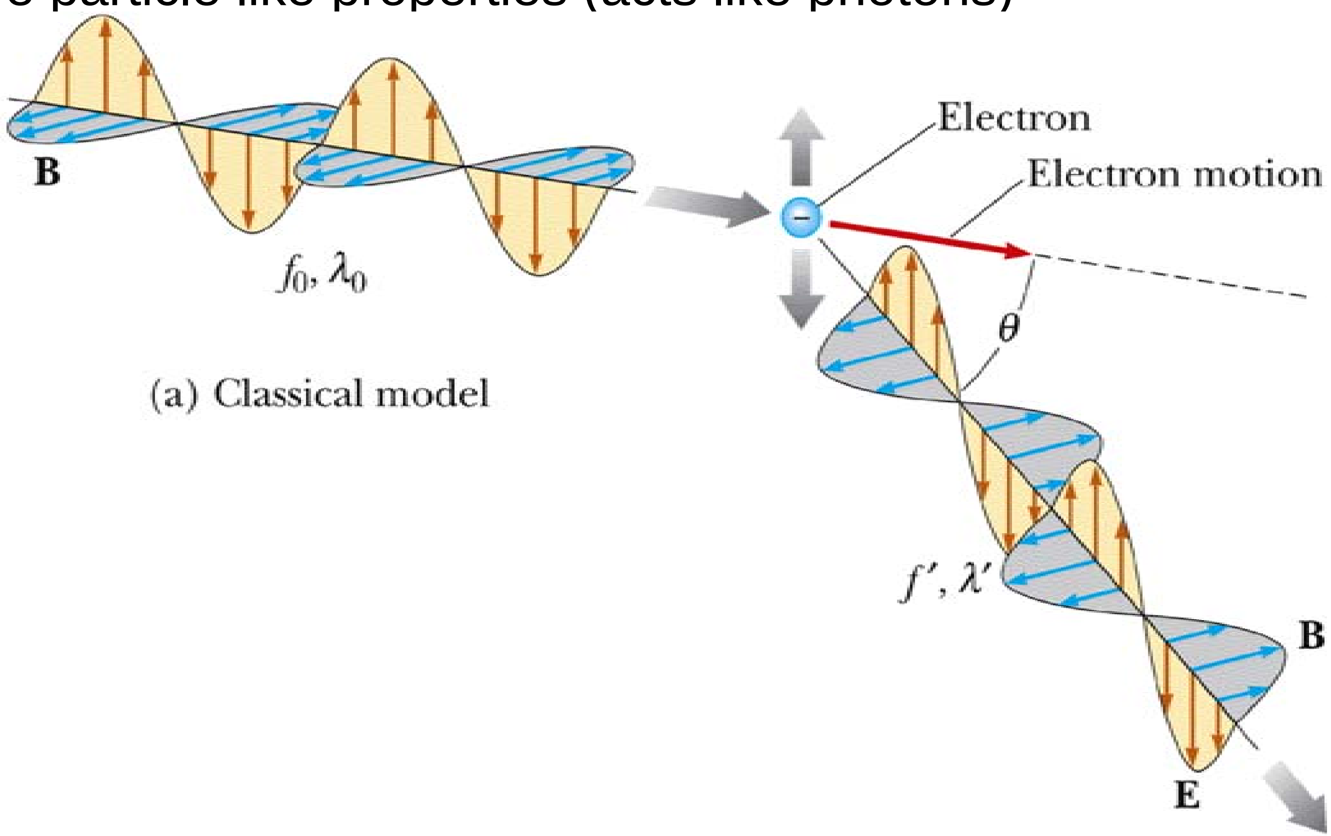
- X rays are EM waves of low wavelength, high frequency (and energy) and demonstrate characteristic features of a wave
  - Interference
  - Diffraction



- To probe into a structure you need a light source with wavelength much smaller than the features of the object being probed
  - Good Resolution $\rightarrow$ $\lambda \ll \Delta$
- X rays allows one probe at atomic size (10^{-10})m

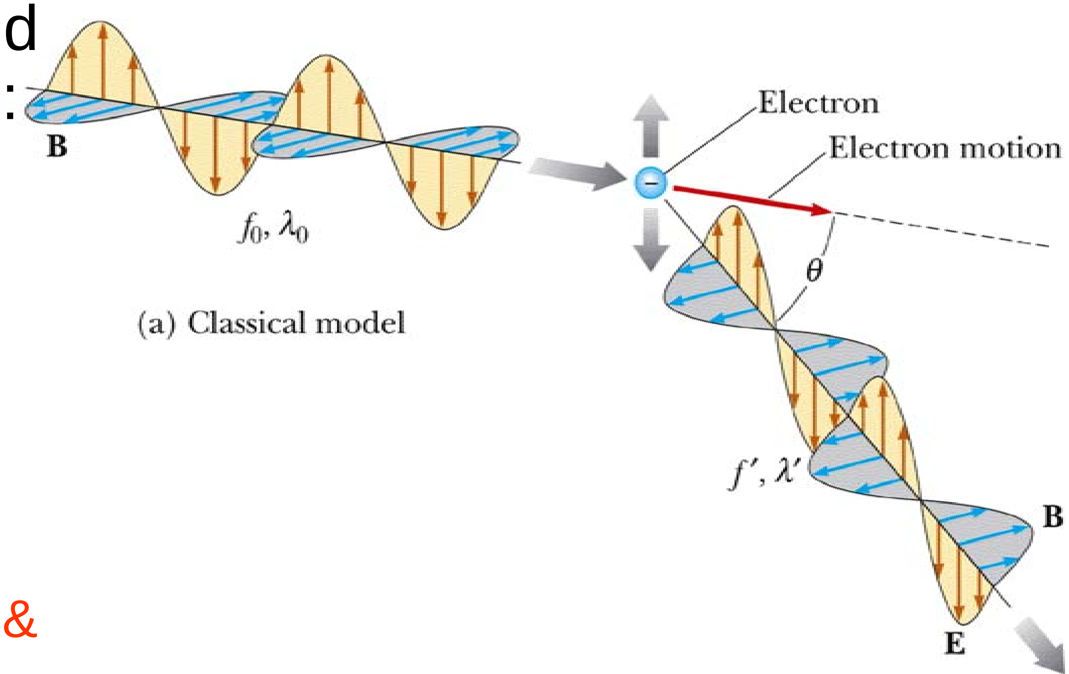
Compton Scattering : Quantum Pool !

- 1922: Arthur Compton (USA) proves that X-rays (EM Waves) have particle like properties (acts like photons)



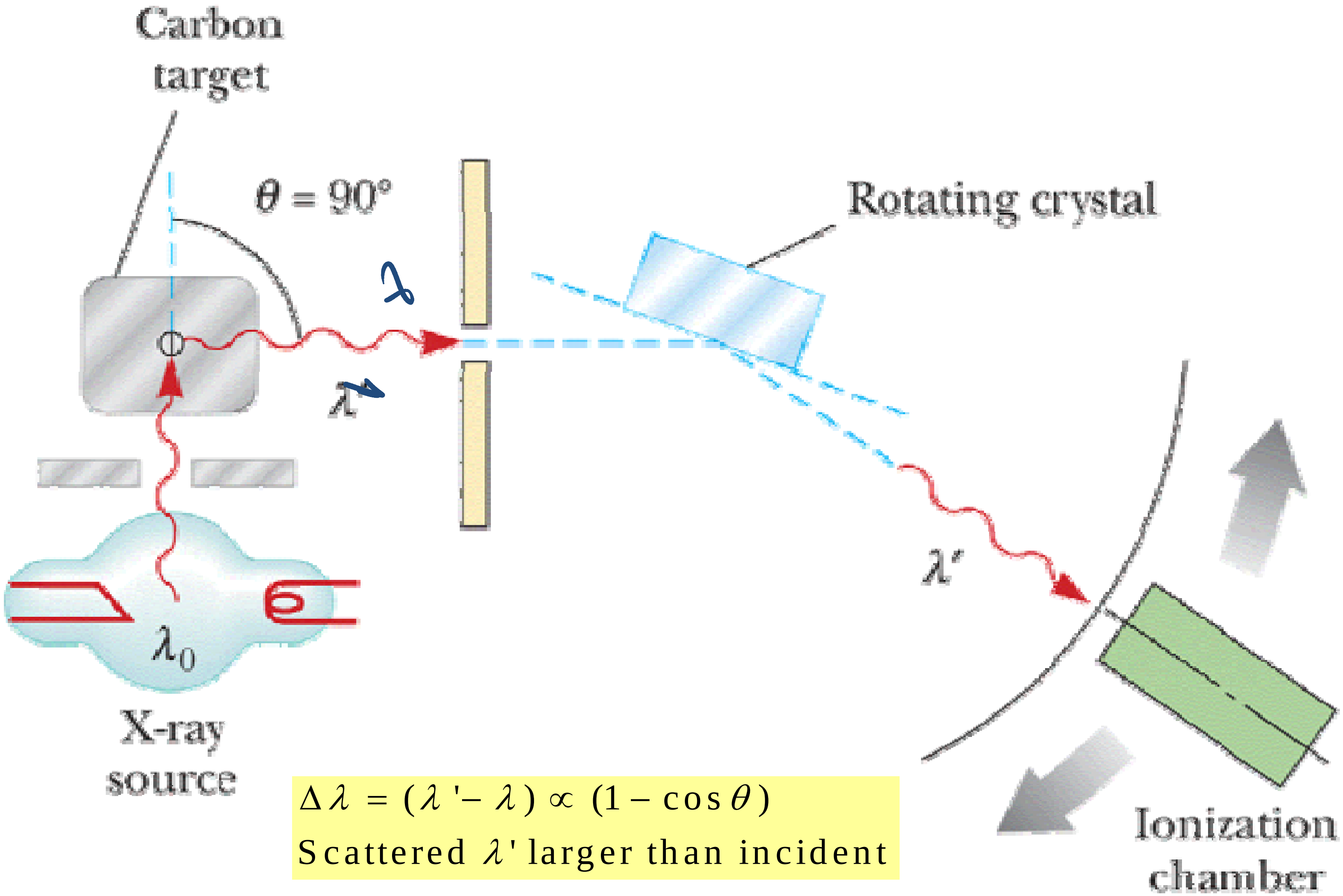
Compton Effect: what should Happen Classically?

- Plane wave [f,λ] incident on a surface with loosely bound electrons →interaction of E field of EM wave with electron: **F** = e**E**
- Electron oscillates with $f = f_{incident}$
- Eventually radiates spherical waves with $f_{radiated} = f_{incident}$
  - At all scattering angles, Δf & Δλ must be zero
- Time delay while the electron gets a "tan" : soaks in radiation



(a) Classical model

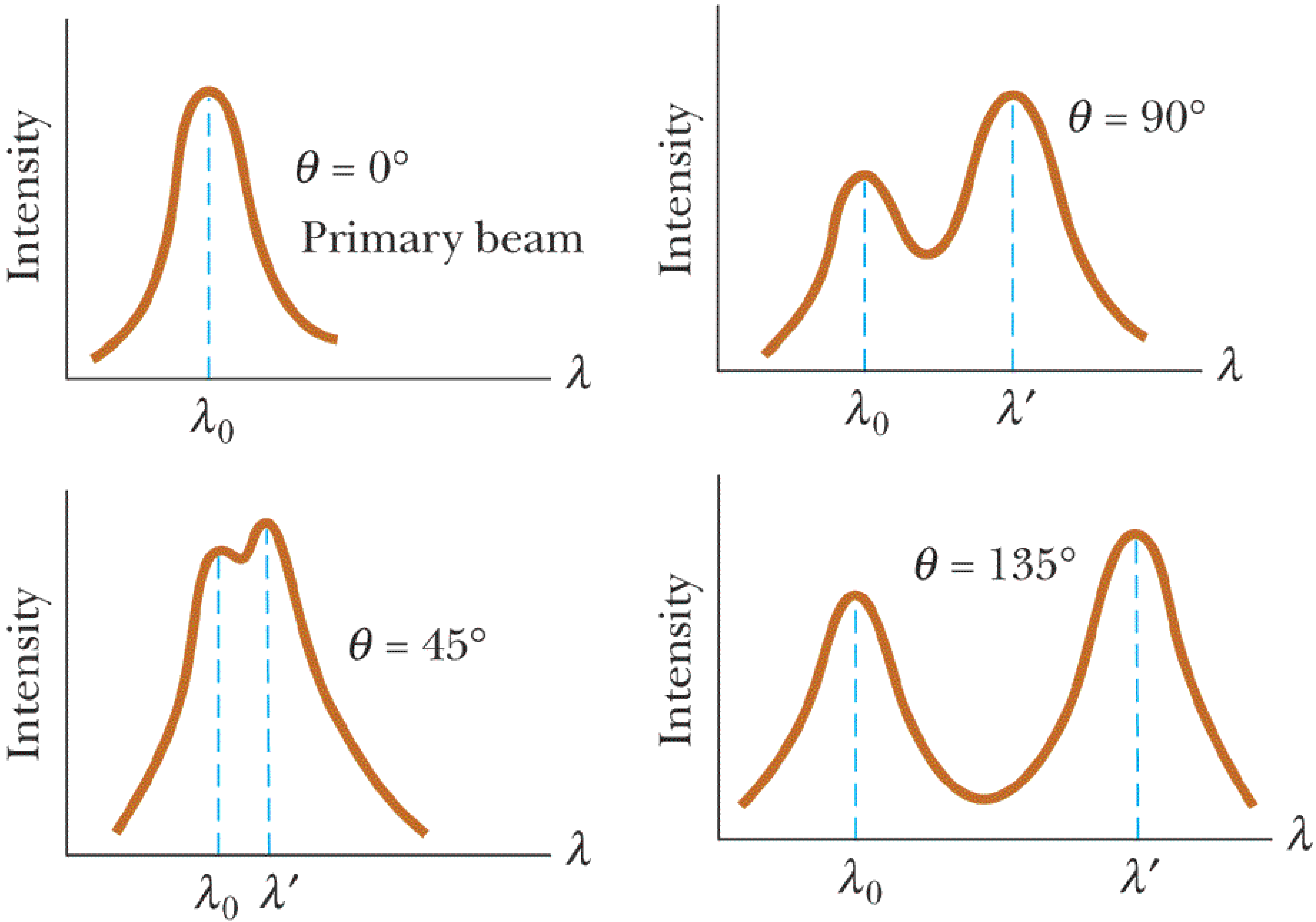
Compton Scattering : Setup & Results



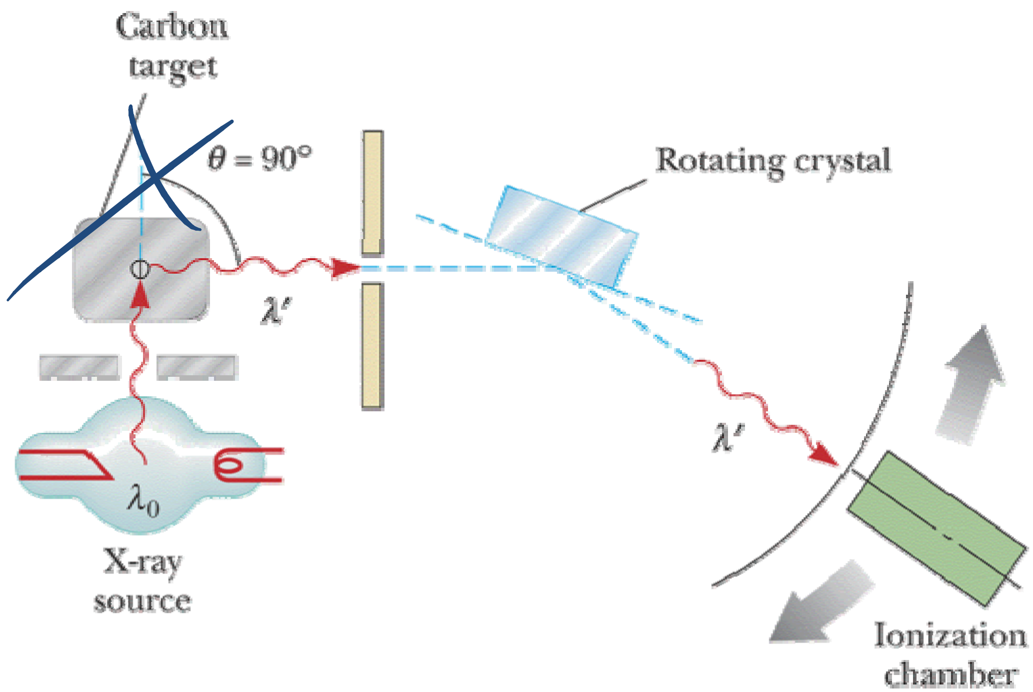
$\Delta\lambda = (\lambda' - \lambda) \propto (1 - \cos\theta)$

Scattered λ' larger than incident

Compton Scattering Observations



Compton Scattering : Summary of Observations

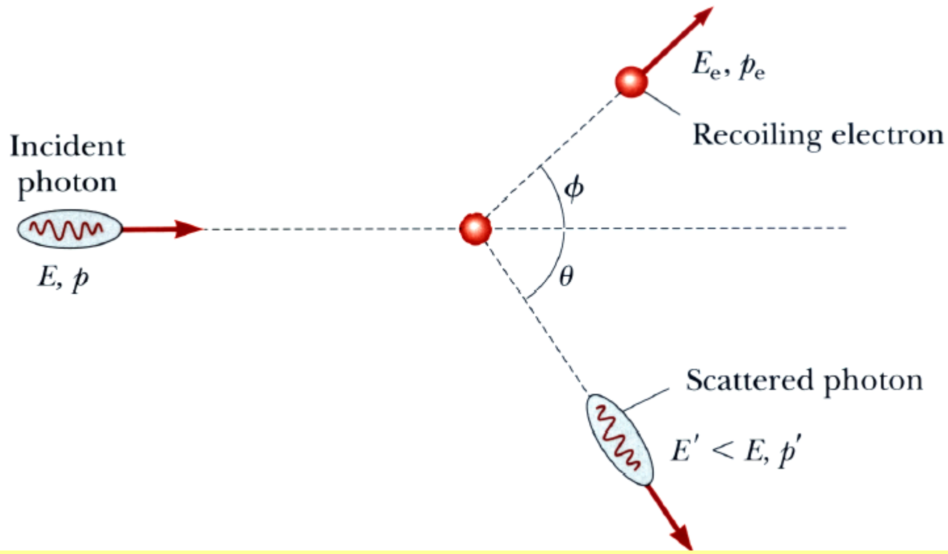


$$\Delta\lambda = (\lambda' - \lambda) \propto (1 - \cos\theta)\ !$$

Not isotropy in distribution of scattered radiation

How does one explain this startling anisotropy?

Compton Scattering: The Quantum Picture



Energy Conservation:

$$E + m_e c^2 = E' + E_e$$

Momentum Conserv:

$$p = p'\cos\theta + p_e \cos\phi$$

$$0 = p'\sin\theta - p_e \sin\phi$$

Use these to eliminate electron deflection angle (not measured)

$$\left((E - E') + m_e c^2\right)^2 = \left[p^2 - 2pp'\cos\theta + p'^2\right]c^2 + (m_e c^2)^2$$

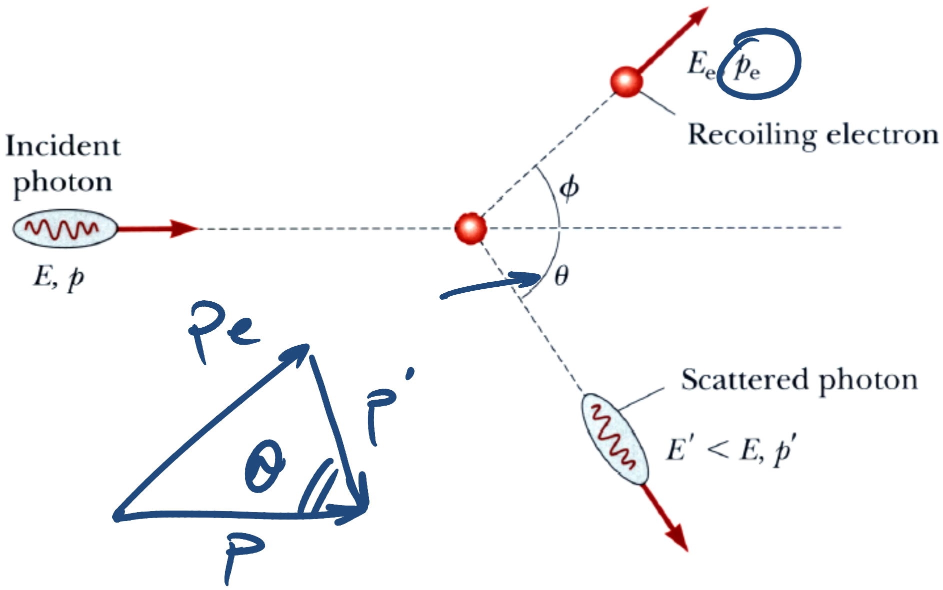
For light $p = \frac{E}{c} \Rightarrow$

$$E^2 + E'^2 - 2EE' + 2(E - E')mc^2 = \left[\frac{E^2}{c^2} - 2\frac{EE'}{c^2}\cos\theta + \frac{E'^2}{c^2}\right]c^2$$

$$\Rightarrow -EE' + (E - E')mc^2 = -EE'\cos\theta$$

$$\Rightarrow \frac{E-E'}{EE'} = -\frac{1}{m_e c^2}(1 - \cos\theta) \Rightarrow \boxed{(\lambda' - \lambda) = \left(\frac{h}{m_e c}\right)(1 - \cos\theta)}$$

Compton Scattering: The Quantum Picture



$p = \frac{\hbar\omega}{c}$

$p = \hbar k$

$p = \hbar \cdot \frac{2\pi}{\lambda}$

Before:

$E_e = m_e c^2$

$E_{PH} = E = \hbar\omega = p \cdot c$

After:

$E_e = \sqrt{(m_e c^2)^2 + p_e^2 c^2}$

$E_{PH} = E' = p'c$

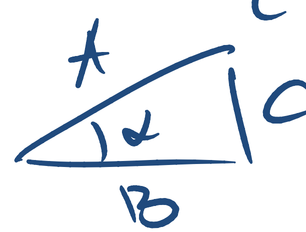
$m_e c^2 + pc = \sqrt{(m_e c^2)^2 + p_e^2 c^2} + p'c$

$p_e^2 = p^2 + p'^2 + 2pp' \cdot \cos\theta$

$(m_e c^2 + (p - p') \cdot c)^2 = m_e^2 c^4 + p^2 c^2 + p'^2 c^2 - 2pp'\cos\theta \cdot c^2$

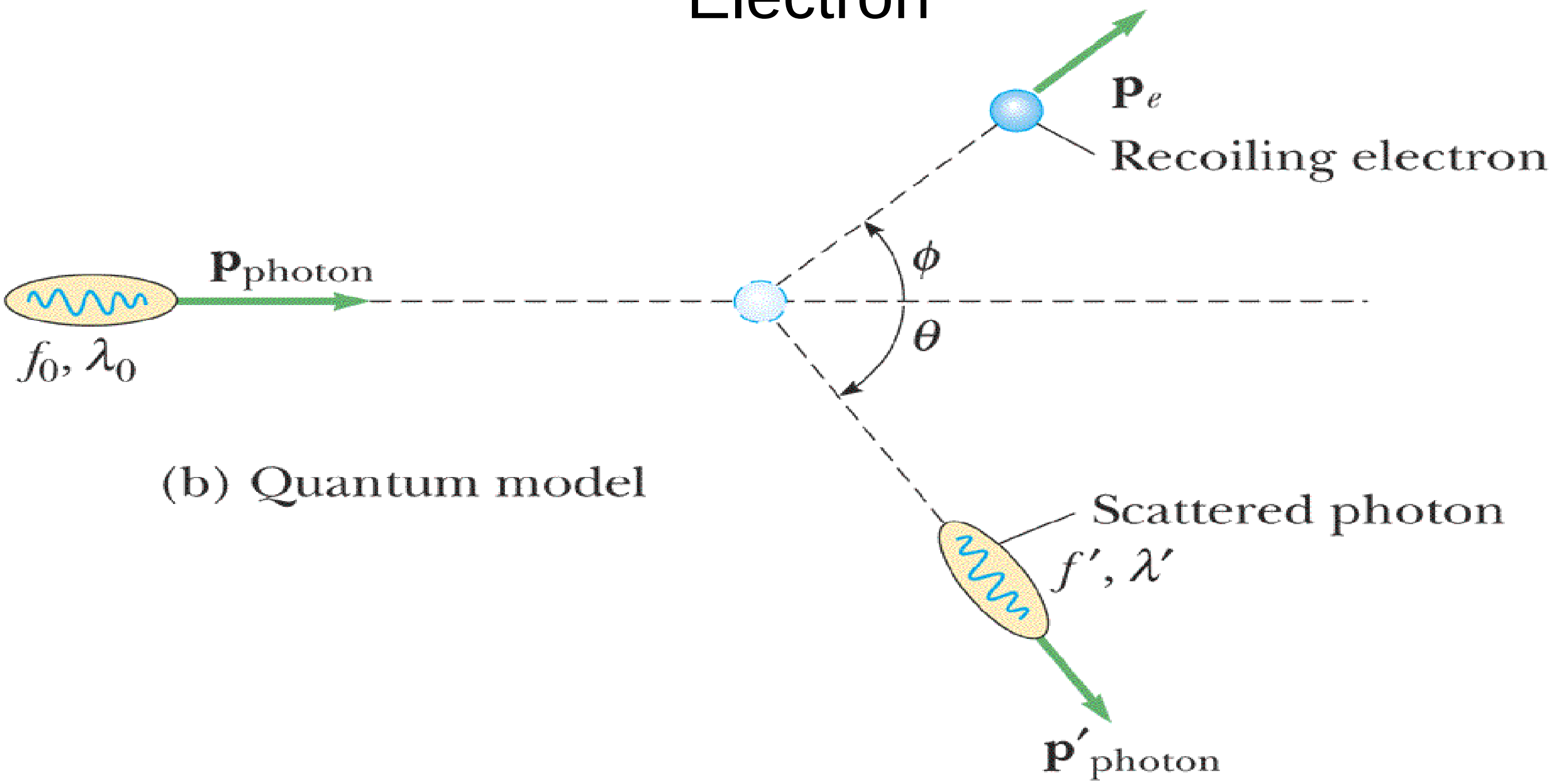
$C^2 = A^2 + B^2$

$2AB\cos\theta$



$p - p' \sim (1 - \cos\theta)$

Rules of Quantum Pool between Photon and Electron

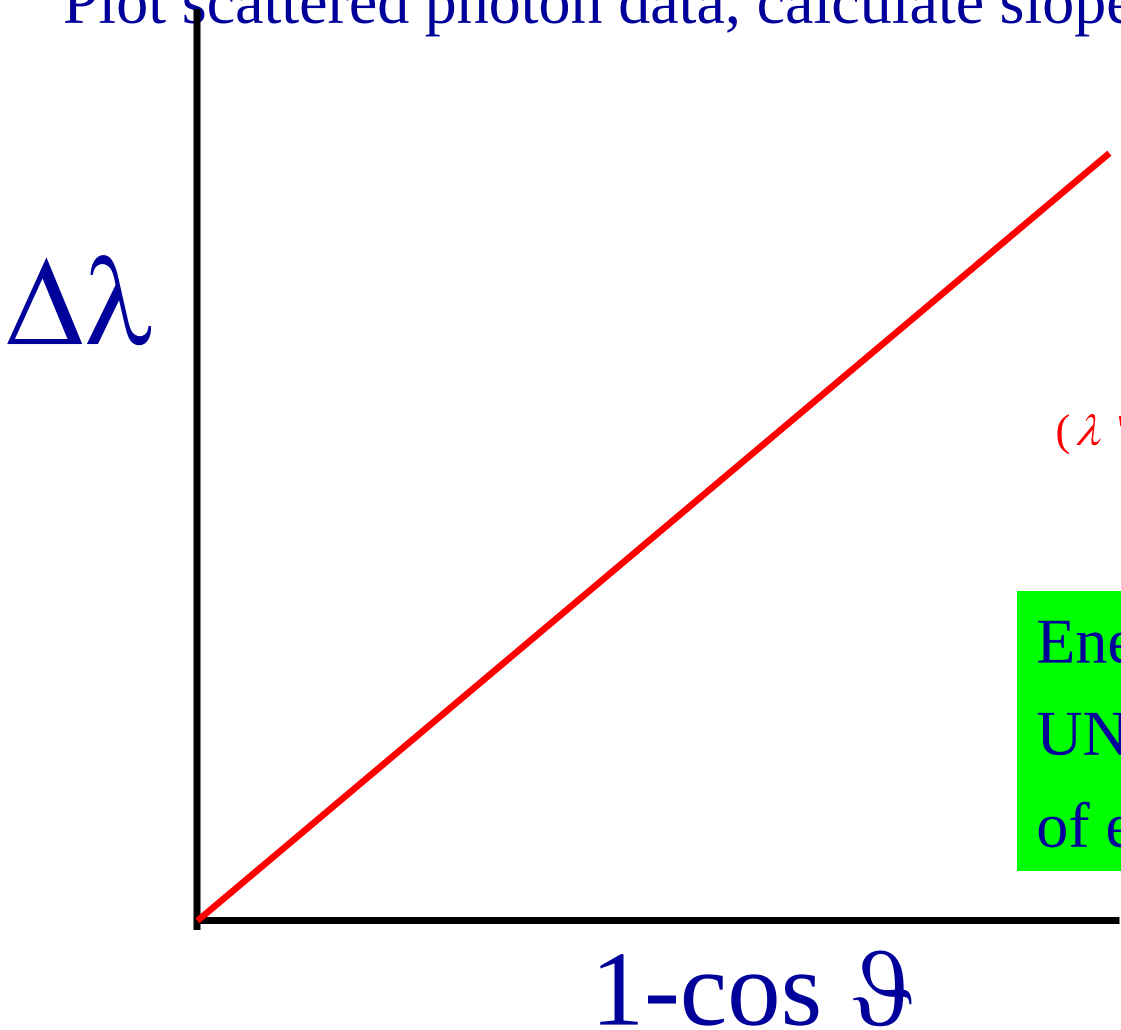


$$(\lambda' - \lambda) = \left(\frac{h}{m_e c}\right)(1 - \cos\theta)$$

Checking for h in Compton Scattering

It's the same value for h again !!

Plot scattered photon data, calculate slope and measure "h"



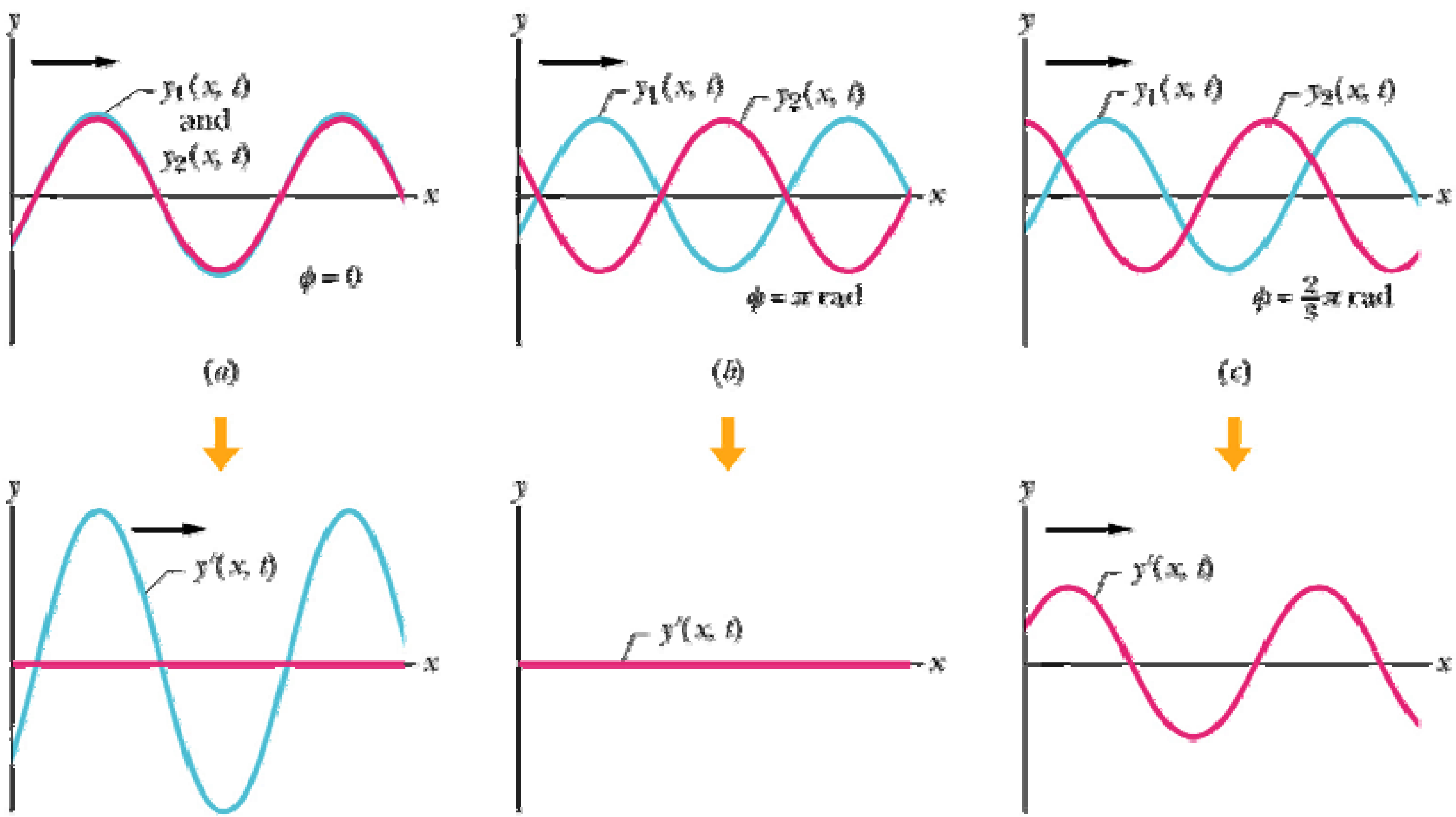
$$(\lambda' - \lambda) = \left(\frac{h}{m_e c}\right)(1 - \cos\theta)$$

Energy Quantization is a UNIVERSAL characteristic of energy transactions !

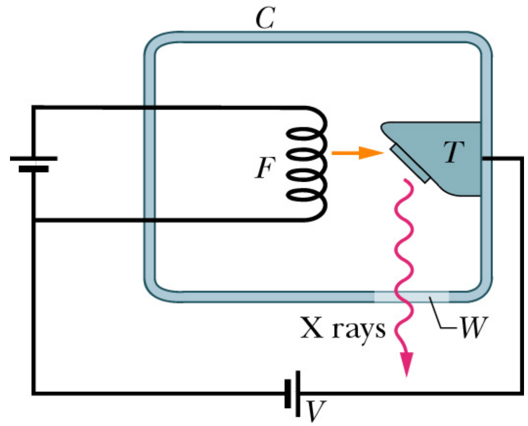
Interference of Waves: A Reminder

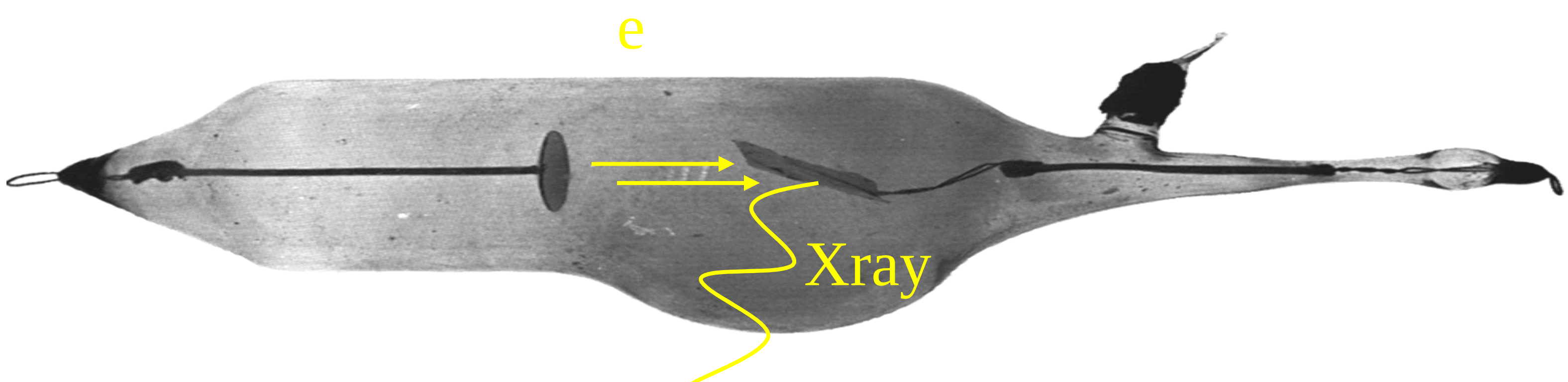
Two Identical waves $y_i(x,t) = y_{max}\sin(k_i x - \omega_i t + \phi_i)$ travel along +x and interefere to give a resulting wave $y'(x,t)$. The resulting wave form depends on relative phase differenc between 2 waves. Shown for $\Delta\phi = 0,\ \pi,\ \frac{2}{3}\pi$

Read Ch17-8 from Resnick et al



An X-ray Tube from 20th Century

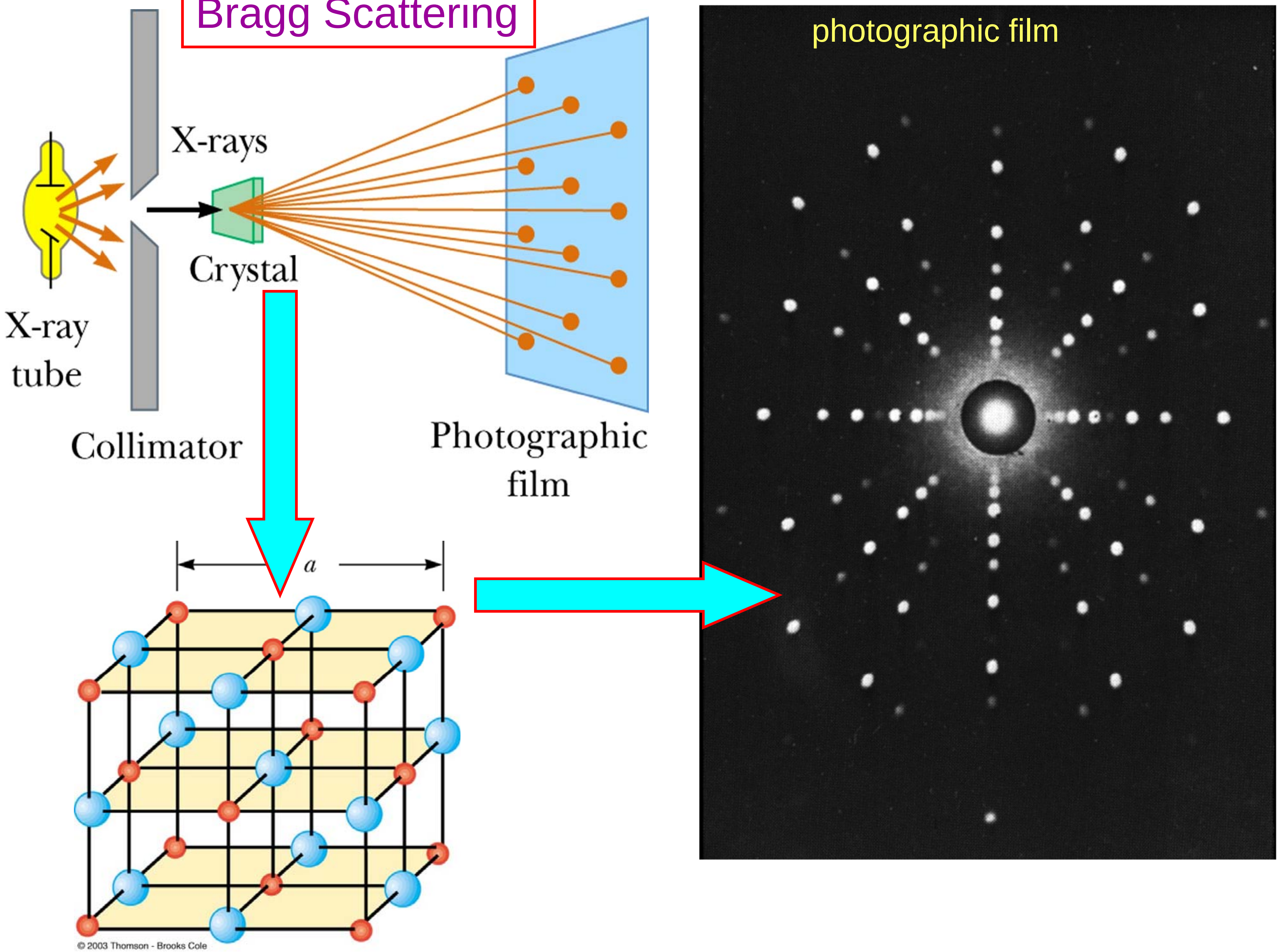




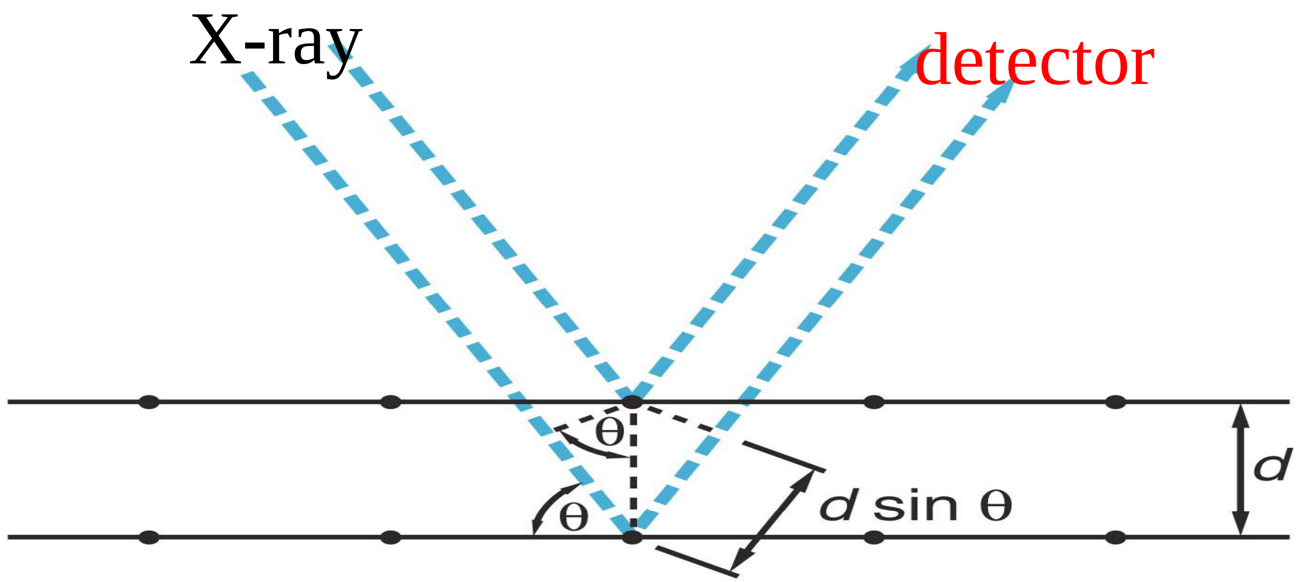
The “High Energy Accelerator” of 1900s: produced energetic light : X Ray , gave new optic to subatomic phenomena

X-ray Synchrotrons,
Argonne National Lab near Chicago


Bragg Scattering



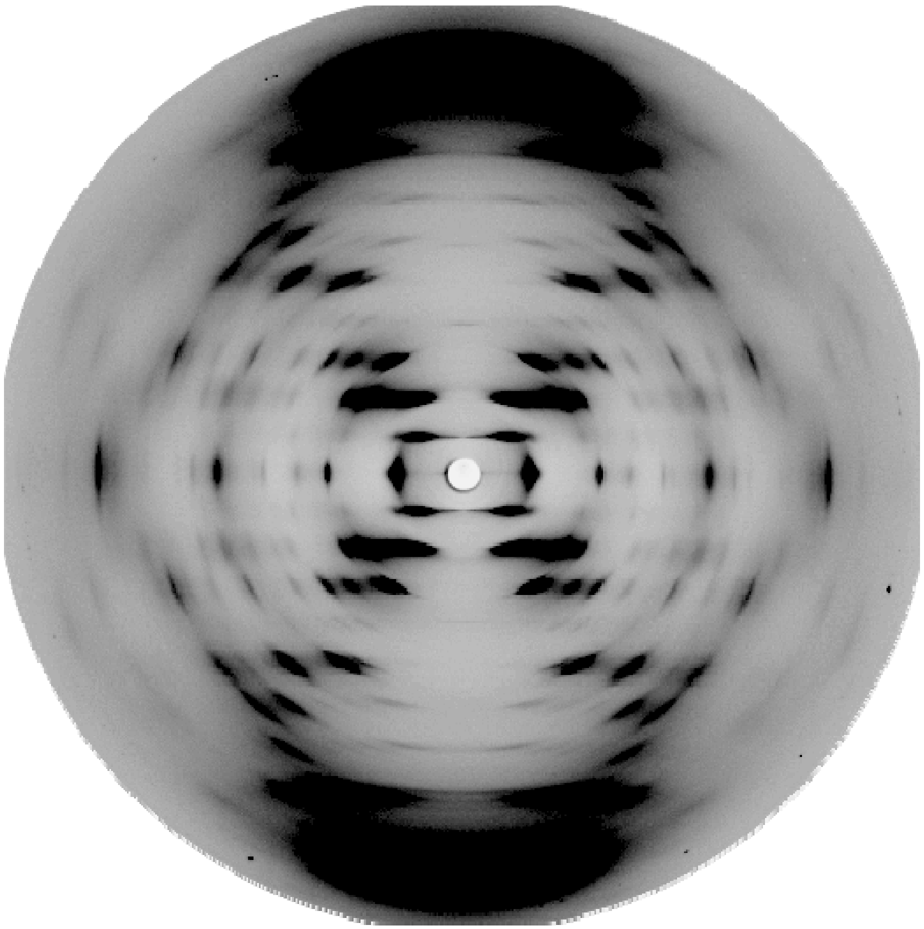
Bragg Scattering: Probing Atoms With X-Rays

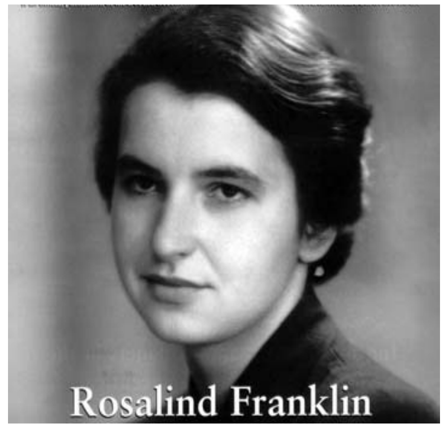


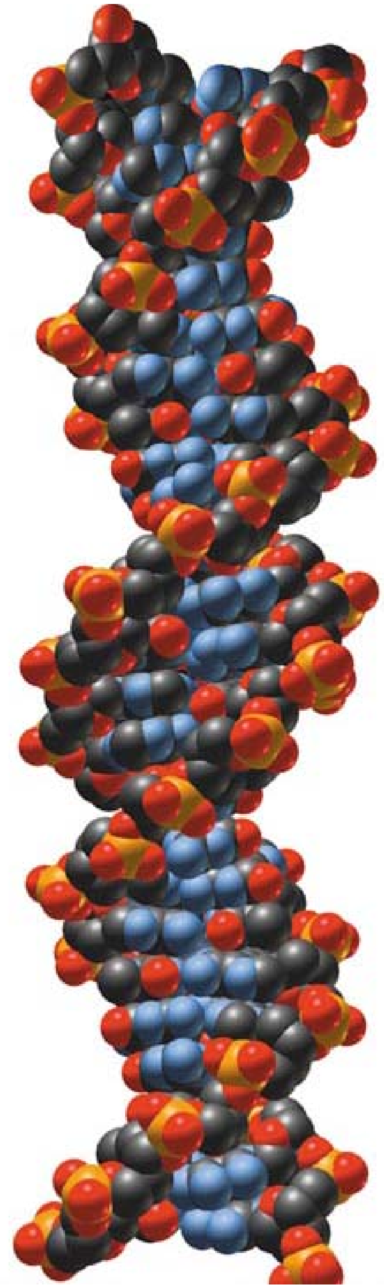
Constructive Interference when net phase difference is 0, 2π etc

This implied path difference traveled by two waves must be integral multiple of wavelength : **$n\lambda = 2d\sin\vartheta$**

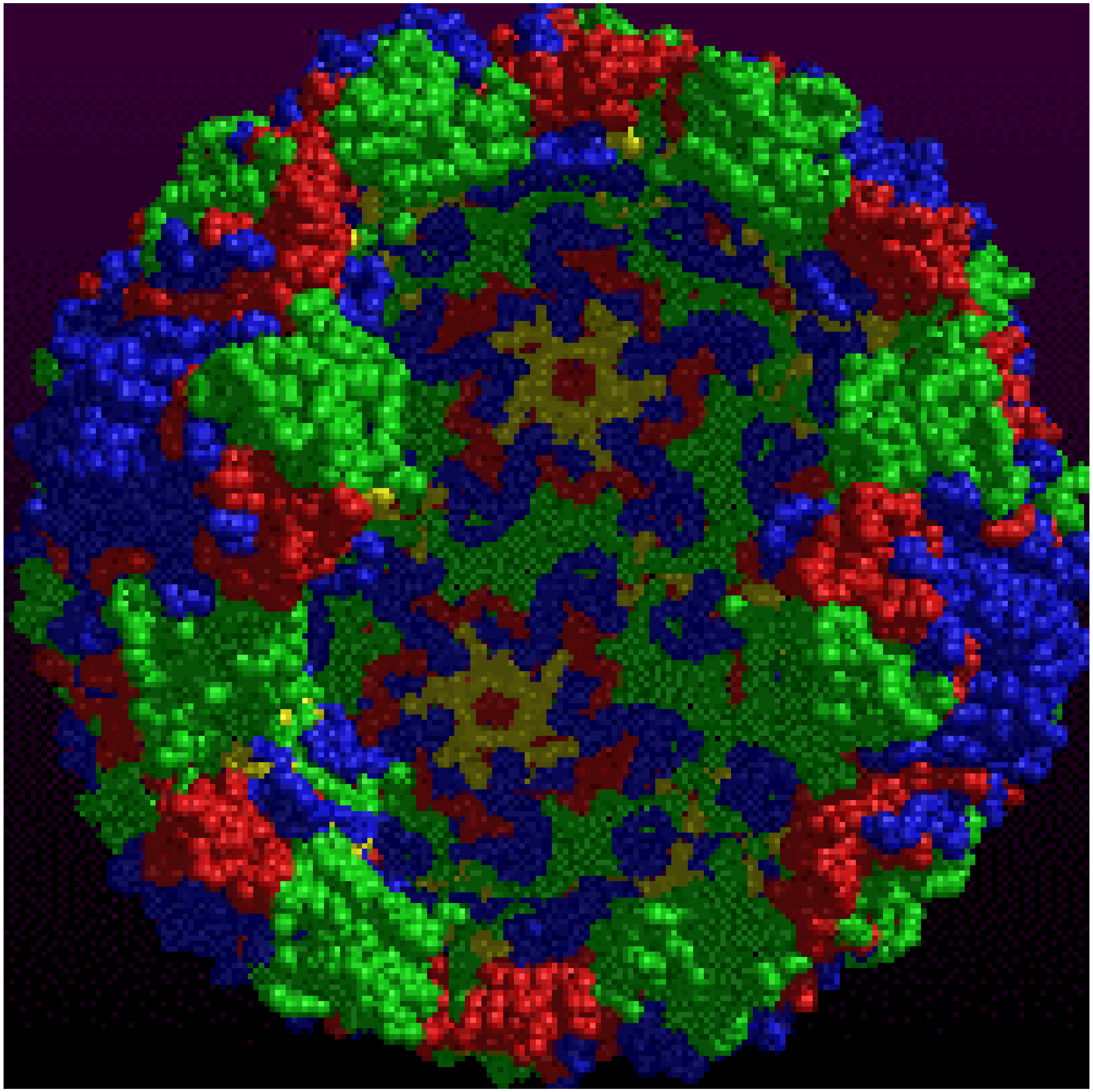
Example : X-Ray Picture of a DNA Crystal and Discovery of DNA Structure !







Proteins inside Rhinovirus reconstructed by x-ray diffraction



Other forms of Interaction of Energy Exchange between Radiation and Matter

$E \,\square\, mc^2+mc^2$

Always same form of

Matter & Antimatter