Course: Engineering Physics
PHY 1701

06-12-2019

Dr. R. Navamathavan

Physics Division

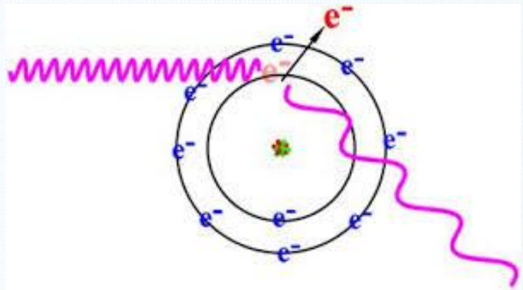
School of Advanced Sciences (SAS)

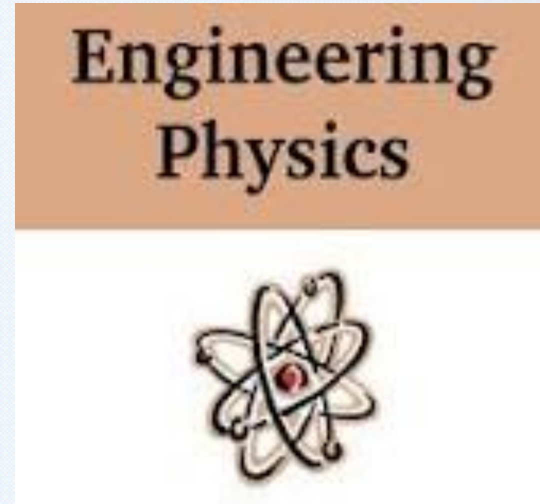
Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

navamathavan.r@vit.ac.in

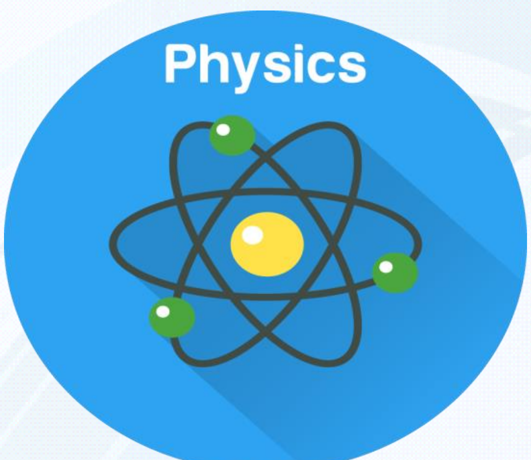
Outline

- Compton Effect

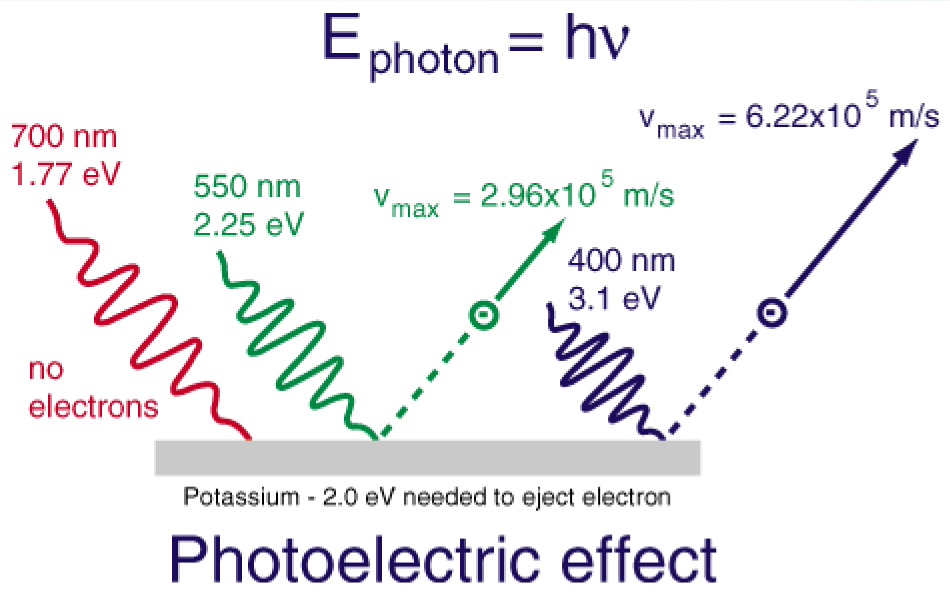




Source
Modern Physics by Arthur Beiser
Pages: 80 - 86



Photoelectric Effect

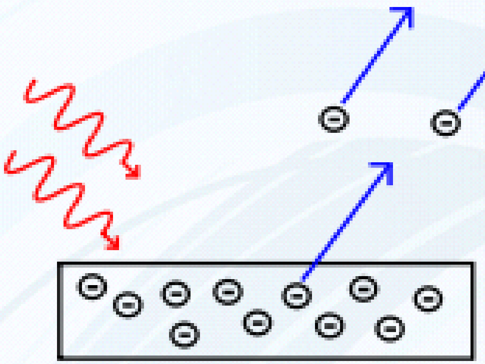


Most commonly observed phenomena with light can be explained by waves. But the photoelectric effect suggested a particle nature for light.

Compton effect
and
derivation
for shift in wavelength

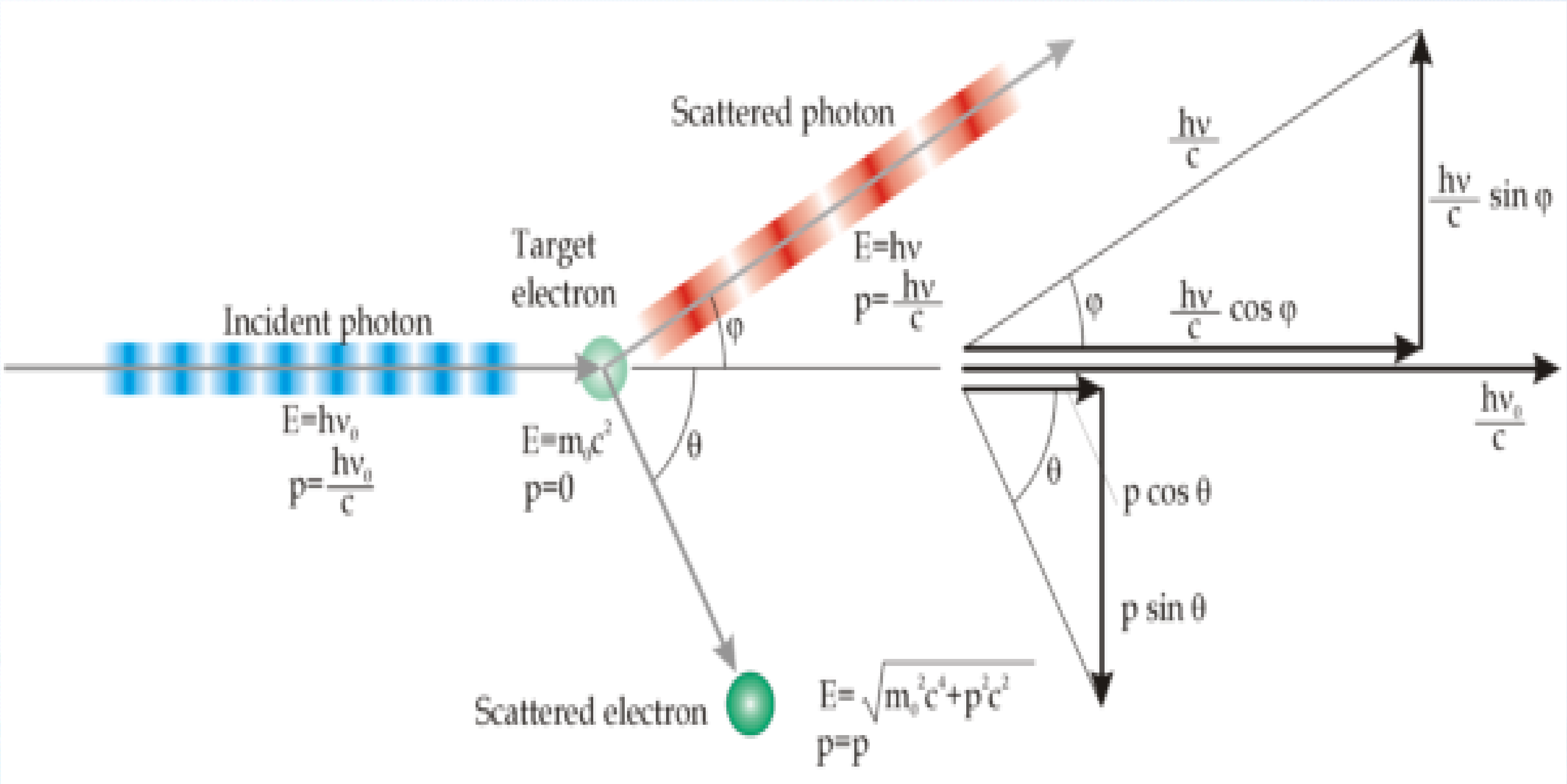
Compton Effect

Compton scattering is an inelastic scattering of a photon by a free charged particle, usually an electron. It results in a decrease in energy (increase in wavelength) of the photon (which may be an X-ray or gamma ray photon), called the **Compton effect**.



Light–matter interaction	
Low-energy phenomena: →	**Photoelectric effect**
Mid-energy phenomena: →	**Thomson scattering** **Compton scattering**
High-energy phenomena: →	**Pair production**

Compton Effect



Compton Effect

Energy before collision:

The energy of the incident photon $= h\upsilon$

The rest mass energy of the electron $= m_0c^2$

Total energy before collision $= h\upsilon + m_0c^2$ ---- (1)

Where

$m_0 \rightarrow$ rest mass of the electron

Compton Effect

Energy after collision:

The final energy of the scattered photon = $h\upsilon'$

The rest mass energy of the electron = mc^2

Total energy after collision = $h\upsilon' + mc^2$ ---- (2)

m → mass of the recoiling electron (i.e)

$$m = m_0/(\sqrt{(1-v^2/c^2)})$$

According to law of conservation of energy

Total energy before collision = Total energy after collision

$$h\upsilon + m_0c^2 = h\upsilon' + mc^2 \quad \text{----} \quad (3)$$

Compton Effect

Momentum before collision:

x – component of the momentum:

Momentum of the photon = $h\upsilon/c$

Momentum of the electron = 0

Total momentum along the x – axis = $h\upsilon/c$ ------ (4)

Compton Effect

Momentum before collision:

y – component of the momentum:

Momentum of the photon = 0

Momentum of the electron = 0

Total momentum along the y – axis = 0 ------ (5)

Compton Effect

<u>Momentum after collision:</u>

x – component of the momentum:

Momentum of the photon = $(h\upsilon' \cos \emptyset)/c$

Momentum of the electron = $mv \cos \Theta$

Total momentum along the x – axis

$$= (h\upsilon' \cos\emptyset)/c + mv \cos\Theta \quad \text{-----} \ (6)$$

Compton Effect

Momentum after collision:

y – component of the momentum:

Momentum of the photon = $(h\upsilon' \sin \emptyset)/c$

Momentum of the electron = $-mv \sin \Theta$

Total momentum along the y – axis

$$= (h\upsilon' \sin \emptyset)/c - mv \sin \Theta \text{ ------ } (7)$$

Compton Effect

$h\upsilon/c = (h\upsilon' \cos \emptyset)/c + mv \cos \Theta$ ----- (8)

$0 = (h\upsilon' \sin \emptyset)/c - mv \sin \Theta$

After rearranging,

$mvc \cos \Theta = h(\upsilon - \upsilon' \cos \emptyset)$ ----- (9)

$mvc \sin \Theta = h\upsilon' \sin \emptyset$ ------- (10)

Compton Effect

Squaring and adding Eqns. (9) & (10):

$$m^2v^2c^2 = h^2(\upsilon^2 - 2\upsilon\upsilon' \cos \varnothing + \upsilon'^2 \cos^2\varnothing) +$$
$$+ h^2 \upsilon'^2 \sin^2\varnothing$$

$$= h^2(\upsilon^2 - 2\upsilon\upsilon' \cos \varnothing + \upsilon'^2) \text{ -------- } (11)$$

From Eqn. (3):

$$mc^2 \quad = h\upsilon - h\upsilon' + m_0c^2$$

$$= h(\upsilon - \upsilon') + m_0c^2$$

On squaring

$$m^2c^4 = h^2(\upsilon^2 - 2\upsilon\upsilon' + \upsilon'^2) + m_0^2c^4 + 2h(\upsilon - \upsilon')\, m_0c^2 \text{ ---- } (12)$$

Compton Effect

Subtracting Eqn. (11) from Eqn. (12),

$$m^2c^2 (c^2-v^2) = -2h^2\upsilon\upsilon' (1-\cos \varnothing) + 2h(\upsilon - \upsilon')\, m_0c^2 + m_0^2c^4 \quad \text{------} \ (13)$$

According to theory of relativity

$$m = m_0/(\sqrt{(1-v^2/c^2)}$$

Squaring and rearranging

$$m^2c^2 (c^2-v^2) = m_0^2c^4 \quad \text{--------} \ (14)$$

Compton Effect

Substituting for $m^2c^2(c^2-v^2)$

$$m_0^2c^4 = -2h^2\upsilon\upsilon'(1-\cos Ø) + 2h(\upsilon - \upsilon')\, m_0c^2 + m_0^2c^4$$

$$2h(\upsilon - \upsilon')\, m_0c^2 = 2h^2\upsilon\upsilon'(1-\cos Ø)$$

$$(\upsilon - \upsilon')/\upsilon\upsilon' = (h/m_0c^2)(1-\cos Ø)$$

$$(1/\upsilon' - 1/\upsilon) = (h/m_0c^2)(1-\cos Ø)$$

$$(c/\upsilon' - c/\upsilon) = (h/m_0c)(1-\cos Ø)$$

$$\lambda' - \lambda = (h/m_0c)(1-\cos Ø) \text{ ------ } (15)$$

$$d\lambda = (h/m_0c)(1-\cos Ø)$$

Compton Effect

dλ – independent of

- wavelength of incident radiation
- the nature of the scattering substance

dλ – only depends on the angle of scattering

Case i) When $\varnothing = 0$, $\cos \varnothing = 1$. → $d\lambda = 0$

Case ii) When $\varnothing = 90^\circ$, $\cos \varnothing = 0$. → $d\lambda = h/m_0c$

in this case, dλ – Compton wavelength

Compton Effect

Case i) When $\phi = 0$, $\cos\phi = 1$. → $d\lambda = 0$

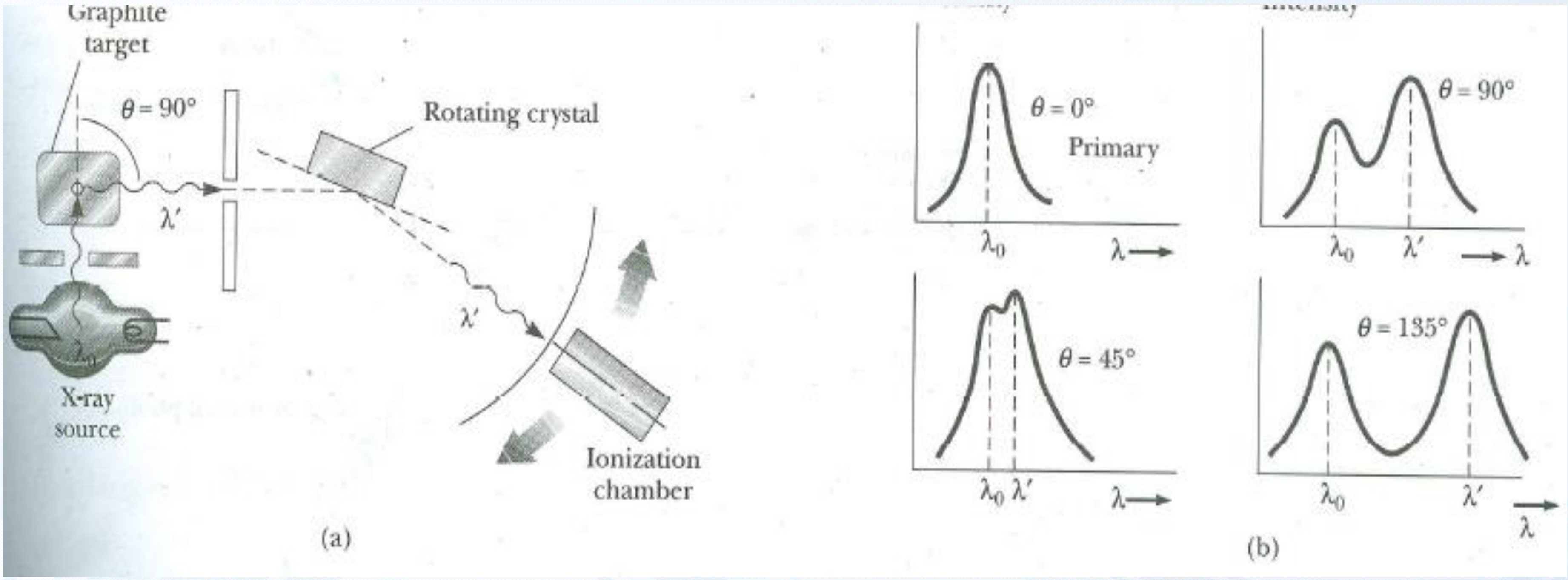
Case ii) When $\phi = 90^\circ$, $\cos\phi = 0$. → $d\lambda = h/m_0c$

in this case, $d\lambda$ – Compton wavelength

Case iii) When $\phi = 180^\circ$, $\cos\phi = -1$

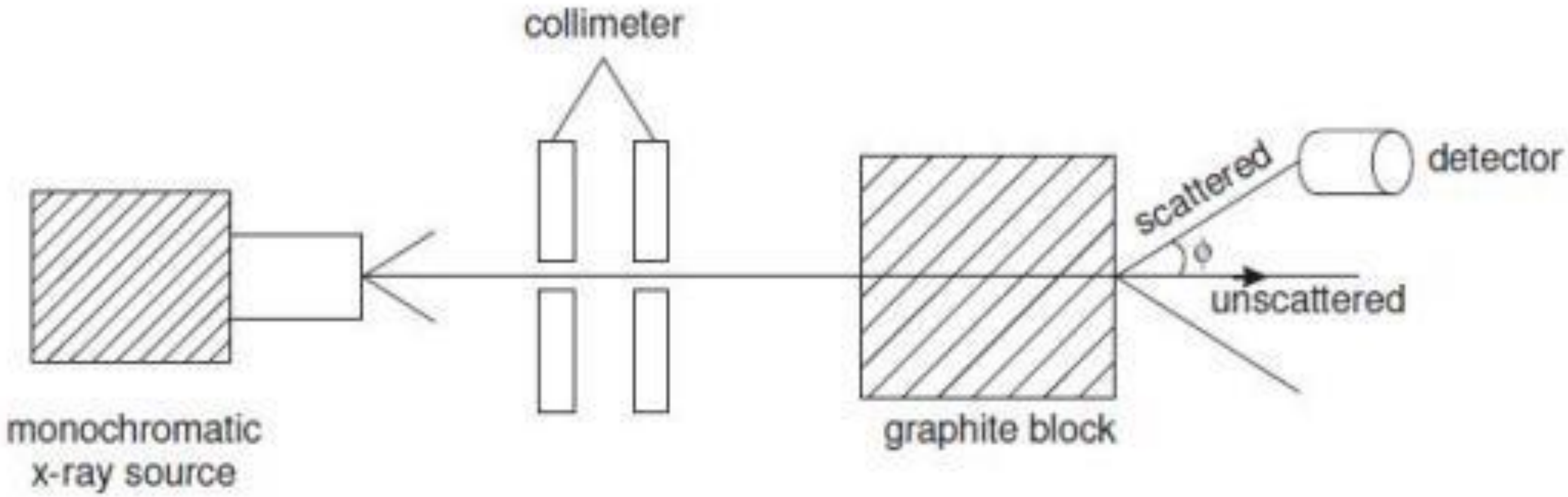
→ $d\lambda$ - maximum

Experimental Demonstration



Experimental Demonstration

Give an experiment verification of compton effect.



In a experiment performed by compton a narrow beam of x-ray was of wavelength approximately equal to 1 A° was made to fall on a graphite block.

The wavelength of the scattered x-rays was recorded for various values of angles of scattering with the help of spectrometer. The graph are then plotted between the intensity of scattered beam and the wavelength for different values of scattering angle.

Experimental Demonstration