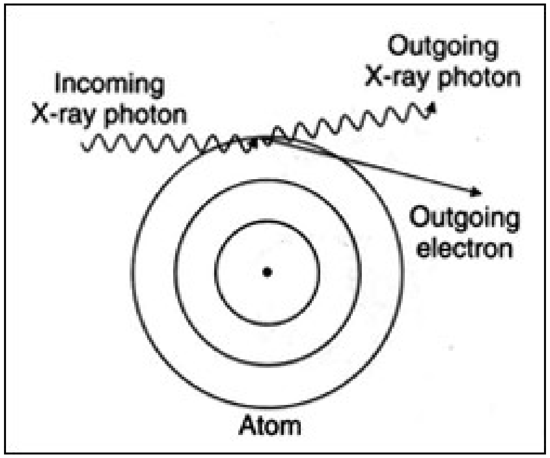
Take Away from Quantum Theory

Photons behave like particles except for the absence of any rest mass. Hence, collisions between photons and electrons should be treated as billiard ball collisions.

Compton Effect

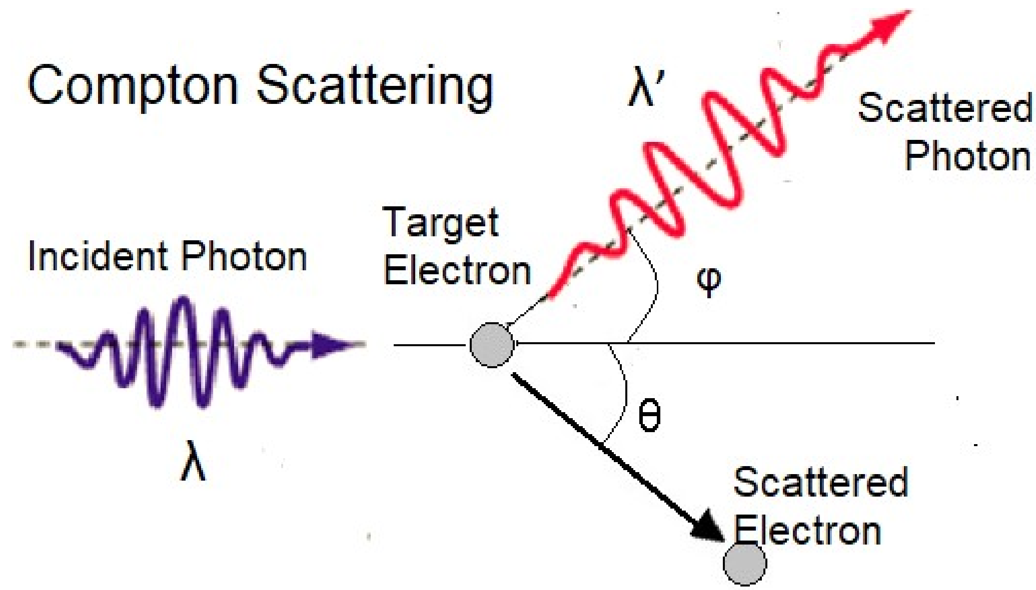
- Inelastic scattering of a photon by a quasi-free charged particle, usually an electron.
- It results in a decrease in energy (increase in wavelength) of the photon (which may be an X-ray photon)



- Part of the energy of the photon is transferred to the recoiling electron.
- Inverse Compton scattering also exists, in which a charged particle transfers part of its energy to a photon.

The classical electromagnetic theory could explain the presence of original wavelength in the scattered photon. However, it could not predict the presence of higher wavelength in the scattered photons.

Figure shows collision between an X-ray photon and an electron assumed to be initially at rest. The photon is scattered away from the original direction of motion and the electron receives the impulse and begins to move.



In the collision the photon loses as much energy as kinetic energy gained by the electron. Separate photons are involved; if the initial photon has the frequency ν associated with it the scattered photon has a lower frequency ν′. In the collision momentum is conserved in each of the two mutually perpendicular directions.

Loss in photon energy = Gain in Kinetic Energy

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$$h\nu - h\nu' = T$$

$$E = \sqrt{m_o^2c^4 + p^2c^2}$$

Since the photon has no rest mass, its total energy is given by

$$E = pc$$

$$p = \frac{E}{c} = h\nu/c$$

Momentum must be conserved in all directions

The initial photon momentum is hv/c and final photon momentum is hv’/c

Apply conservation of momentum

$$\frac{h\nu}{c} + 0 = \frac{h\nu'}{c}\cos\varphi + p\cos\theta$$

and perpendicular to this direction

$$0 = h\nu'/c\,\sin\varphi - p\sin\theta$$

Multiply these equations by c

$$pc\cos\theta = h\nu - h\nu'\cos\varphi$$

$$pc\sin\theta = h\nu'\sin\varphi$$

Squaring and adding these equations

$$p^2c^2=(h\nu)^2 - 2(h\nu)(h\nu')\cos\phi+(h\nu')^2$$

$$E = T + m_o c^2 \qquad E = \sqrt{m_0^2 c^4 + p^2 c^2}$$

$$[T + m_0 c^2]^2 = m_0^2 c^4 + p^2 c^2$$

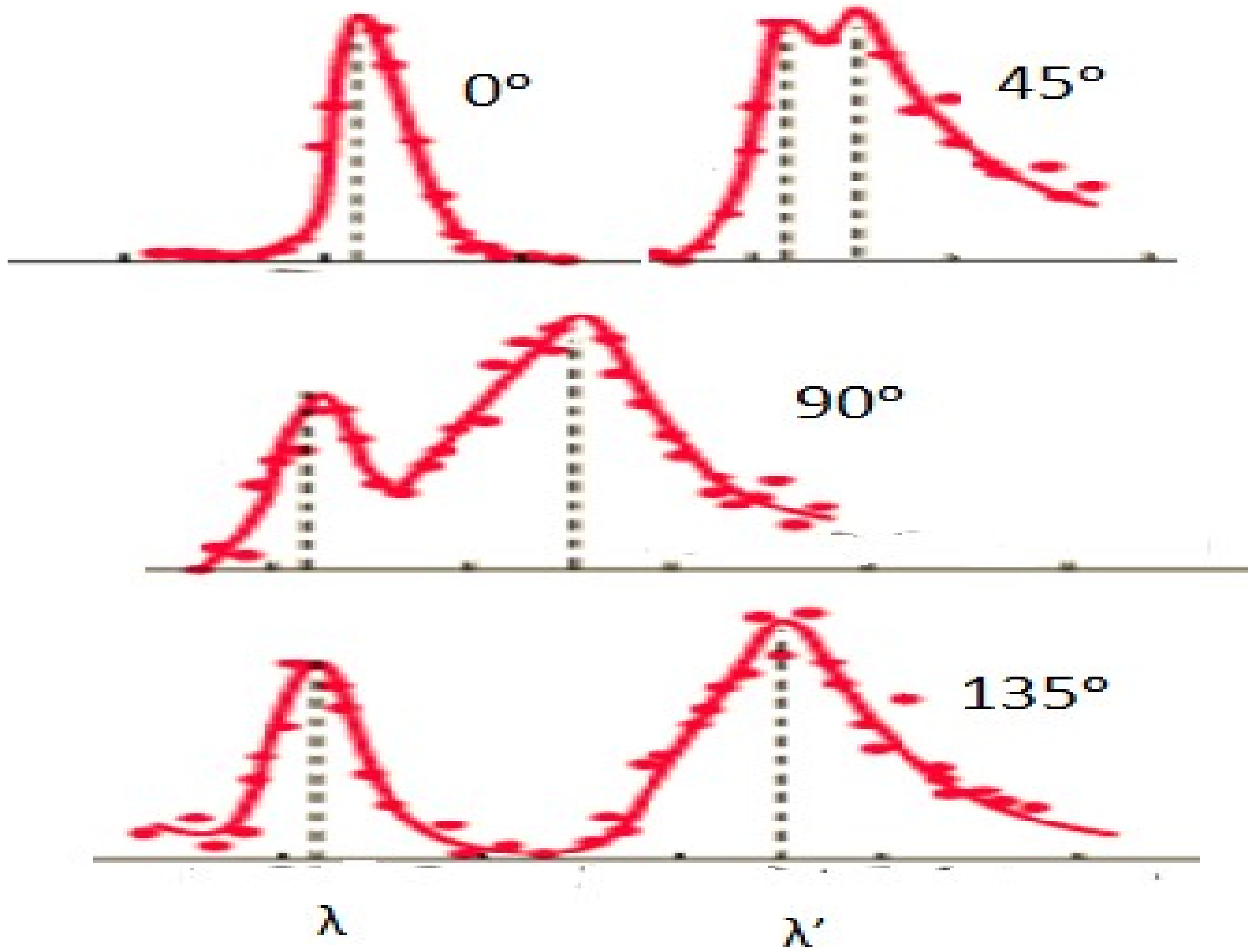
$$P^2 c^2 = T^2 + 2 m_0 c^2 T$$

$$T = h\nu - h\nu'$$

$$\mathbf{P^2 c^2 = (h\nu)^2 - 2\,(h\nu)\,(h\nu') + (h\nu')^2 + 2\,m_0\,c^2\,(h\nu - h\nu')}$$

$$\lambda - \lambda' = \left(\frac{h}{m_0 c}\right)(1 - \cos\varphi)$$

Variation of Change in Wavelength as a Function of Scattering Angle of the Photon



Results of Compton Effect

i. Change in wavelength is independent of the wavelength used. (h/m_0c) is called Compton wavelength which for an electron is equal to 0.024 Å.

ii. The maximum change in wavelength is twice the Compton wavelength, 0.048 Å.

iii. The presence of higher wavelength in the scattered radiation could be explained.

iv. The presence of original wavelength in the scattered radiation could be explained in the following way:

Some of the photons might not be able to collide with electrons, rather they could directly collide with the atom as such. In such cases the mass of the electron in the denominator would be taken as the mass of the whole atom. Thus $\lambda - \lambda'$ would be negligible.

- At a time (early 1920's) when the particle (photon) nature of light suggested by the photoelectric effect was still being debated, the Compton experiment gave clear and independent evidence of particle-like behavior of photons.

- Compton was awarded the Nobel Prize in 1927 for the "discovery of the effect named after him.