CL5_Q1. Why classical physics cannot explain the results of Compton's experiment?

Answer

According to the wave theory, X-rays force electrons in the atoms of the target material to execute forced oscillations. The oscillating electrons emit radiation with the same frequency as that of the incident radiation. This radiation is called Rayleigh-scattered radiation. Further, the electrons radiate waves uniformly in all directions. Thus, as per wave theory

i) The scattered radiation should have the same wavelength as that of the incident radiation
ii) The wavelength of the scattered radiation should not show dependence on the scattering angle, θ.

The above conclusions are contrary to the experimental observations. It means that the wave theory fails to explain the Compton Effect.

CL5_Q2. What are the angles at which the Compton shift is minimum and maximum? What are the conclusions drawn from these angles?

Answer

Compton shift $\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta)$ varies from zero for $\theta = 0^0$, corresponding to grazing collision with incident photon being scarcely deflected.

$\frac{2h}{m_e c}$ for $\theta = 180^0$ corresponding to a head on collision, the incident photon being reversed in direction.

Conclusions:

- when $\theta = 0^0$, the change in wavelength $\Delta\lambda = 0$. Therefore there is no loss of energy for the photon if the scattering angle is zero.

- when $\theta = 180^0$, the change in wavelength will be twice the Compton wavelength.

CL5_Q3. What is Compton shift? According to classical theory, the scattered X rays have the same frequency as the incident wave. Explain.

Answer

When X rays interact with the material medium, the scattered beam has a different wavelength as compared to the incident wavelength. The change in the wavelength $\boldsymbol{\Delta\lambda} = \boldsymbol{\lambda_f} - \boldsymbol{\lambda_i}$ is known as the Compton Shift

Classical theory considers X radiation as a classical electromagnetic wave. The electric field vector in the incident wave of frequency v acts on the free electrons in the target and sets them oscillating at that same frequency. These oscillating electrons move back and forth in turn emitting electromagnetic waves which have the same frequency v as that of the incident wave.

CL5_Q4. What is the energy of the smallest energy x-ray photon for which the Compton scattering could result in doubling the original wavelength?

Answer

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

Here $\lambda' = 2\lambda$, this gives $\lambda = \frac{h}{m_e c}(1 - \cos\theta)$

As λ is inversely proportional to energy $\left(E = \frac{hc}{\lambda}\right)$, λ has to be maximum for smallest energy X-ray photon.

Therefore, $\theta = 180^0$ and $\lambda = 4.84 \times 10^{-12}\ m$

Energy of the x-ray photon, $E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{4.84\times10^{-12}} = 4.11 \times 10^{-14}\ J.$