Study of Compton Scattering

Introduction

Compton scattering is an example of inelastic scattering of light by a charged particle, where the wavelength of the scattered light is different from that of the incident radiation. In 1920, Arthur Holly Compton observed scattering of x-rays from electrons in a carbon target. He found that the scattered x-rays have a longer wavelength than the incident x-rays. The shift of the wavelength increased with scattering angle according to the Compton formula:

$$\lambda_\theta - \lambda_0 = \Delta\lambda = \frac{h}{m_e c}(1 - cos\theta) \qquad (1)$$

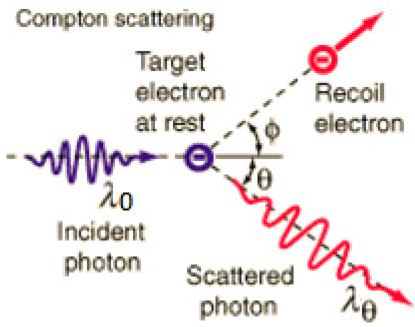

Fig.1: Compton scattering

where λ_θ and λ_0 are wavelengths of incident and scattered photon respectively, h is the planck's constant, m_e is the rest mass of electron, c is the velocity of light, θ and ϕ are angles of scattered photon and recoil electron respectively (Fig. 1). The value of ($h/m_e c$ = 0.02426 A^0) is called Compton wavelength of electron. In terms of energy Eq. 1 can be rewritten as

$$E_\theta = E_0 \frac{1}{1+(\gamma.(1-\cos\theta))} \qquad (2)$$

where E_θ and E_0 are energy of incident and scattered photon respectively and $\gamma = \frac{E_0}{m_e c^2}$. For high energy photons with ($\lambda \ll 0.02\ A°$ or $E \gg 511keV$), the wavelength of the scattered radiation is always of the order of the Compton wavelength whereas for low energy photons ($E \ll 511keV$), the Compton shift is very small. In other words, in non-relativistic energy regime, Compton scattering results approaches the results predicted by classical Thompson scattering.

Compton's experiment had a lot of significance that time since it gave a clear and independent evidence of particle-like behaviour of light. Compton was awarded the Nobel Prize in 1927 for the "discovery of the effect named after him".

The differential Compton scattering cross section was correctly formulated by Klein-Nishina in 1928 using quantum mechanical calculations. This formula is famously known as Klein-Nishina formula which is expressed as follows:

$$\frac{d\sigma}{d\Omega} = r_0^2 \left(\frac{1+cos^2\theta}{2}\right)\left(\frac{1}{(1+\gamma(1-cos\theta)^2}\right)\left[\frac{\gamma^2(1-cos\theta)^2}{(1+cos^2\theta)(1+\gamma(1-cos\theta))} + 1\right] \qquad (3)$$

Here, $r_0 = (e_0/4\pi\varepsilon_0 mc^2)$ is the is the classical electron radius and has the value $r_0 = 2.818 \times 10^{-15}$ m. This result is for the cross section averaged over all incoming photon polarizations. By integrating Eq. (7) over all angles, the total cross section can be obtained.

In our experiment gamma rays from a Cesium-137 source are used as the source of photons that are scattered. Difference in the incident and scattered energy and wavelength of the photons is determined by a calibrated scintillation detector placed at different scattering angles. The relative intensities I_θ of the scatter radiation peaks can be compared with the predictions of the Klein-Nishina formula for the differential effective cross section $(\frac{d\sigma}{d\Omega})$ by calculating the calibration factor C using the formula below:

$$C = \frac{1}{n} \cdot \sum_{\theta=0}^{n} \frac{I_\theta}{\left(\frac{d\sigma}{d\Omega}\right)} \quad (4)$$

Objective:

(I) **Energy calibration of scintillation detector**

(II) **Determination of change in wavelength of the scattered gamma radiation as a function of the scattering angle**

(III) **Determination of the differential cross-section using Klein-Nishina formula and calculation of calibration factor.**

Apparatus:

1. Cs-137 radioactive gamma source
2. Mixed preparation radioactive source for calibration (Am-241 and Cs-137)
3. Source holder in form of a lead block with a hole of 12 mm diameter at the centre to accommodate radioactive sources. Additional blind hole for inserting a steel pin as angular direction indicator
4. NaI scintillation detector and its holder with lead shielding for defined direction of incoming gamma radiation
5. High voltage power supply (1.5kV)
6. Cylindrical pure aluminium/copper rod as centre of scattering.
7. Additional lead shielding (movable) to reduce the intensity of unscattered gamma radiation, particularly for small scattering angles and short distances between source, scatterer and detector.
8. Multichannel analyzer (256 channels) and Related software in a desktop PC
9. Experimental panel with graduated angular scale

Experimental Setup:

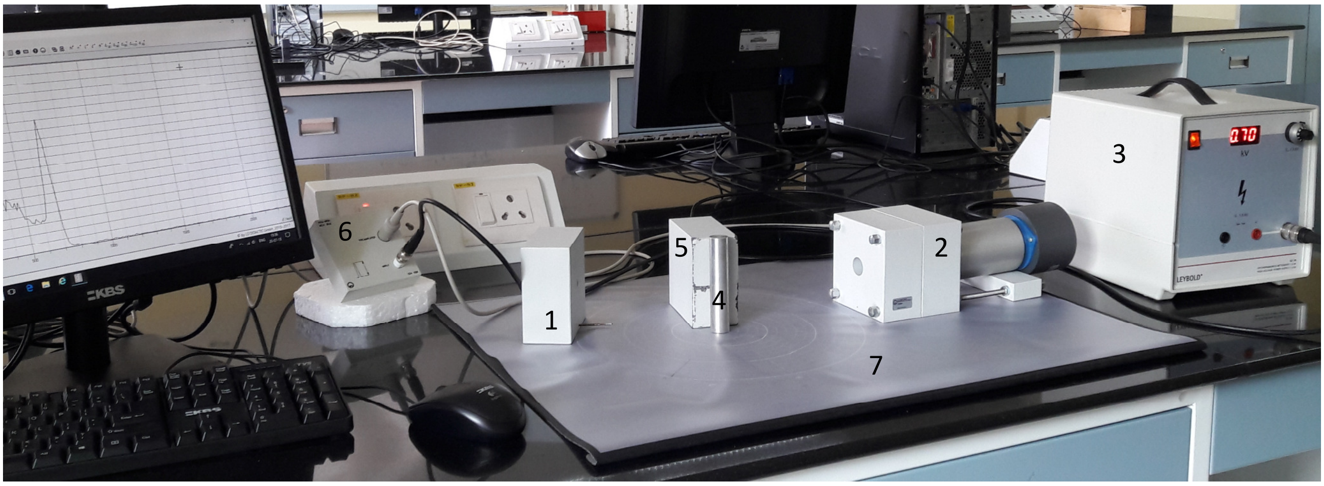

Fig 2. Experimental set up for Compton scattering experiment consisting of Source holder, Scintillator detector with lead shielding, High voltage supply, Scatterer, Additional movable shielding, MCA and a Experimental panel with angular scale (shown respectively as nos. 1-7)

The complete experimental set up is shown in Fig.2 and can be visualized in the following sequence. A radioactive Cs-137 source produces 662 KeV γ-rays which can escape the shielded cavity only through a small hole. The beam is collimated and reaches an aluminium rod (the target or scatterer). Some portion of the γ-rays are scattered by the electrons in the target which are detected and counted by the scintillator detector. The detected signal is further processed by an MCA and the complete spectrum is displayed on the computer. By placing the source at different angles on the experimental angular panel, the scattered radiations are collected to study the angular dependence of Compton scattering.

Procedure:

Spend some time to understand each part of the set up. Assemble all the accessories to set up the experiment as shown in Fig. 2. Familiarize yourself with the software required to acquire and analyze the spectra (refer to the software manual provided separately). **Set the operating voltage for the detector at an optimized value of ~ 0.7kV.**

(I) Calibration

Using the mixed source (refer Annexure I for details of the source), record the calibration spectra at $\theta = 0$ without the scatterer. Calibrate the channels of MCA with peak energy of the acquired spectrum and save it in the computer.

(II) Energy of scattered γ-rays as a function of θ

Using the Cs-137 source (refer Annexure II for details of the source), record a spectrum for every desired scattering angle θ. Use additional shielding as necessary. A typical spectrum after calibration is shown in Fig.3. For a reliable determination of the peak energy of the scattered radiation E_θ, a measurement with and without scatterer should be made for every θ. Evaluation of the difference of the two spectra is obtained using the software. Now analyze the spectra to determine the peak scattered energy and I_θ.

Notes:

1) The measuring time per scattering angle must be selected according to the desired accuracy and the distances between source, scatterer and detector.

2) Greater distances between source, scatterer and detector increase the angular resolution, but require longer measuring times due to the lower counting rates.

3) At small scattering angles, particularly for short distances, additional lead shielding is required to suppress the background caused by unscattered radiation.

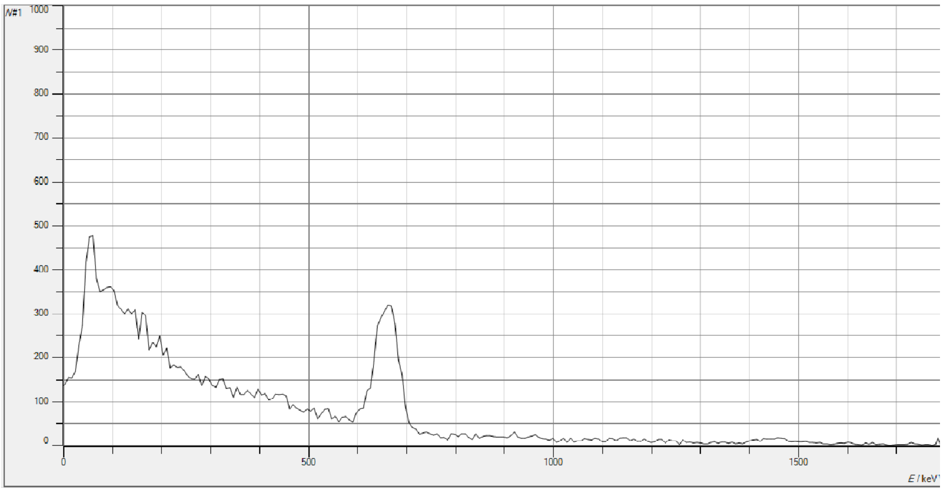

Fig. 3: A typical gamma ray spectrum obtained for Cs-137 after calibration

(III) Differential cross section and calibration factor:

Calculate the differential scattering cross-section using Eq. 3 and plot it as a function of θ. Determine the calibration factor C using Eq.4.

Graphs/Results/Discussion:

References:

1. Manual from supplier (LD-didactic)
2. https://www.physics.wisc.edu/undergrads/courses/spring2017/407/experiments/compton/compton.pdf
3. R.P. Singhal and A.J. Burns, American Journal of Physics **46**, 646 (1978)