IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

Impact Factor: 6.252

Volume 2, Issue 8, May 2022

Cross-Section Measurement of In-coherent Scattering from Annular ^{241}Am Gamma Ray Source

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Abstract: *Compton scattering of gamma- rays has been carried out with the aluminum target at a fixed angle of $65^0 \pm 2.5^0$. ^{241}Am gamma ray source, having 59.57 KeV energy and a long half-life of 432.2 years has been used to carry out the scattering. The strength of the source is 1000 mCi and it has an annular geometry. Scintillation detector NaI (Tl) of type 708 having a crystal size $1\frac{3}{4}'' \times 2''$ connected to a Multichannel Analyzer (MCA) has been used for this study. MCA was calibrated using ^{133}Ba, and ^{137}Cs sources through ACCUSPEC software. The data accumulated was used to estimate the energy of the backscattered peak of the said sources and compared with their respective theoretical value. Spectrums were accumulated directly from ^{241}Am and the shift in the photo-peak of ^{241}Am with the aluminum scatterer. Data was used to calculate the scattering cross-section and compared with its theoretical value using Kline and Nishina's equation. A good agreement is found in theoretical and experimental values.*

Keywords: Compton Scattering, Differential Scattering Cross-section, Multichannel Analyzer, ^{241}Am Gamma Ray Source.

I. Introduction

Radioactivity is the property of unstable nuclei. They emit invisible (alpha particles, beta particles or gamma rays) radiations to attain a stable nuclear configuration. Alpha particle is positively charged He nucleus, beta particles are electrons and gamma rays are electromagnetic waves. Gamma rays being neutral are difficult to detect but when interact with metal can produce electrons or charged particles, which can be detected easily. Gamma rays interact with the matter and can transfer its energy either partially or totally to the metal electrons giving rise to Compton effect [1], [2] or Photoelectric effect respectively. Characteristics of a gamma ray spectrum are a Compton continuum, back-scattered peak, Compton edge and a photo peak. If the scattered gamma-ray escapes from the detector only a fraction of the energy of gamma ray is deposited in the detector, which gives rise to Compton continuum extending from zero energy up to the Compton edge in the spectrum and will not contribute to the photo-peak. Gamma rays may be scattered by ~180^0 by Compton interaction through the housing material of the radioactive source, through the shielding material, ceiling, floor or any material surrounding the experimental setup before entering the detector. This results a backscatter peak in the spectrum.

The gamma-ray sources generally used in Compton-scattering [3] are ^{241}Am, ^{123m}Te and ^{198}Au with energies 59.57KeV, 159.0 KeV and 412 KeV respectively. Among these ^{241}Am has the longest half-life and gives constant source strength for a longer period of time. The disadvantage of the ^{241}Am source is that only 30% of the total gamma rays are emitted as the 59.57 KeV gamma-rays and self-absorption is high. At this energy the ratio of photo-electric to Compton cross-section becomes greater than one for atomic numbers greater than 15. In spite of these shortcomings, ^{241}Am source remains desired source for carrying out Compton scattering experiments.

The electron cross-section was classically derived by the Sir J.J. Thomson[4] but experimental results were not found to match with the cross-section formula predicted by him. Oskar Klein and Yoshio Nishina's formula[5] of differential cross-section was one of the first results obtained from the study of quantum electrodynamics.

It considers the relativistic and quantum mechanical effects. The Klein–Nishina formula gives the differential scattering cross section of photons scattered from a single free electron in lowest order of quantum electrodynamics. At low frequencies and high frequencies, it yields Thompson and Compton scattering respectively. In this study Compton scattering cross-section for 59.57 KeV gamma rays has been determined in the pulse height distribution mode of the spectrum. The theoretical value of the cross-section has been obtained from Kline and Nishina's equation [5].

Published data on gamma scattering has been collected from Scopus data base and analyzed. Total 218 papers have been found for the title "Compton Scattering by Gamma Rays" from the year 1960 till 2022. These papers cover a wide spectrum of measurements and calculations on Compton scattering spanning from tunable laser gamma sources[6]–[8], inverse Compton scattering[9]–[11], doubly differential collision cross-sections[12] for double-photon Compton scattering, quantum beam generation[13] and many more. Several papers are available on Compton scattering[1], [14] from ^{241}Am gamma rays and cross-section[12], [15], [16] measurements have been done for different materials. No evidence has been found in literature for the ^{241}Am annular source usage. The ^{241}Am source used in the present work has high activity and peculiar geometry as shown in fig. 1.

II. Materials and Method

^{241}Am gamma ray source, having 59.57 KeV energy and long half-life (432.2 years) has been supplied by The Radiochemical Centre, Amersham, U.K. ^{133}Ba source has two photo-peaks at energies 82.343 keV and 354.203 keV respectively. Photo-peak of ^{137}Cs is at 666.539 keV. The MCA system was calibrated [17], [18] using ^{133}Ba and ^{137}Cs sources for 1 Kev/channel. The position of the back-scattered-peak of ^{22}Na, ^{137}Cs and ^{60}Co were determined using this calibration. The MCA system was recalibrated for 0.5 KeV/channel, to be able to measure the Compton shift accurately. NaI(Tl) detector is usually preferred for γ-photon detection[19] due to its high efficiency[20]. The γ-ray spectra for ^{241}Am was accumulated by directly exposing the source to the NaI (Tl) detector. Compton scattering with Al target was carried out at a fixed angle $165^0 \pm 2^0$ by using the experimental set up.

III. Experimental set-up

The design of the scattering chamber along with the scatterer position, collimator and source holder is shown in fig. 1. In accordance with the source geometry the collimation is done by a hollow conical lead block, marked 'd', with a central cone marked 'b' having an axial hole of diameter 0.9 cm. in the center. The gamma rays from the annular source are collimated to the position of the scatterer placed on the top of the lead block marked 'd', at an angle of 15^0 to the vertical axis of geometry. Gamma rays are scattered at a fixed angle of 165^0 and pass through the axial hole of the central cone (marked 'b'), which also acts as a collimator for the scattered gamma rays. Scattered gamma rays reach to the detector placed axially below the whole geometry. An adequate shielding of lead around and below the source is also done (marked 'a') so that no direct radiation reaches to the detector and the working place from the source. The source to detector distance in this setup is 3.65 cm. and the distance from the scatterer to the detector is 12 cm. This annular geometry of the source and scattering chamber is used to get maximum intensity of gamma rays to be scattered from the detector.

The high strength and the annular geometry of the source makes it possible to get high number of counts within the least possible time which are required for the statistical accuracy in gamma ray Compton scattering study. The central collimating cone has the axial hole of diameter 9.0 mm. The maximum area of the detector crystal along with good collimation has been used in this experiment so that the radiation after scattering at ($165^0 \pm 2.5^0$) are detected. The whole of the geometry is made in pieces and can be fitted at their right position with the help of the pins provided (marked 'c'). The scattering chamber is shielded in a thick lead cylinder of 2.5 cm. thickness and with an upper lid of thickness 2.5 cm. to avoid the hazards of radiations from such a strong source. The total length and diameter of the scattering chamber are nearly 13 cm. and 9.0 cm. respectively.

The complete assembly is placed on the table top with a hole of diameter 9.0 mm. in the center, which allows the scattered radiation to reach the detector window placed axially below the table. The source and the detector are therefore separated by a thick lead base plate (marked 'a') of chamber and wooden table top.

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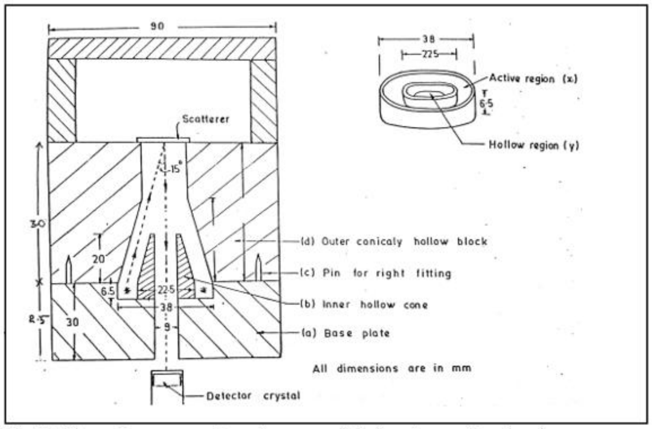

Fig. 1. Schematic representation of source and design of scattering chamber.

IV. Results and Discussion

The MCA system calibration data for 1 Kev/channel to obtain the two photo-peaks of ^{133}Ba and ^{137}Cs at channel numbers 82, 354 and 666 respectively. Calibration data is presented in table I.

Table I: Calibration Data for 1 Kev/channel for ^{133}Ba, and ^{137}Cs Sources

Source	Energy (Kev)	Area	Central Channel	FWHM	Gaussian Ratio
^{133}Ba	82.343	15529	82.343	4.043	1.355
^{133}Ba	354.203	98339	354.203	38.594	0.933
^{137}Cs	666.539	78014	666.539	61.292	0.934

The spectra of ^{22}Na, ^{60}Co and has been obtained to find out the energy of the back-scattered peak. The spectra obtained for ^{22}Na and ^{60}Co are shown in fig 2 and figure 3. respectively. The comparison of the experimentally observed back-scattered peak energy with theoretical energy values are given in the table II. E_{Ph}, E_C and E_B represent the energy of photo peak, Compton edge and back-scattered peak respectively.

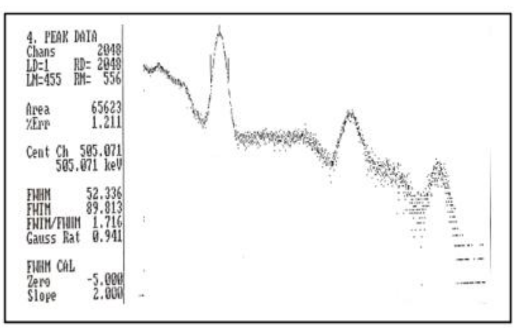

Fig. 2. Spectrum of ^{22}Na for the calibration of 1 Kev/channel of MCA.

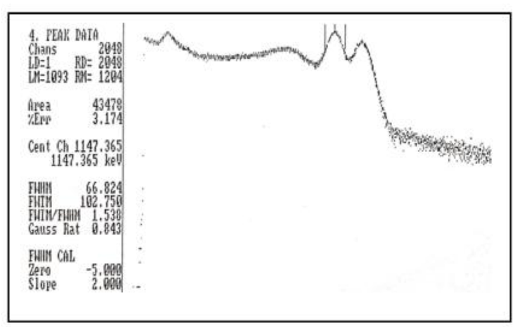

Fig. 3. Spectrum of ^{60}Co for the calibration of 1 Kev/channel of MCA.

Table II: Data for Energy dependence of Compton edge and back scattered peak. Energies of photo-peak, back-scattered peak and Compton edge for ^{22}Na, ^{60}Co and ^{137}Cs sources.

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Source	Energy of Photo peak (keV) (E_P)	Energy of Compton Edge (keV) (E_C)	$E_B = E_{Ph} - E_C$ (Kev) Calculated	E_B (Kev) (Theory)	E_B (Kev) (Observed)
^{22}Na	505.1	304.9	200.2	168.9	170.3
^{137}Cs	663.2	446.5	216.7	189.9	184.3
^{60}Co	1147.4	919.8	227.6	211.9	209.8
					214.4

Table II infers that the observed value of the backscattered peak matches very well with the theoretical value. However, calculated energy of back scattered peak (E_B) is systematically larger, which may be due to an underestimation of the Compton edge (E_C) on author's part, while taking the observations.

The spectrum of ^{241}Am is shown in fig. 4 and various peaks are identified. Compton scattering with Al target was carried out at a fixed angle $165^0 \pm 2^0$ by using a Compton scattering setup. The back scattered peak of ^{241}Am has been shown in figure 5. DMAN program available in ACCUSPEC software [17] was run and by using the TOT function, the counts under the peak were obtained. The obtained data is shown in table III.

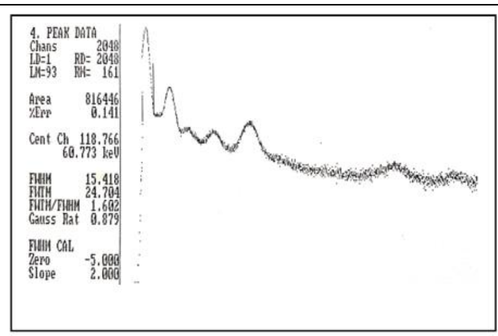

Fig. 4. Spectrum of ^{241}Am for the calibration of 0.5 Kev/channel of MCA.

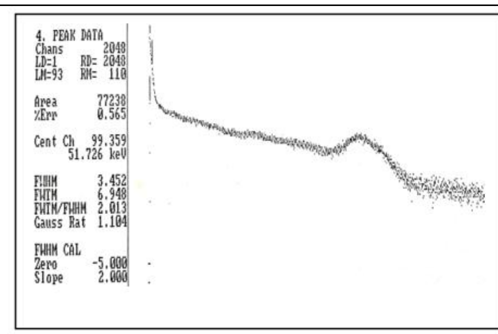

Fig. 5. Spectrum of ^{241}Am for the scattered peak position.

Table III: Data Obtained using DMAN Program

Parameters	Un-scattered peak position	Scattered peak position
Centroid channel	118.77	99.36
Energy (KeV)	60.78	51.73
Total Counts		231465

Theoretical value of the cross-section for ^{241}Am (E_γ =59.57 KeV) has been evaluated by Kline and Nishina's formula.

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

r_0 is the classical electron radius and $\alpha = \frac{E_\gamma}{m_0c^2}$. Measured value of the differential cross-section has been obtained by

$$\left[\frac{d\sigma}{d\Omega}\right]_{\text{Measured}} = \frac{\Sigma_\gamma{}'}{N\,\Delta\Omega\, I}.$$

$\Sigma_\gamma{}'$ is the ratio of the sum under the photo peak to the intrinsic peak-efficiency[21], [22]. N, $\Delta\Omega$, R and I are the number of electrons in the scattering sample, solid angle in steradians of detector, distance between the detector and the number of incident gamma rays\cm^2 \sec. at the scattering sample respectively.

IV. CONCLUSIONS

1. The observed energy of the back-scattered peak in ^{22}Na, ^{137}Cs and ^{60}Co agrees very well with the theoretical value.
2. The observed gamma ray scattering cross-section of 59.57 Kev gamma ray of ^{241}Am from Al target at ($165^0 \pm 2.5^0$) using the accumulated data has been found to be $\left[\frac{d\sigma}{d\Omega}\right]_{\text{Measured}} = 2.66 \times 10^{-26}$ cm^2 /steradian. The theoretical value obtained using the Kline and Nishina's formula is $\left[\frac{d\sigma}{d\Omega}\right]_{\text{Theoretical}} = 5.186 \times 10^{-26}$ cm^2/steradian.
3. Due to practical difficulties like fixed geometry and high activity of the source scattering measurements at other angles were not possible.

ACKNOWLEDGEMENT

Author is thankful to Head, Department of Physics, I.I.T. Roorkee and Dr. A. K. Jain. Professor, I.I.T. Roorkee, Roorkee for providing the facilities needed for carrying out the experiment and supervising the work.

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