The Asymmetry of the Compton Profiles and its Dependence on the Geometrical Resolution *

D. L. Anastassopoulos and G. D. Priftis
Department of Physics, University of Patras, GR-261 10, Patras, Greece

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The asymmetry of Compton Profiles (CPs) measured with a 60-keV ^{241}Am source on an Al monocrystal, cut along [111], is reported for three different geometrical resolutions. It is found that the geometry of the spectrometer has a substantial effect on the asymmetry of the CP. The better the geometrical resolution the smaller the asymmetry of the CPs.

Key words: Compton profile; Compton asymmetry; Geometrical resolution; Compton spectroscopy; γ-ray spectroscopy.

1. Introduction

It is a well established experimental fact that nearly all measured Compton profiles show a significant residual asymmetry, regardless of the relative energy-dependent corrections taken into consideration, such as the Compton scattering cross-section, absorption and multiple scattering.

However, according to the impulse approximation, which is the theory applied for the interpretation of the Compton scattering experiments almost exclusively, the obtained CPs should be symmetric.

Several workers in the past have tried to investigate the origin of this asymmetry. Cooper et al. [1] have examined the contribution of the air scattering in the tail of the resolution function and have reported that its influence on the profile was insignificant.

Holt et al. [2], in an investigation of this asymmetry, suggest that the impulse approximation is not valid when a ^{241}Am source is used, and they conclude that further quantitative work is needed.

Inelastic scattering within the source (self-scattering) has been investigated by Manninen et al. [3] for 60-keV ^{241}Am and by Rollason et al. [4] for ^{198}Au, ^{51}Cr and ^{192}Ir. Manninen et al. suggest that the asymmetrical part of the detector response function must be removed with a resolution-dependent deconvolution scheme [5] in order to account for the variation of the resolution function across the CP. On the other hand, Rollason et al. suggest a method of correction and applied it to their measurements. They found a residual asymmetry of about -1.5% of $J(0)$, the maximum value of the CP, that is not yet explained and is independent of the source energy.

Despite all the efforts made until now, the asymmetry of the CP remains and cannot be explained and removed.

In the present work, CP measurements from a 60-keV ^{241}Am source on an Al monocrystal, cut along [111], are obtained with three different geometrical resolutions (GR). The influence of the geometrical resolution on the asymmetry of the CP is investigated and discussed.

2. Experimental Procedure

It is well known [6] that the GR is a function of the primary energy, the scattering angle φ and the uncertainty of the scattering angle $\pm\Delta\varphi$. In this work the GR is altered by changing the scattering angle φ and the uncertainty $\pm\Delta\varphi$ for a given primary energy. For this reason two different collimation systems have been used, based on a 300 mCi ^{241}Am disc source, in connection with the experimental set-up described in [7], resulting in three different GRs. The first GR (GR1, Fig. 1) corresponds to a collimation system that has a mean scattering angle of 170° and a FWHM of 2°, equivalent to 28 eV of energy spread or 0.04 a.u. of momentum [7]. The other two GRs (GR2 and GR3, Fig. 2) correspond to a collimation system that has a mean scattering angle of 160° and a FWHM depen-

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Reprint requests to D. L. Anastassopoulos, Department of Physics, University of Patras, Patras 26110, Greece.

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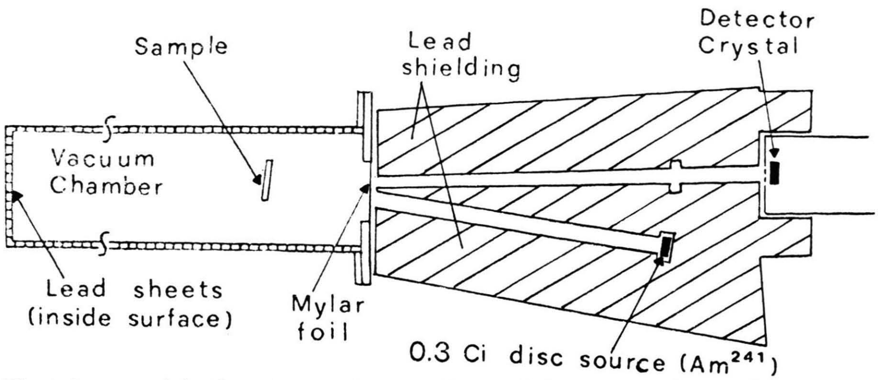

Fig. 1. Layout of the Compton spectrometer for $\varphi = 170°$, corresponding to GR1.

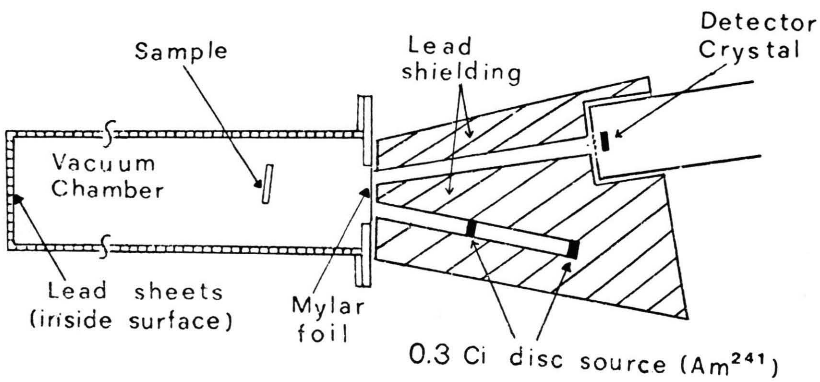

Fig. 2. Layout of the Compton spectrometer for $\varphi = 160°$, corresponding to GR2 and GR3.

dent on the source-to-sample distance. The GR2 corresponds to a distance equal to 18 cm resulting in a FWHM of 3°, which is equivalent to 85 eV of energy spread or 0.13 a.u. of momentum. The GR3 corresponds to a distance equal to 12 cm resulting in a FWHM of 5°, which is equivalent to 132 eV of energy spread or 0.21 a.u. of momentum.

All CPs were measured with the same detecting system. The pure-Ge solid-state detector has a resolution of 357 eV FWHM at 59.54 keV gamma-ray energy.

The samples used were two aluminium monocrystals cut along the [111] direction, with a diameter of 2.5 cm and thicknesses of 1.0 mm and 3.2 mm, respectively, purchased from Metal Crystals Ltd., Cambridge. The signal-to-noise ratio as well as the geometrical and total resolution for each experimental arrangement are shown in Table 1.

The raw data of all measured spectra, after background subtraction, were corrected for energy-dependent Compton cross-section and absorption in the sample. Following the determination of the peak of the CP, its asymmetry was obtained by subtracting the high-energy side $J(+)$ from the low-energy side $J(-)$ of each corrected CP and expressed in percentage of $J(0)$.

3. Results and Discussion

The CP asymmetries for the 3.2 mm thick sample are plotted in Figure 3. The curves A, B, C correspond to the three different geometrical resolutions GR1, GR2 and GR3, respectively. It is clearly shown that the asymmetry decreases as the GR is improved.

Parameters that affect the asymmetry, such as source self-scattering in gamma-ray sources and validity of the impulse approximation, cannot explain the observed differences between the above curves, since the same source and the same scatterer have been used

Table 1.

Exper. arrangement	Geometrical resolution (a.u.)	Total resolution (a.u.)	Sample thickness (mm)	Signal/background ratio
GR1	0.04	0.52	3.2	800
GR2	0.13	0.54	1.0	1000
	0.13	0.54	3.2	3500
GR3	0.21	0.56	1.0	2300
	0.21	0.56	3.2	7000

for all three GRs. Thus we conclude that the differences between asymmetries must be attributed to the different geometrical resolutions of the experimental arrangements.

The asymmetries of CPs for the sample with 1 mm thickness are plotted in Figure 4. It is obvious that the asymmetries of the CPs follow the same behaviour as with the sample of 3.2 mm thickness, presented in Figure 3.

By comparing Figs. 3 and 4 it follows that the asymmetry becomes larger as the thickness of the sample increases. This is most probably due to multiple scattering and can be explained in the following way. The existing methods for correcting CPs from multiple scattering are based on the assumption that the CP is symmetric and the correction from multiple scattering has no significant effect on the asymmetry. However, if it is assumed that the spectrum, that comes from single scattering, has an asymmetry with the side of low energy larger than the side of high energy, then the spectrum of double scattering will present a larger asymmetry because it is a convolution of two single-scattering spectra. Therefore, as the sample becomes thicker and the ratio of double to single scattering increases, the spectrum will present larger asymmetry.

The detector response function has a low-energy tail. A similar tail is obtained in the spectrum of the incident beam owing to the source self-scattering. These two effects may introduce a large amount of asymmetry in the CP. In order to correct this asymmetry, the spectral resolution function was measured directly from the source under conditions that mimic the sample-to-detector geometry (for the two different scattering angles) and this function is used to deconvolute the measured spectra [5, 7]. Finally, the deconvoluted spectra were smoothed by convolution only with the symmetric part of the resolution functions [5]. The final asymmetries, after the above corrections, are

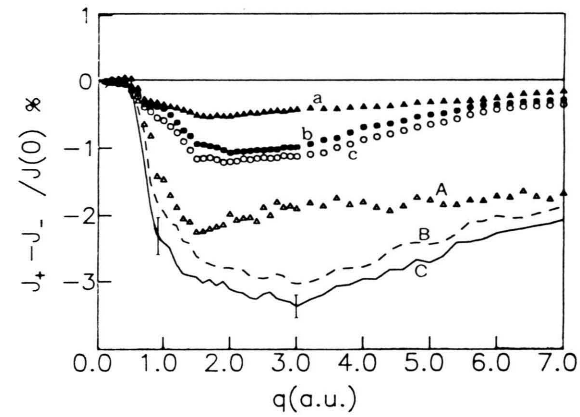

Fig. 3. Asymmetry of the experimental CP of aluminium (3.2 mm thick) in the [111]-direction after correction for background, absorption and the energy dependence of the scattering cross-section. Curves A (open triangles), B (dashed), and C (solid) correspond to the GR1, GR2 and GR3, respectively. Curves a (filled triangle), b (filled circles) and c (open circles) correspond to curves A, B, and C, respectively, followed by an additional correction for the low-energy tail of the incident beam.

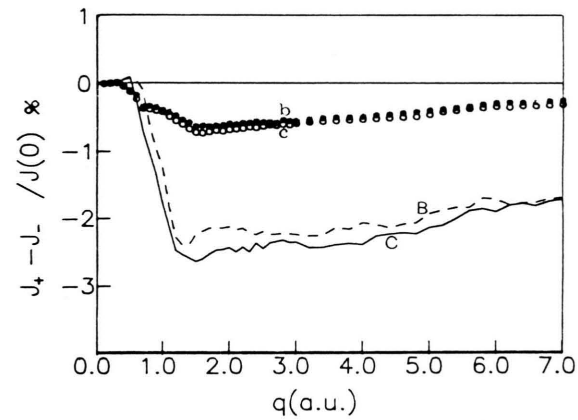

Fig. 4. Asymmetry of the experimental CP of aluminium (1.0 mm thick) in the [111]-direction after correction for background, absorption and the energy dependence of the scattering cross-section. Curves B (dashed) and C (solid) correspond to GR2 and GR3, respectively. Curves b (filled circles) and c (open circles) correspond to curves B and C respectively, followed by an additional correction for the low-energy tail of the incident beam.

shown in Fig. 3 with curves a, b, c and in Fig. 4 with curves b and c.

From Fig. 3, curves a, b, c, and from Fig. 4, curves b, c, it is concluded that the curves with the best GR show the smallest asymmetry. This is in agreement with the conclusion already drawn from Fig. 3, curves

A, B, C, and Fig. 4, curves B, C. By comparing curve a with curves b and c in Fig. 3 it is shown that after all corrections have been made the asymmetry decreases drastically as the GR becomes better, but a small amount of less than 0.5% for the best GR persists. The above finding suggests that the remaining asymmetry should tend to zero as the GR tends to zero, i.e. as the scattering angle approaches 180° [6, 9]. Furthermore, the "universal remaining asymmetry" reported by Rollason et al. [4] could thus be explained in the context of the above considerations.

4. Conclusions

The experimental results presented in this work show that the geometry of the spectrometer has a profound effect on the asymmetry of the CP. Smaller asymmetries on CPs are achieved with the improvement of the geometrical resolution of the spectrometer. It is believed that the residual asymmetry that is reported in other experiments is due to the finite GR and tends to be zero as the scattering angle approaches 180°.

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