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Section A

The influence of geometrical resolution of a gamma ray spectrometer on the asymmetry of Compton profiles

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 directional Compton profile of aluminium single crystal has been measured with 60 keV gamma-radiation. The results show that as the geometrical resolution of the spectrometer becomes better the asymmetry of Compton profiles decreases.

1. Introduction

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

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

Several workers in the past have tried to investigate the origin of this asymmetry. Cooper et al. (1978) [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 an ^{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 the maximum of CP ($J(0)$), 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.

Recent CP measurements on Ni with Am source [6] resulted in smaller asymmetry than measurements [7] which were conducted with the same scatterer, with Au source, and which have better total resolution but a worse geometrical one. This indicates that the finite geometrical resolution (GR), inherent in all Compton scattering experiments, may introduce an asymmetry in the CP.

The above mentioned indication is also supported by a theoretical argument which is given and discussed in detail in section 3 of this paper.

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

2. Experimental procedure

It is well known [8] that the GR is a function of the primary energy, the scattering angle ϕ and the uncertainty of the scattering angle $\pm\Delta\phi$. In this work the GR is altered by changing the scattering angle ϕ and the uncertainty $\pm\Delta\phi$ 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 connec-

Table 1
Some characteristics of the different experimental arrangements

Experimental arrangement	Geometrical resolution [a.u]	Total resolution [a.u]	Sample thickness [mm]	Signal/noise 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

tion with the experimental setup described elsewhere [6], resulting in three different geometrical resolutions. The first geometrical resolution GR1 corresponds to the collimation system which 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 [6]. The other two geometrical resolutions (GR2 and GR3) correspond to a collimation system which has a mean scattering angle of 160° and a FWHM dependent on the source–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 total resolution of the spectrometer for the GR1 arrangement has a FWHM of 0.52 a.u. of momentum near the peak of the CP. The total resolution for the GR2 and GR3 arrangements is 0.54 and 0.56 a.u. of momentum respectively [8]. The channel width was fixed at 60.5 eV while the drift of the detecting system was checked two times daily. About 2×10^7 counts were accumulated under the Compton area for each profile.

The samples used were two aluminium monocrystals cut along the [111] direction, with a diameter of 2.5 cm and thickness of 1.0 mm and 3.2 mm respectively purchased from Metal Crystals Ltd. Cambridge. The signal-to-noise ratio changes from 800 to 7000 depending on the arrangement and on the thickness of the sample used. This ratio as well as the geometrical and total resolution 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 low energy side $J(-)$ from the high energy side $J(+)$ of each corrected CP and expressed in percentage of $J(0)$.

3. Results and discussion

The CPs asymmetries for the 3.2 mm thickness sample are plotted in fig. 1. 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 which 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 in 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 fig. 2. It is obvious, that the asymmetries of the CPs follow the same behaviour as with the sample of 3.2 mm thickness, presented in fig. 1.

By comparing figs. 1 and 2 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

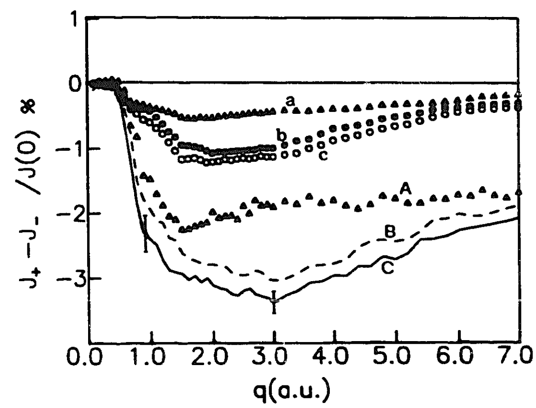

Fig. 1. Asymmetry of the experimental CP of aluminium (3.2 thick) in the [111] direction after correction for background, absorption and the energy dependence of the scattering cross section. Curves A (open triangles), B (dashed) and C (solid) correspond to the GR1, GR2 and GR3 respectively. Curves a (filled triangles), b (filled circles) and c (open circles) correspond to curves A, B and C respectively following additional correction for the low energy tail of the incident beam.

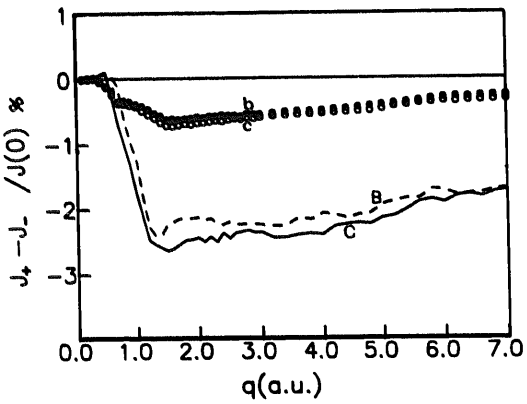

Fig. 2. Asymmetry of the experimental CP of aluminium (1.0 mm thick) in the [111] direction after correction for background, absorption and the energy dependence of the scattering cross section. Curves B (dashed) and C (solid) correspond to the GR2 and GR3 respectively. Curves b (filled circles) and c (open circles) correspond to curves B and C respectively following additional correction for the low energy tail of the incident beam.

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.

Measurements on asymmetry of Compton profiles with aluminium scatterer have been reported recently by Cardwell et al. [9], who report an asymmetry of 4% $J(0)$ using an annular ^{241}Am source, following corrections for absorption and for energy dependence of the scattering cross section. Having applied in the present work, the same corrections and asymmetry of 3% of $J(0)$ is found for the worst GR (GR3) and for a thicker sample than the one in Cardwell's work. Although detailed comparisons with the present work cannot be made, since details for their geometrical resolution are not reported, the authors attribute this difference to the annular geometry of their source, which gives a non fixed scattering vector and a poorer geometrical resolution.

The detector response function has a low-energy tail. A similar tail is obtained in the spectrum of the incident beam due to the source self-absorption. These two effects may introduce a large amount of asymmetry in the CP. In order to correct this asymmetry, the spectrum of 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 [6]. Finally the deconvoluted spectra were smoothed by convolution only with the symmetric part of the resolution function. The final asymmetries, after the above corrections are shown in fig. 1 with curves a, b, c and in fig. 2 with curves b and c.

From figs. 1a, b, c and from figs. 2b, c it is concluded, that the curves with the best GR show the smallest asymmetry. This is in agreement with the conclusion drawn from figs. 1A, B, C and fig. 2B, C. By comparing curve a with curves b and c in fig. 1 it is shown, that after all corrections have been made the asymmetry decreases drastically as GR becomes better. The above results suggest that the remaining asymmetry (less than 0.5% for the best GR) should tend to zero as the GR tends to zero, that is as the scattering angle approaches 180° [8,10].

The fact that the geometrical resolution may introduce an asymmetry in the CP can be understood in the following way:

The usual determination of angular distribution of the scattering angle by a Monte Carlo calculation yields to a symmetric Gaussian which is characterized by a mean scattering angle ϕ and an angle uncertainty $\pm\Delta\phi$. It is well known that the position of the peak of the CP varies from the position of the incident beam as $\sin^2(\phi/2)$. This means that the symmetric angular distribution of the scattering angle implies a variation of the CP peak (and hence of the whole CP) according to $\sin^2((\phi \pm \Delta\phi)/2)$ which is not a symmetric function around the mean scattering angle ϕ. The asymmetry thus introduced depends on the variation of $\sin^2(\phi/2)$, that is of $\Delta(\sin^2(\phi/2)) = \sin\phi\ \Delta\phi$.

From the above considerations it is evident that a measured CP has an inherent asymmetry due to the finite width of the scattering angle $\Delta\phi$, and depends on the $\sin\phi$ of the scattering angle ϕ. Consequently this asymmetry tends to be zero as ϕ approaches 180° (in this special case $\sin^2((\phi \pm \Delta\phi)/2)$ is symmetric around ϕ), in accordance with the present experimental results.

Furthermore the "universal remaining asymmetry" reported by Rollason et al. [4] can be explained in the context of the above considerations.

4. Conclusions

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

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