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Measurement of the Compton and Coherent Scattering Differential Cross-Sections

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Abstract

The total atomic Compton and coherent scattering differential cross section of Al, Sn and Ta for 59.5 keV gamma rays of Am-241 point source have been measured for scattering angles $\theta = 81^\circ$, 85.5°, 90° and 94.5° by a direct method with an energy dispersive x-ray spectrometer. The background correction and detection efficiency are also included the study. The experimental results are comparatively given with some available theoretical data obtained with some approximation methods.

1. Introduction

Scattering is a kind of interaction of electromagnetic radiation with matter and can be examined in two ways as coherent and incoherent. An accurate knowledge of both differential cross section is useful in the calculation of radiation attenuation, reactor shielding, industrial radiography, transport and energy deposition in medical physics and in a variety of other fields [1].

Incoherent scattering of gamma radiation by free electrons is satisfactorily explained by the theory of Klein-Nishina [2]. At higher energies a different type of experiment was concerned with an experimental determination of the deviations of the differential cross section $d\sigma/d\Omega$ for Compton scattering as descriped by the Klein-Nishina formula. In these experiments Compton scattering from K-electrons has been separately investigated by measuring coincidences between Kx-rays and Compton scattered photons [3-7]. Earlier experimental investigations on the total atomic Compton scattering differential cross sections have been confined at higher energies [8-16] and at lower energies [17-19]. Coherent scattering of 59.5 keV gamma rays by bound electrons has been studied by several investigator [20-23]. Standing and Jovanovich has given a method for coherent scattering cross section. With this method the accuracy of the cross section determination is still limited by the accuracy of the intensity determination of the main and auxiliary source [24]. P. P. Kane et al., developed a new technique for the determination of scattering cross sections of lead by using Al as a reference scattering sample [9-11].

In the present study, the Compton and coherent scattering differential cross sections for 59.5 keV photons are directly (without reference sample) determined from observed pulse-height distributions. The theoretical Compton and coherent scattering differential cross sections for the 59.5 keV photons from Al, Sn and Ta target atoms are calculated by using the equations [24]

$$\frac{d\sigma_c}{d\Omega} = \frac{d\sigma_{KN}}{d\Omega} S(x,Z) \quad (1)$$

$$\frac{d\sigma_{coh}}{d\Omega} = \frac{d\sigma_T}{d\Omega} \left[F(x,Z)\right]^2, \quad (2)$$

where $d\sigma_{KN}/d\Omega$ is the Klein-Nishina cross sections of an electron, $d\sigma_T/d\Omega$ is the Thomson scattering cross sections, $S(x,Z)$ is the incoherent scattering function, $F(x,Z)$ is the atomic form factor, Z is the atomic number, $x = (\sin\theta/2)/\lambda, \theta$ is the angle of scattering and λ(Å) is the photon wavelength. The theoretical values of $S(x,Z)$ and $F(x,Z)$ are tabulated by Hubbell et al [24] on the basis of nonrelativistic Hartree-Fock calculatinos.

2. Experimental

The experimental arrangement is shown in Figure 1. The gamma source 10μCi Am-241, was placed at the bottom of a lead collimator. The lead collimator was placed on a horizontal bar which could rotate 180° around a horizontal axis, in the vertical place, centered on lead-shielded dipstick Ge(Li) detector. The Ge(Li) detector, having a diameter of 10mm with a depth of 5mm, was used to detect the Compton and coherent scattered 59.5keV gamma photons. The resolution of the detector (FWHM) was found to be 190eV at the 5.9keV MnKα line. High-purity thinner elemental foils of Al, Sn and Ta (all of purity higher than 99.9%) were used as scatters. The thickness of Al, Sn and Ta are 0.0089, 0.018 and 0.044 gr/cm^2, respectively. The target-detector and target-source distances were set to 15cm and each circular target had an area of π(25mm)^2. The detector was also shielded by a lead collimator with 75 mm length and 4.6 mm wall thickness. The scatteed photons are collimated by a detector collimator having a 10mm diameter aperture.

The electronic set up was a standard one consisting of a stabilised detector voltage supply unit, a FET preamplifier and a 1024 channel pulse-height analyser. The scattered gamma ray spectra were obtained with the detector and multichannel analyser for angles of scattering θ=81°, 85.5° and 94.5°. A representative spectrum of photons scattered by Sn is shown in Figure 2.

To get the net scattering spectrum, each pulse height spectrum of scattered gamma rays was collected for 4.23·10^{4}s and the background spectrum obtained under the same experimental conditions are subtracted from this spectrum. The detection efficiency of

Ge(Li) detector was determined by placing the radioactive test sources (Am-241(14,18,21,59.5 keV) and Ba-133 (31, 81 keV) at the target position and recording the spectra.

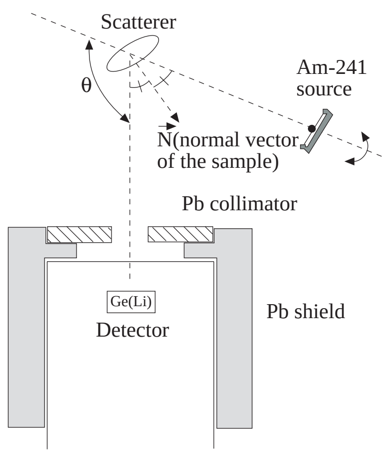

Figure 1. Geometry and shielding arrangement of the experimental set up

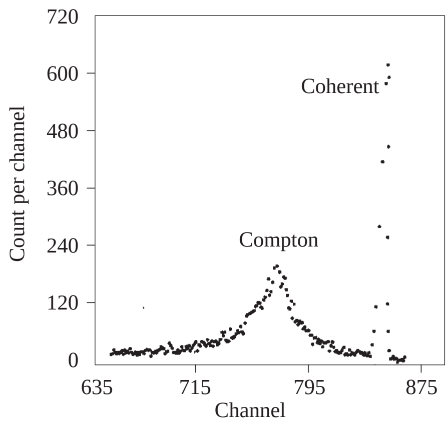

Figure 2. Representative spectrum of 59.5 keV photons scattered at 85.5° by Sn.

3. Results and Discussion

It is easy to show that the differential cross sections for the Compton and coheent scattergng of gamma rays by a target atom can be obtained by using the equations

$$\frac{d\sigma_c}{d\Omega} = \frac{N_{nc} r^2 \varepsilon}{N(1-T)\rho d A \varepsilon_{nc}} \tag{3}$$

$$\frac{d\sigma_{coh}}{d\Omega} = \frac{N_c r^2}{N(1-T)\rho dA}, \tag{4}$$

where N_{nc} is the net photopeak counting rate of the Compton scattering, N_c is the net photopeak counting rate of the coherent scattering, N is the measured number of photons impinging on the detector in unit time when the source placed at the scatter position, T is the transmission factor, ρ is the number of scatter atoms in the sample, r is the distance between centres of the sample and detector crystal, ε_{nc} and ε are the detection efficiencies of the system for Compton scattered photons and incident photon energy respectively, and dA is the upper surface area of the detector crystal.

Table 1. Total Compton and coherent scattering differential cross sections per atom

			$d\sigma_{coh}/d\Omega$		$d\sigma_c/d\Omega$	
Element	θ (deg.)	x (Å^1)	Theo. (10^{-24}cm^{2}sr^{-1})	Expt.	Theo. (10^{-24}cm^{2}sr^{-1})	Expt
Al	81.0	3.113	-	-	0.430	0.534
	85.5	3.254	-	-	0.419	0.626
	90.0	3.390	-	-	0.411	0.610
	94.5	3.520	-	-	0.409	0.637
Sn	81.0	3.113	0.840	0.773	1.473	1.735
	85.5	3.254	0.724	0.848	1.441	1.938
	90.0	3.390	0.667	0.851	1.427	1.915
	94.5	3.520	0.635	0.750	1.430	1.250
Ta	81.0	3.113	2.376	1.257	2.042	2.097
	85.5	3.254	2.097	1.470	2.001	2.318
	90.0	3.390	1.808	1.504	1.983	2.979
	94.5	3.520	1.583	1.477	1.990	2.744

The efficiency of the gamma-ray detector for Compton spectra was assumed to be the same as for the photon spectra from source at each scattering angle. The calculation of the various factors such as geometry, efficiency etc. are not necessary and some of the statistical and systematical errors in the measurement of N_{nc}, N_c and N are measured in the same experimental geometry and take place as ratios in equations (3) and (4). The measured Compton and coherent scattering differential cross sections are given in Table 1. As seen from Table 1, Compton and coherent scattering differential cross sections increase with increasing atomic number. As we know, there is no experimental study in the literature with the same parameters (scattering angles and target atoms) we used. For that reason, comparison of the present results are not possible. But it can be seen from Table 1 there is qualitative agreement between the present experimental results and the theoretical values within the experimental errors. The error associated in the evaluation of the photopeak area is less that 1.02 %. The total error in the transmission factor is estimated to be about 2%. The uncertainty in setting the sample angle and scattering angle is about 1%. The error in N is estimated to be about 3 %. Uncertainty in the thickness determination is about 4%.

As a result, it is shown by a direct method that the Compton and coherent differential cross sections per atom by using calibrated sources in a given experimental geometry depend on the scattering angle [23, 26, 27] and the atomic number of the scatterer elements.

In order to obtain more accurate values needed is a number of relevant experimental values for large angles and low photon energy.

References

[1] B.S. Ghumman, V.B. Acharya and B. Sing, *J. Phys. B: At. Mol. Phys.*, **14** (1981) 3905.

[2] O. Klein and Y. Nishina, *Z. Phys.*, **52** (1929) 858.

[3] M. Singh, *Phys. Let.*, **33A** (1970) 70.

[4] S.T.P.V.J. Swamy and D.R.S. Murty, *Physica Scpripta*, **23** (1981) 21.

[5] K.L. Allawadhi, S.L. Verma, B.S. Ghumman and B.S. Sood, *Phys. Rev.*, **A17** (1977) 1058.

[6] G. Basavaraju, P.P. Kane and S.M. George, *Nuc. Inst. and Meth. In. Phys. Res.*, **A255** (1987) 86.

[7] S.G. Shivaramu and B. Sanjeavaiah, *Nuc. Inst. and Meth.*, **140** (1977) 529.

[8] P.P. Kane, J. Mahajani, G. Basavaraju and A.K. Priyadarsini, *Nucl. Inst. and Meth.*, **155** (1978) 467.

[9] P.P. Kane, G. Basavaraju, J. Mahajani and A.K. Priyadarsini, *Phys. Rev.*, **A28** (1983) 1509.

[10] P.P. Kane, G. Basavaraju, M. Lad Saharsha, K.M. Varier, L. Kissel and R.H. Pratt, *Phys. Rev.*, **A36** (1987) 5626.

[11] J.C. Dow, J.P. Lestone, R.B. Taylor and I.W. Whittingham, *J. Phys. B: Mol. Opt. Phys.*, **21** (1988) 2425.

[12] J. Eichler, S. Barros and A.M. Concalves, *Naturforsch*, **37a** (1982) 1124.

[13] Rao V. Viswesvara and Rao D. Venkateswara, *Phys. Rev.*, **A28** (1983) 1527.

[14] G. Pinto, N. Govinda Nayak, K.M. Balakrisha, N. Lingappa and K. Siddappa, *J. Phys. B: At. Mol. Opt. Phys.*, **23** (1990) 3759.

[15] D.A. Bradley, C.S. Chong, A.A. Tajuddin, A. Shukri and A.M. Ghose, *Phys. Rev.*, **A45** (1992) 2095.

[16] C. Özmutlu, *Int. J. Appl. Radiat. Isot.*, **36** (1985) 699.

[17] Y. Kurucu, S. Erzeneoğlu, Y. Şahin, and R. Durak, *IL Nuovo Cimento*, **16D** (1994) 555.

[18] Y. Namito, S. Ban, H. Hirayama, N. Nariyama, H. Nakashima, Y. Nakane, Y. Sakamoto, N. Sasamoto, Y. Asano and S. Tanaka, *Phys. Rev.*, **A51** (1995) 3036.

[19] S.S. Nandi, R. Dutta, N. Chaudhuri, *J. Phys. B.: At. Mol. Phys.*, **20** (1987) 4027.

[20] N.G. Nayak, K. Siddappa, K.M. Balakrisha, N. Lingappa, *Phys. Rev.*, **A45** (1992) 4490.

[21] S. Erzenoğlu, Y. Kurucu, R. Durak and Y. Şahin, *Phys. Rev.*, **A51** (1995) 4628.

[22] S. Erzenoğlu, R. Durak, Y. Kurucu and Y. Şahin, *Tr. J. of Phys.*, **19** (1995) 752.

[23] K.G. Standing and J.V. Jovanovich, *Can. J. Phys.*, **40** (1962) 622.

[24] J.H. Hubbell, Wm J. Veigele, E.A. Bringgs, R.T. Brown, D.T. Cromer and R.J. Howerton, *J. Chem. Ref. Data*, **4** (1975) 471.

[25] S. Erzenoğlu, Y. Kurucu, R. Durak and Y. Şahin, *Physica Scripta*, **54** (1996) 153.

[26] Y. Kurucu, S. Erzenoğlu, R. Durak and Y. Şahin, *Appl. Spect. Rew.*, **32** (1997) (in press).