EXPERİMENTAL STUDIES ON THE COHERENT SCATTERING OF 59.5 keV γ-RAYS

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ABSTRACT

In this study, we have measured differential cross sections for coherent scattering by experimentally. A high-purity germanium detector was used to determine differential cross sections for coherent scattering of 59.5 keV γ-rays. The experiment was performed using a filtered point source of Am-241 of intensity 100 mCi. To obtain the net pulse height spectra of scattered γ-rays, a background spectrum without the scatterer was stripped from the spectrum acquired for the same time and experimental conditions. The experimental differential cross sections were compared with theoretical values calculated from predictions of nonrelativistic (NRFF), relativistic (RFF) and relativistic modified (RMFF) form factor theories.

1. INTRODUCTION

Coherent scattering is an important process of photon interaction below 1 MeV. Coherent scattering cross sections are used in such diverse applications as medical X-ray technology, power reactor shielding, industrial radiation processing and analysis of nuclear physics experiments [1].Mainly, there are two approaches to obtain a detailed description of coherent scattering processes: *i*) Numerical partial-wave calculations of elastic scattering amplitudes and *ii*) form factor formalism [2]. A reference data set of theoretical predictions is presented for a grid of 10 elements (Z=13-103) and 7 energies (59.5 keV-1.33 MeV) at 55 scattering angles (0-180°) by Kane *et al.* [3]. Hubbell *et al.* [1,4] and Schaupp *et al.* [5] have tabulated the nonrelativistic, relativistic and relativistic modified form factors for a wide range of photon momentum transfer for all elements in the periodic table. Coherent scattering process has been extensively studied experimentally as well as theoretically. The experimentally differential cross sections for coherent scattering have been studied in several experiments [2, 6-16]. In the present investigation, we have measured whole atom differential cross sections for the coherent scattering of 59.5 keV γ-rays by Fe in the angular range of 55-105°.

2. EXPERIMENTAL

The schematic arrangement of the experimental setup used in the present study is shown in Fig.1. The experiment is performed using a filtered point source of Am-241 of intensity 3.7×10^9 Bq (100 mCi) which essentially emits monoenergetic (59.5 keV) γ-rays. The source was housed at the center of a cylindrical lead shield of 1 cm diameter and 3.4 cm length. High-purity thin elemental foils of Al and Fe (purity higher than 99.5%) were used as scatterer. The thickness of Al and Fe foils are 0.0074 and 0.0143 g/cm^2, respectively.

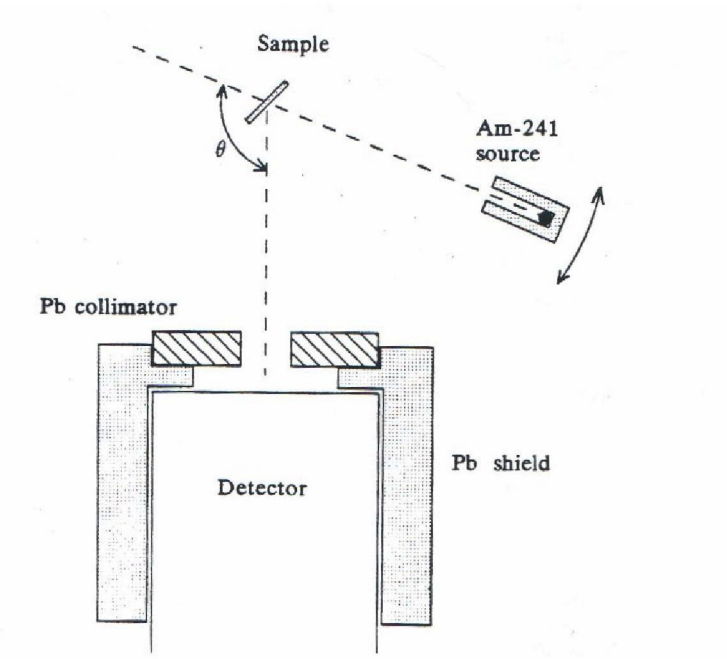


Fig. 1. Schematic diagram of the experimental arrangement.

A high-purity Ge detector was used to detect coherently scattered 59.5 keV γ-rays. The detector was also shielded by a lead collimator. The resolution of the detector (FWHM) was found to be 230 eV at 5.9 keV Mn K_α line. The manufacturer lists the Be window thickness as 130 μm and the gold contact thickness as 40.0 μg/cm^2. The detector was connected to a Nuclear Data series multichannel analyser. The spectra were recorded in a 1024 channel analyser. The target-detector and target-source distances were set to 3.2 cm and each circular target had an area of 25π mm^2. Each pulse height spectrum of scattered γ-rays was collected for 14400 s live time. To obtain the net pulse height spectra of scattered γ-rays, a background spectrum without the scatterer was stripped from the spectrum acquired for the same time and experimental conditions.

The differential cross section for coherent scattering of γ-rays by a target atom is obtained using the relation [17]

$$\frac{n_{coh}}{n_{Al}} = \frac{T}{T_{Al}} \frac{N}{N_{Al}} \frac{\varepsilon}{\varepsilon_C} \left[\frac{d\sigma_{Al}}{d\Omega} \right]^{-1} \frac{d\sigma_{coh}}{d\Omega} \tag{1}$$

Where T_{Al} is the transmission factor for Al at Compton energy, T is the transmission factor of target at 59.5 keV, N and N_{Al} are the number of atoms in the scatterer and Al, respectively, ε_C and ε are the detector photopeak efficiencies for Compton and coherent scattered of γ-rays, respectively, n_{coh} is the number of coherently scattered photons , n_{Al} is the number of photons Compton scattered from Al. The Compton scattering cross sections of Al:

$$\frac{d\sigma_{Al}}{d\Omega} = \frac{d\sigma_{KN}}{d\Omega} S(x.Z = 13) \tag{2}$$

Where $d\sigma_{KN} / d\Omega$ is the Klein-Nishina cross section per electron, $S(x, Z = 13)$ is the incoherent scattering function for Al, x is the photon-momentum transfer:

$$x = \frac{\sin(\theta/2)}{\lambda} \tag{3}$$

Where θ is the angle of scattering, λ is the wavelength of the incident radiation in Angstrom. The theoretical coherent differential cross sections are calculated by using:

$$\frac{d\sigma_{coh}}{d\Omega} = \frac{d\sigma_T}{d\Omega}\left[F(x,Z)\right]^2 \tag{4}$$

Where $F(x,Z)$ is the atomic form factor and $d\sigma_T / d\Omega$ is Thomson scattering cross section:

$$\frac{d\sigma_T}{d\Omega} = \frac{1}{2}r_e^2(1+\cos^2\theta) \tag{5}$$

Where r_e is the classical electron radius. The self-absorption correction was performed for all samples in our experiments.

3. RESULTS AND DISCUSSION

The main focus of the present study is on angular distribution of 59.5 keV γ-rays coherent scattering differential cross sections of Fe. The experimental differential cross sections for coherent scattering are graphically compared with the theoretical values calculated from predictions of nonrelativistic, relativistic and relativistic modified form factor theories in Fig.2. Also, experimental results are compared with results of S-matrix theory [3] in Fig.2. As seen from Fig. 2, the coherent scattering cross sections are decreasing with the increasing scattering angle. The experimental differential cross sections are in good agreement with the predictions of all three form factor formalisms but in better agreement with that of RFF. So, the present experimental work upholds the superiority of the RFF theory. It is clear from Fig. 2 that the experimental results agree well with the S-matrix results.

In this work, we have performed a critical comparison of predictions and measurements. The form factor theories give agreement with experiments in the intermediate photon momentum transfer region ($1< x <10$ Å^{-1}). But, we conclude that the theoretical cross sections based on numerical calculations of S-matrix theory are more precise than the predictions of the form factor theories. Similar results have also been reported by earlier investigators [3, 7].

The error associated with the evaluation of the photopeak area is less than 1.06%. The precision in the scattering angle is about ±4%. The total error in the transmission factor is estimated to be about 2%.

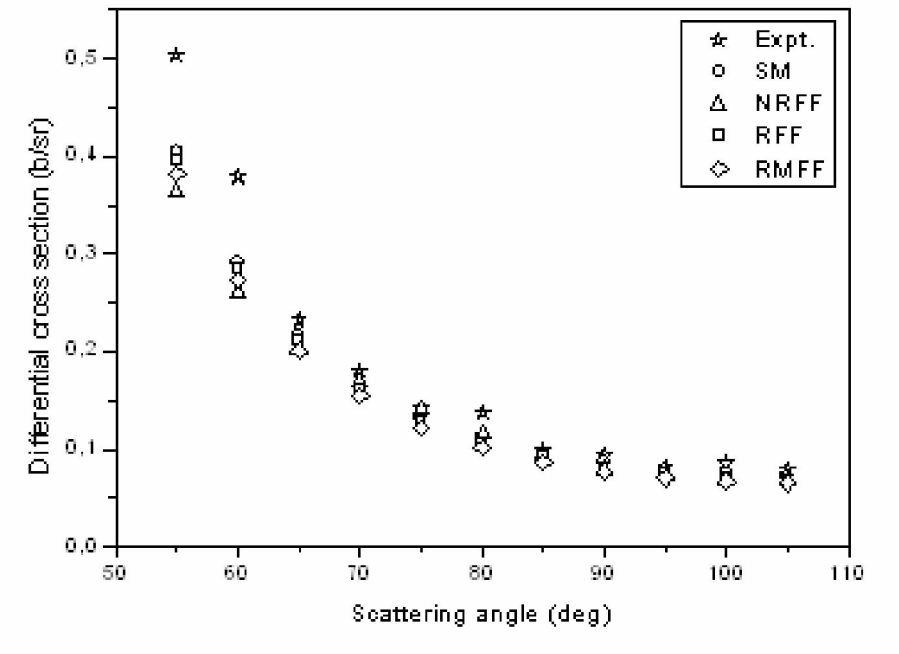


Fig. 2. Differential cross sections vs. scattering angle for Fe.

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