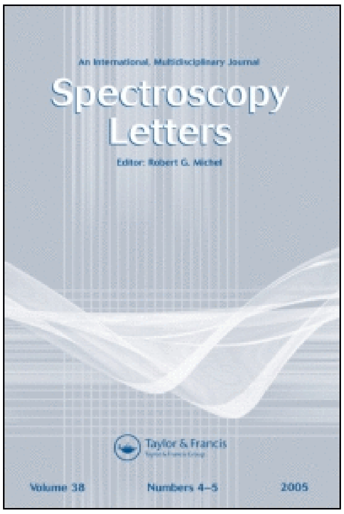

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Measurement of Differential Cross Sections for Coherent Scattering of 59.5 Kev γ Rays in the Atomic Range 26≤Z≤82

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MEASUREMENT OF DIFFERENTIAL CROSS SECTIONS FOR COHERENT SCATTERING OF 59.5 KEV γ RAYS IN THE ATOMIC RANGE $26 \leq Z \leq 82$

Keywords: Scattering cross sections and form-factors

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ABSTRACT

Differential cross sections for coherent scattering of 59.5 keV gamma rays at 115° were measured for 12 elements in atomic range $26 \leq Z \leq 82$. Experimental results were compared with theoretical values.

INTRODUCTION

The elastic scattering of photons by atoms includes Rayleigh scattering, Nuclear Thomson scattering, Delbrück scattering and Nuclear resonance scattering in the X-ray energy region. The Rayleigh scattering, which is the scattering from bound atomic electrons, is predominant at all scattering angles. The knowledge of the Rayleigh scattering amplitudes is important in various fields, such as solid state structure studies, nuclear resonance fluorescence and X-ray diagnostics. The values of elastic scattering cross sections are important for reliable evaluations of narrow-beam X-ray attenuation coefficient, particularly close to the K-shell ionisation threshold[1]. In recent years great progress has been achieved in understanding this process which, except in the forward direction, is increasingly dominated by scattering from the inner atomic shells[2-4].Kissel et al[3,4] has developed a prescription for evaluation of Rayleigh scattering amplitudes where the contributions of inner shells are evaluated using second-order S-matrix elements and outer-shell contributions are calculated using relativistic modified form-factor theories. To obtain a detailed description of the coherent scattering process generally two approaches are used which are numerical partial-wave calculations of elastic scattering amplitudes and form-factor formalism.

There are three different formalisms of the form-factor approach, namely, nonrelativistic [5], relativistic [6] and relativistic modified [7] formalisms. Form-factors calculations on the basis of these formalisms are available for a wide range of photon-momentum transfer and for all elements. For a detailed comparison of the predictions of form-factor theories, experimental results are available at low ($x<1$), and at high ($x>10$ Å^{-1}) momentum-transfer values. However, the experimental measurements of differential cross sections of coherent scattering are scant for energies under 100keV and in the intermediate momentum-transfer region $1<x<10$ Å^{-1}. We have therefore undertaken a systematic work to determine accurate values of differential cross sections in this range of intermediate momentum transfer, and the results obtained for 4.048Å^{-1} momentum transfer. In this paper results are obtained for 59.5 keV γ rays coherently scattered at 115° corresponding to 4.048Å^{-1} photon-momentum transfer. The cross sections for 12 elements in the region $26 \le Z \le 82$ were measured in the present work. Measured cross sections are compared with different formalisms of form-factor theory.

EXPERIMENT

The experimental arrangement has been described in our earlier work Ref. [14]. The point type Am-241 source with nominal activity has 3.7×10^{9}Bq (100mCi) and essentially emits monoenergetic (59.5 keV) γ-rays. The source was housed at the center of a cylindrical lead shield of 1.2 cm diameter and 1.9 cm length. From Al to Pb all foil samples are high-purity elemental foils (all of purity higher than 99.9 %) which are used as scatterers. The thickness of all foil samples from Al to Pb ranged from 0.0074 to 0.072g/cm^2. To detect coherently scattered 59.5 keV γ-rays a 5 mm thick and 8 mm diameter planar Ge(Li) detector was used for the measurements. The detector was also shielded by a lead colimator.Energy resolution of a Ge(Li) detector (FWHM) was found to be 190 eV at 5.9 keV. The spectra were recorded in a 1024 channel analyzer. The target-detector and target-source distances were set to 4 cm and each circular target had an area of 16π mm^2. The pulse height spectrum of scattered γ-rays by all foil samples was collected for 21.6×10^{3} s live time.

With the intention of obtaining 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. A representative spectrum of 59.5 keV γ-rays scattered at 115° by Pb is shown in Fig. 1.

The differential cross-section for coherent scattering of γ-rays by a target atom is obtained using the relation[1]

$$\frac{n_{coh}}{n^{Al}} = \frac{T}{T^{Al}} \frac{N}{N^{Al}} \frac{\in}{\in_c} \left[\frac{d\sigma^{Al}}{d\Omega} \right]^{-1} \frac{d\sigma_{coh}}{d\Omega} \qquad (1)$$

where T^{Al} and T are, respectively, the transmission factors for Al at Compton energy and for 59.5

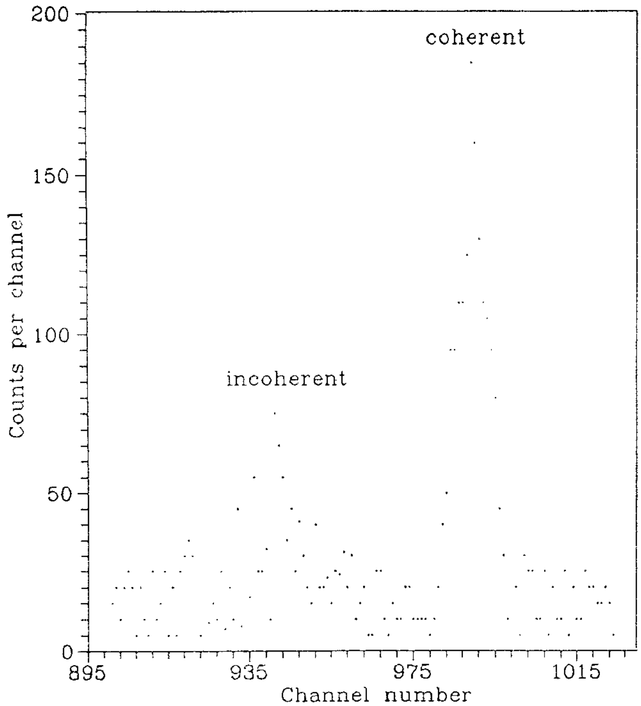

Fig.1. A representative spectrum of 59.5 keV γ-rays scattered at 115° by Pb

keV energy with the target. N^{Al} and N are the number of scattering atoms in Al and the scatterer, $\in_c$ and $\in$ are, respectively, the detector photopeak efficiencies for Compton and coherent scattered γ-rays [$(\in/\in_c) \approx 1$ at 59.5 keV energy] and $d\sigma^{Al}/d\Omega$ is the Compton scattering cross section of the aluminium atom:

$$\frac{d\sigma^{Al}}{d\Omega} = \frac{d\sigma^{KN}}{d\Omega} S(x, Z=13) \qquad (2)$$

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:

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

where θ is the angle of scattering, λ is the wavelength of the incident radiation in Ångström.

The theoretical coherent scattering differential cross sections are calculated by using

$$\frac{d\sigma_{coh}}{d\Omega} = \frac{1}{2} r_e^2 \left(1 + \cos^2\theta\right)\left[F(x, Z)\right]^2 \qquad (4)$$

Table I. Experimental and theoretical differential coherent scattering cross sections ($d\sigma/d\Omega$) (b/sr) at 4.048 $Å^{-1}$ photon-momentum transfer

Element	Experimental		Theoretical		
	Present Exp.	Literature exp.	Ref.5	Ref.6	Ref.7
$_{26}$Fe	0.066	–	0.069	0.067	0.063
$_{28}$Ni	0.068	–	0.082	0.077	0.072
$_{29}$Cu	0.073	–	0.090	0.084	0.078
$_{30}$Zn	0.089	–	0.098	0.091	0.084
$_{40}$Zr	0.203	–	0.259	0.244	0.221
$_{41}$Nb	0.255	–	0.283	0.270	0.244
$_{42}$Mo	0.257	–	0.308	0.298	0.269
$_{47}$Ag	0.383	–	0.447	0.463	0.415
$_{50}$Sn	0.468	–	0.536	0.575	0.512
$_{73}$Ta	0.881	–	1.405	1.476	1.226
$_{79}$Au	1.143	–	1.802	1.906	1.564
$_{82}$Pb	1.207	–	2.040	2.197	1.791

where, r_e is the classical electron radius, Z is the atomic number of the scattering atom and $F(x,Z)$ is the atomic form-factor. The self-absorption correction was performed for all samples used in our experiments.[9].

RESULTS AND DISCUSSION

The experimental results for coherent scattering differential cross sections are presented with theoretical values, calculated using nonrelativistic form-factors (NRFF)[5], relativistic form-factors(RFF)[6] and relativistic modified for factors (RMFF)[7] in Table 1. The error in the experimental cross sections is of the order of 5.4%. This error arises due to various parameters involving eq.(1) to evaluate the cross sections.

To the best of our knowledge there are no experimental data on differential cross sections reported in literature for 59.5 keV at this angle.

The differential cross sections, as a function of the target atomic number Z is shown in Fig. 2 with relativistic modified form-factor [7] and experimental calculations. Although our experimental results agree with NRFF, RFF and RMFF theories, there is better over all agreement with the RMFF theory. So, the present experimental work upholds the superiority of the RMFF [7] theory as reported by earlier investigators [1,7,10-22]. It can be observed from Table 1 that the form-factors for Fe, Ni, Cu, Zn, Zr, Nb, Mo, Ag and Sn in the low and medium-Z region are in good agreement with the predictions of all three formalisms. The differences in the values predicted by these three formalisms become conspicuous only for high-Z elements. In the high-Z region the present results deviate more and more from RFF and NRFF values and are in better agreement with RMFF theory.

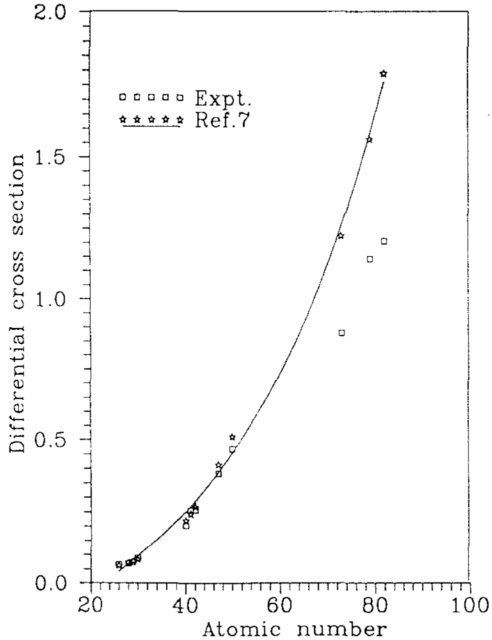

Fig.2. Graphical comparison of the experimental and theoretical coherent scattering differential cross sections.

It may further be noted from Fig. 2 that our experimental results for Ta, Au and Pb are lower than the predictions of the RMFF theory. The conspicuous deviations may be related to the fact that the K-edges of these elements (67.4 keV for Ta,80.7 keV for Au and 83 keV for Pb) are in proximity of the energy for coherently scattered γ rays These deviations are attributed to the dispersion effects near K-edges.

As a result, RMFF theory is more appropriate in predicting the form-factor in the intermediate photon momentum transfer region ($1<x<10$ Å^{-1}). Hence RMFF theory can be used with confidence to calculate coherent scattering cross sections.

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