

Compton Cross Section of 662 keV Photons from the K-shell of Co, Cu, Ge, Nb, Mo and Ag

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Z. Naturforsch. **37a**, 1124–1126 (1982); received July 31, 1982

From the intensity of K x-rays produced by 662 keV photons the sum of the total cross sections of the photoelectric and Compton effects on this shell is obtained for the atoms with $Z = 27, 29, 32, 41, 42$ and 47 . The contribution of the photoeffect is about 15% for Co ($Z = 27$), 50% for Mo ($Z = 42$) and 70% for Ag ($Z = 47$). Using theoretical cross section for the photoeffect the total Compton cross section on the K-shell is evaluated. The results agree with the free electron value.

Introduction

Inelastic or Compton scattering of photons on individual atomic shells shows in general deviations from the free electron behaviour [1]. In some experiments the differential cross section for K-shell scattering at 145 keV [2], 279 keV, 320 keV and more intensively at 662 keV [1] was measured. The results are only partially in agreement with theoretical calculations including the binding of electrons. The integration of the experimental values yields the total cross section with a low precision, only. Thus it is not clear if the free electron Klein-Nishina total cross section can be used for scattering on the K-shell.

Recently, Allawadhi et al. [3] made direct measurements of the integral Compton cross section for γ -scattering on the K-shell for some elements with atomic number between 39 and 50 at an energy of 662 keV. They measured the intensity of the K-shell x-rays produced after the scattering process. Contributions from the photoeffect were subtracted using theoretical cross sections. The x-rays were detected using a thin NaI detector. For the atoms studied the contribution of the Compton effect to the K x-ray production is only 50%–25% (Fig. 1) making the analysis difficult. In this paper atoms with lower atomic number ($Z = 27 - 47$) were studied where the contribution of the K-shell Compton effect is considerably higher. In addition a Si detector with better resolution was used.

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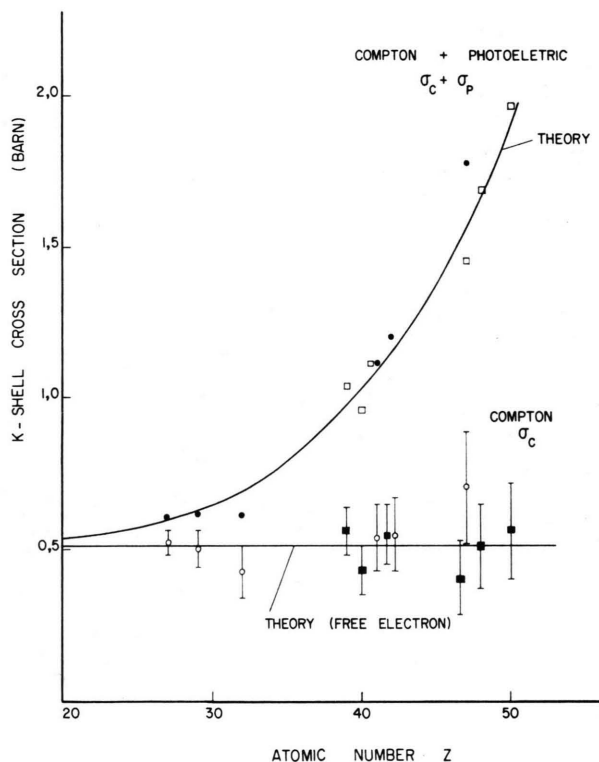


Fig. 1. Experimental results (\bullet = measured total K-shell cross section $\sigma_p + \sigma_c$; \circ = derived Compton K-shell cross section; \blacksquare and \square = experimental results of [3]).

Experimental Method

Photons entering the target produce K-shell vacancies because of the Compton and photoelectric interaction. The vacancies are filled by emission of x-rays and Auger electrons. The K x-rays are emitted isotropically. For their detection a 4 mm thick and 4 mm diameter Si x-ray detector was used at a distance of 6.6 cm from the target. For pro-

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ducing the γ -beam a calibrated ^{137}Cs source with $1.52 \cdot 10^9 \text{ Bq} \pm 2\%$ was used, which emits 662 keV γ -rays and Ba K-conversion x-rays with a mean energy of 32.9 keV. The x-rays were filtered with a 3.3 mm lead sheet. The distance between the targets with an area of about 1.5 cm^2 and the source was 11.5 cm.

For some low Z elements (Co and Cu) absolute and relative measurements were performed. Since the detector efficiency is not known for higher x-ray energies, for Nb, Mo and Ag, relative cross sections were measured, using a 145 keV ^{141}Ce source.

For the determination of the absolute cross section the effective solid angle of the detector was measured using a 10 keV x-ray from a γ -source, which was mounted at the place of the target. In these measurements the counting rates with and without a shield, having a 2 mm borehole on the detector axis, were compared. The detector efficiency was assumed to be unity for the K x-rays of Co, Cu, and Ge, which lie in the range of 7–11 keV. (Comparison with relative measurement at 145 keV on Co and Cu showed that this procedure is reasonable.) The absorption of the x-rays in the target was calculated, using the interpolated theoretical absorption coefficients given in [4], excluding the scattering processes. Absorption of the incident beam was neglected. The emission of Auger electrons was considered, using for the fluorescence yields ω_K fitted values of Table III.IV of [5]. For the low energy x-rays the corrections for absorption in the air were calculated to be about 5%.

The measured counting rate is proportional to the sum of the total Compton cross section σ_c on the K-shell and the corresponding photoelectric cross section σ_p . Numerical values of σ_p of [6] and [7] are available, which are in agreement within the precision needed in our work.

For the K x-rays of Nb, Mo and Ag it is difficult to determine the detector efficiency and only relative measurements were performed. At the same geometrical conditions the K x-ray intensity from the same target was measured using 662 keV and 145 keV photons. The x-rays from the ^{141}Ce source were shielded using 0.5 mm silver, yielding a monochromatic beam. The source has a half life of 32.5 days and the activity was about 50 times less than that of the Cs source. Normalization of the cross sections was made in the usual way. The x-ray in-

tensity of Hf ($Z=72$) was measured for both γ -energies and compared with the theoretical K-shell photoelectric cross sections of [6] and [7]. The Compton cross section in this case yields only a small correction and the free electron value can be used. The same is true for the theoretical K-shell cross sections at 145 keV for the other elements studied.

For measuring the K-shell intensities, a conventional multichannel analyzer was used. Typical counting times for one spectrum were between 3 hours and 3 days.

Results and Discussion

In Table 1 the experimental sums of the Compton and photoelectric cross sections $\sigma_c + \sigma_p$ for scattering on the K-shell of Co, Cu, Ge, Nb, Mo and Ag are given for 662 keV. For the elements Co, Cu and Ge absolute values were measured, which are presented in the third column. For Co and Cu also relative measurements were made, comparing the counting rates with measurements at 145 keV. Within the experimental error the same result was obtained. For Nb, Mo and Ag only relative measurements were performed, which are shown in the fourth column.

The experimental results can be compared with the theoretical data given in the fifth column of Table 1. For the K-shell photoelectric cross section σ_p the data of [6] and [7] were used. Since no other value is available for the integral K-shell Compton scattering, the free electron value of $\sigma_c = 0.51 \text{ barn/atom}$ was added, which practically coincides at this energy with the results of the tables given by Hubbel [8]. Within the experimental error of about 10% the measurements and theory agree. The photoelectric theory is believed to be accurate within a few percent at the energy studied and it is possible to subtract this cross section from the experimental value. The resulting K-shell Compton cross section σ_c is shown in Table 1. With an error of about 10%–25% agreement with the free electron value was found. In the last column of the table some earlier experimental results of [3] in the region $Z=39-50$ are shown, yielding the same conclusion.

In Fig. 1, the existing experimental data are plotted and compared with theoretical predictions. Certainly a deviation from the free electron value

Table 1. Experimental results for the K-shell cross sections. In the third and fourth columns the experimental values for the sum of the Compton and photoelectric cross section are shown, derived by different methods. In the fifth column the theoretical sum is given. In the sixth column the experimental K-shell Compton cross section is shown. Comparison with other measurements is made in the last column.

Element	Z	K-shell cross section (barn)				
		$(\sigma_c + \sigma_p)_{\text{Exp}}$ Absolute	$(\sigma_c + \sigma_p)_{\text{Exp}}$ Relative	$\sigma_c + \sigma_p$ Theory	σ_c Derived	σ_c Ref. [3]
Co	27	0.67	0.55	0.60	0.52 ± 0.05	
Cu	29	0.62	0.62	0.63	0.50 ± 0.06	
Ge	32	0.61	—	0.69	0.42 ± 0.09	
Y	39	—	—	—	—	0.56 ± 0.08
Zr	40	—	—	—	—	0.43 ± 0.08
Nb	41	—	1.12	1.09	0.54 ± 0.11	—
Mo	42	—	1.20	1.16	0.55 ± 0.12	0.55 ± 0.10
Ag	47	—	1.78	1.58	0.71 ± 0.18	0.40 ± 0.12
Cd	48	—	—	—	—	0.51 ± 0.14
Sn	50	—	—	—	—	0.56 ± 0.16

can be measured more easily for low Z atoms. On the other hand theoretically such a deviation should be smaller for these atoms. In every case the precision of the experiments must be raised for being able to detect binding effects in the integrated K-shell Compton cross sections in this energy region.

Acknowledgements

We wish to thank the Institute of Physics, PUC, Rio de Janeiro, for lending the Si-detector. The work was supported by FINEP, CNPq and by Stiftung Volkswagen, Germany, partially.

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