Measured energy dependence of K-shell photoelectric cross sections for Ti, Fe, Ni, and Zn in the energy region 9–18 keV

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(Received 7 November 1984)

Our earlier measurements of the energy dependence of K-shell photoelectric cross sections for Y, Mo, Ag, and Sn in the energy region 18–44 keV have been extended to elements Ti, Fe, Ni, and Zn in the energy range $9 \leq E \leq 18$ keV. The experiment has been performed under improved experimental conditions using a modified double-reflection geometrical setup and Si(Li) detector in place of a NaI(Tl) detector used in the earlier measurements. The results compare well with the theoretical calculations, confirming the earlier trend down to 9 keV.

In order to fill the existing void, we have extended our earlier measurements[1] of the energy dependence of K-shell photoelectric cross sections for Y, Mo, Ag, and Sn in the energy region 18–44 keV to the elements Ti, Fe, Ni, and Zn in the energy region 9–18 keV and report the results in this Brief Report. Making use of the property of the polarization of γ rays scattered at 90°, the double-reflection geometrical setup used for the earlier measurements is modified so as to reduce the background contamination due to the scattering of photons under the fluorescent x-ray peak of the secondary target element. The schemes of the present and earlier experimental geometries are shown in Fig. 1. Circular primary targets (P) of Zn, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, and Mo of 4 cm diameter are irradiated, in turn, with a collimated beam of 59.57-keV γ rays[2] from an $\sim$1-Ci ^{241}Am source (R). The external conversion x rays in the primary targets and the γ rays scattered from them are allowed to fall, in turn, on circular secondary targets (S) of Ti, Fe, Ni, and Zn in the form of circular metallic foils of diameter 4 cm and thicknesses 9.0–12.3 mg/cm^2. The K x rays emitted from the secondary target elements are counted with an Ortec Si(Li) x-ray detector of active area 200 mm^2 and thickness 5 mm with a Be window of thickness 0.05 mm coupled to a Nuclear Data (ND) 600 analyzer system. The resolution of the detector is $\sim$300 eV at 5.9 keV. In the present experiment the detector is placed in a plane perpendicular to that of the source, primary target, and secondary target. The plane-polarized γ rays obtained after first scattering from the primary target do not scatter at 90° from the secondary target into their own plane of polarization. The new geometrical setup thus results in an appreciable reduction in the scattering background. With the present setup a signal-to-background ratio of as large as 10:1 is obtained in most of the cases, in comparison with 1:1 in the earlier experiment.[1] A typical K-shell x-ray spectrum is shown in Fig. 2. The primary and secondary targets are so chosen that the absorption edge of all secondary targets is lower than K-shell x-ray energy but higher than the L-shell x-ray energy of the primary targets. The intensities of the primary K-shell x rays falling on the secondary targets are measured with a Bicron scintillation spectrometer[3] with a 0.04-in.-thick and 2-in.-diam NaI(Tl)

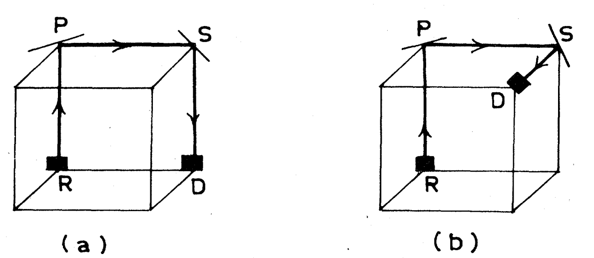

FIG. 1. Schemes of the present and the earlier (Ref. 1) experimental geometries used for measurement of photoelectric cross sections: R—Radiation source; P—pimary target; S—secondary target; D—detector. (a) Earlier geometry (Ref. 1); present geometry.

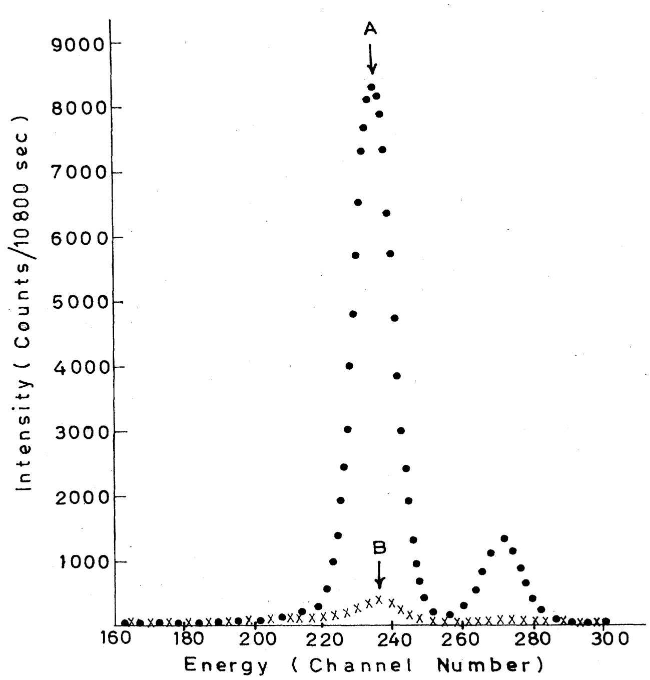

FIG. 2. Secondary spectra recorded with Si(Li) low energy photon spectrometer. A—Nb primary and Zn secondary; B—equivalent Al primary and Zn secondary.

TABLE I. Present measurements of relative K-shell photoelectric cross sections $\sigma(E)/\sigma(E_{\text{ref}})$ of Ti, Fe, Ni, and Zn are compared with theoretical calculations of Scofield (Ref. 5). E and E_{ref} are weighted mean values (Ref. 4) of K-shell fluorescence emission lines $(\bar{K}\alpha, \bar{K}\beta)$ of the primary target elements. The E_{ref} for all target elements is 16.035 keV.

X-ray energy (E) (keV)	Experimental $\sigma(E)/\sigma(E_{\text{ref}})$	Theoretical $\sigma(E)/\sigma(E_{\text{ref}})$
	(i) Ti	
8.735	4.90 ± 0.25[a]	5.418
10.005	3.80 ± 0.21[a]	3.755
11.372	2.30 ± 0.13[a]	2.626
12.087	1.90 ± 0.10[a]	2.215
13.596	1.50 ± 0.08[a]	1.595
14.384	1.40 ± 0.08[a]	1.362
15.200	1.20 ± 0.07[a]	1.166
16.035	1.00 ± 0.00[a]	1.000
16.896	0.840 ± 0.046[a]	0.785
17.781	0.810 ± 0.045[a]	0.743
	(ii) Fe	
8.735	4.90 ± 0.27[b]	5.114
	4.60 ± 0.25[c]	
10.005	3.50 ± 0.19[b]	3.597
	3.60 ± 0.20[c]	
10.676	2.90 ± 0.16[b]	3.019
	2.70 ± 0.15[c]	
11.372	2.70 ± 0.15[c]	2.545
	2.10 ± 0.12[c]	
12.087	2.10 ± 0.12[b]	2.159
	1.90 ± 0.10[c]	
13.596	1.50 ± 0.08[b]	1.572
	1.70 ± 0.09[c]	
14.384	1.40 ± 0.08[b]	1.350
	1.10 ± 0.06[c]	
15.200	1.00 ± 0.06[b]	1.161
	1.10 ± 0.06[c]	
16.035	1.00 ± 0.00[b]	1.000
	1.00 ± 0.00[c]	
16.896	0.960 ± 0.053[b]	0.864
	0.910 ± 0.050[c]	
17.781	0.810 ± 0.044[b]	0.749
	0.730 ± 0.040[c]	
	(iii) Ni	
8.735	5.00 ± 0.27[b]	4.930
	4.20 ± 0.23[c]	
10.005	3.50 ± 0.19[b]	3.532
	3.30 ± 0.18[c]	
10.676	3.30 ± 0.18[b]	2.970
	2.70 ± 0.15[c]	
11.372	2.90 ± 0.16[b]	2.512
	2.40 ± 0.13[c]	
12.087	1.90 ± 0.10[b]	2.135
	2.30 ± 0.13[c]	
13.596	1.80 ± 0.10[b]	1.561
	1.50 ± 0.08[c]	
14.384	1.40 ± 0.08[b]	1.344
	1.30 ± 0.07[c]	
15.200	1.20 ± 0.07[b]	1.159
	1.20 ± 0.07[c]	
16.035	1.00 ± 0.00[b]	1.000
	1.00 ± 0.00[c]	
16.896	0.880 ± 0.048[b]	0.866
	0.910 ± 0.050[c]	
17.781	0.750 ± 0.041[b]	0.752
	0.710 ± 0.039[c]	

TABLE I. (*Continued*).

X-ray energy (E) (keV)	Experimental $\sigma(E)/\sigma(E_{ref})$	Theoretical $\sigma(E)/\sigma(E_{ref})$
	(iv) Zn	
10.005	3.40 ± 0.19^b	3.413
	3.50 ± 0.19^c	
11.372	3.10 ± 0.17^b	2.856
	3.30 ± 0.18^c	
12.087	2.10 ± 0.11^b	2.452
	1.90 ± 0.10^c	
13.596	1.60 ± 0.09^b	1.545
	1.50 ± 0.08^c	
14.384	1.40 ± 0.08^b	1.336
	1.50 ± 0.08^c	
15.200	1.20 ± 0.07^b	1.157
	1.30 ± 0.07^c	
16.035	1.00 ± 0.00^b	1.000
	1.00 ± 0.00^c	
16.896	0.830 ± 0.047^b	0.867
	0.810 ± 0.045^c	
17.781	0.690 ± 0.038^b	0.759
	0.740 ± 0.041^c	

[a]Measurements made using combined $K\alpha$ and $K\beta$ x-ray peaks.
[b]Measurements made using $K\alpha$ x-ray peak only.
[c]Measurements made using $K\beta$ x-ray peak only.

crystal and a 0.005-in. Be window, placed at the position of the secondary target.

For a set of two primary targets P and P_{ref}, whose weighted mean[4] K-shell x-ray energies $\overline{K}\alpha$ and $\overline{K}\beta$ are E and E_{ref}, and a given secondary target S, the ratio $\sigma(E)/\sigma(E_{ref})$ of the K-shell photoelectric cross section in S at E and E_{ref}, respectively, is calculated using Eq. (1) of our earlier paper (Ref. 1). The other details are the same as explained earlier.[1]

The experimental values of the ratio of the K-shell photoelectric cross sections $\sigma(E)/\sigma(E_{ref})$ are compared with theoretical values interpolated from the values given by Scofield[5] in Table I. E and E_{ref} are the weighted mean values of the $K\alpha_1$, $K\alpha_2$, $K\beta_1$, etc., fluorescence emission lines of the target elements. The errors shown in the experimental values are ~5%–6% and are due to counting statistics and the uncertainties involved in the absorption coefficients[6] used for the determination of the self-absorption correction factors and the detection efficiencies. A fairly good agreement between experiment and theory shows that the theoretical calculations of Scofield for K-shell photoionization cross sections are valid down to 9 keV.

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