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Measurement of L-shell photoelectric cross-sections in lower intermediate Z elements at 6 keV

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Abstract. L-shell photoelectric cross-sections have been measured at 6 keV for eight elements in the range $40 \leqslant Z \leqslant 53$. The measurements agree with theoretical calculations.

Keywords. Photoelectric cross-sections; fluorescent x-rays; K-shell; L-shell.

1. Introduction

In the review article on atomic photo-effect by Pratt *et al* (1973), it was pointed out that our understanding of atomic photo-effect is most deficient at high energies above 5 MeV, at low energies below 10 keV and for low Z ($Z < 13$) at all energies. At energies below 10 keV, it is attributed to the non-availability of any individual shell experimental data and the rapid deterioration of the theoretical predictions due to inadequacies of the effective central potential model. In this paper, we report our measurements of L-shell photoelectric cross-sections in eight elements in the range $40 \leqslant Z \leqslant 53$ at 6 keV. The method of measurement and the results are discussed in the following sections.

2. Method of measurement

The Mn K x-rays of weighted mean energy 5·959 keV (Storm and Israel 1970) from $\sim$ 50 mCi ^{55}Fe radiation source were collimated to fall on the targets of elements Zr, Nb, Mo, Ag, Cd, In, Sn and I in a conventional 90° reflection geometry (Allawadhi and Sood 1975) and the emitted L-shell fluorescent x-rays were measured with a Si(Li) low energy photon spectrometer. The targets of elements Zr, Mo, Ag, In and Sn were in the form of metallic foils and were obtained from Reactor Experiments Inc., USA. The targets of other elements *i.e.* Nb, Cd and I were prepared as pellets from their chemical compounds. In case of Sn, the experiment was performed with targets of both Sn and SnO. The agreement between the results within experimental errors in the two cases, justified the use of compounds when metallic targets are not available. The spectrometer consisted of 200 mm^2 active area $\times$ 5 mm thickness, with 0·05 mm thick Be window Si(Li) detector, ORTEC charge sensitive pre-amplifier (model 117B), ORTEC amplifier (model 571); ORTEC gated bias amplifier (model 444) and ND 600 series analyser system and its resolution was $\sim$ 250 eV at 5·9 keV. A typical spectrum recorded with the spectrometer when a silver target was irradiated with Mn K x-rays is

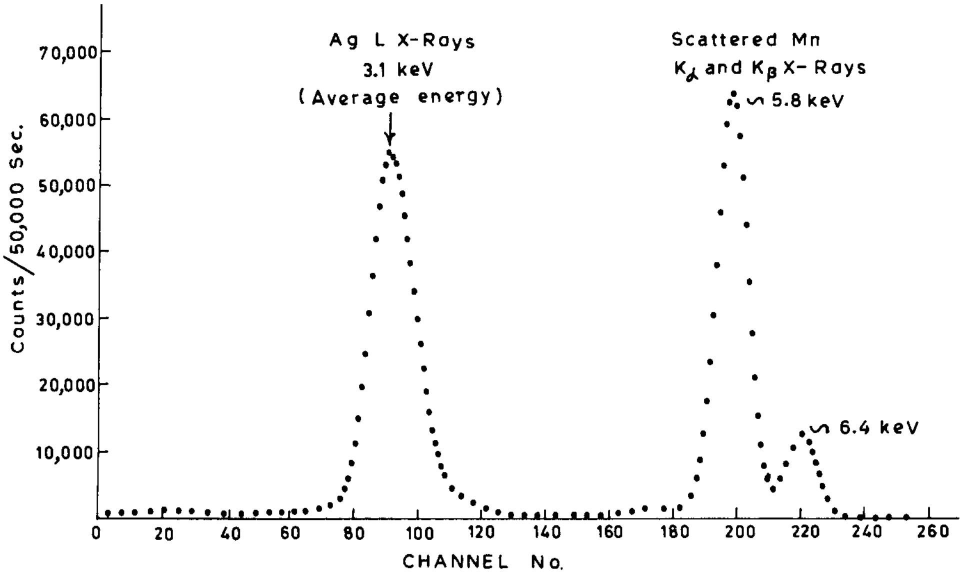

Figure 1. Spectrum recorded with Si(Li) spectrometer when Ag target was irradiated with 5·959 keV Mn K x-rays from ^{55}Fe source. The first peak is due to Ag L x-rays and the next two are due to scattered Mn K_α and K_β x-rays.

shown in figure 1. The L x-rays are seen as a single composite peak in the spectrum due to the limited resolution of the spectrometer. The other peaks in the spectrum are due to scattered Mn K_α and K_β x-rays and are well resolved from the L x-ray peak. The spectrum recorded without any target showed a general background much lower than that obtained with any target in position. The ratio of the counting rates with and without target, in the channels covering the L x-ray peak, was $\sim 100:1$. Hence the effect of scattering from the surroundings in the region of fluorescent L x-ray peaks was insignificant and only fluorescent L x-rays emitted from the target, which were of interest in the present experiment, were measured. The other details of the experiment were similar to the one reported earlier (Allawadhi *et al* 1978). The experimental values of the L-shell photoelectric cross-sections $\sigma_L(X)$ were determined from the following relation:

$$\sigma_L(X) = n_L(x) \Big/ \left\{ \left[S(X) \cdot \frac{\omega_1}{4\pi} \cdot a(X) \cdot \frac{\omega_2}{4\pi} \cdot \varepsilon(x) \right] \cdot \frac{N}{M} \cdot t_{\mathrm{eff}_L}(x) \cdot \bar{\omega}_L \right\} \tag{1}$$

where $n_L(x)$ is the intensity of L fluorescent x-rays as measured with the spectrometer under the photopeak when the target under investigation is irradiated with Mn K x-rays from ^{55}Fe source, $S(X)$ is the intensity of the x-rays emitted from the source, $a(X)$ is the correction factor for absorption of x-rays in source, air column etc., N is the Avogadro's number, M is the atomic weight of the target element, $\bar{\omega}_L$ is the average L shell fluorescence yield, ω_1 and ω_2 are target-source and target-detector solid angles and $\varepsilon(x)$ is the photopeak efficiency of the detector, $t_{\mathrm{eff}_L}(x)$ is the effective thickness of the target and is the product of the actual thickness t and the absorption correction factor $\beta(x)$. $t_{\mathrm{eff}_L}(x)$ in a target of thickness t is given by (Arora *et al* 1981)

$$t_{\mathrm{eff}_L}(x) = \sum_{i=1}^{n} p_i \frac{1 - \exp[-(\mu_X + \mu_{ix})/\cos\theta]t}{(\mu_X + \mu_{ix})/\cos\theta}.$$

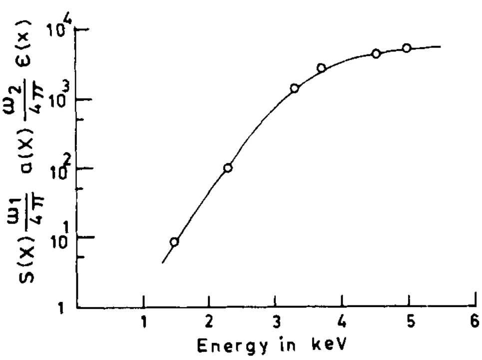

Figure 2. Plot of $[S(X)\cdot(\omega_1/4\pi)\cdot(a(X))(\omega_2/4\pi)\cdot(\varepsilon(x))]$ *vs* photon energy.

Table 1. Comparison of the present measurements of L-shell photoelectric cross-sections $\sigma_L(X)$ at 5·959 keV with theoretical values of Scofield (1973).

		L-shell photoelectric cross-sections (b/atom)	
Z	Element	Present measurement ($\times 10^4$)	Theoretical ($\times 10^4$)
40	Zr	(3·4 ± 0·4)	(3·75)
41	Nb	(3·5 ± 0·4)	(4·11)
42	Mo	(3·8 ± 0·4)	(4·50)
47	Ag	(7·0 ± 0·7)	(6·80)
48	Cd	(7·1 ± 0·7)	(7·34)
49	In	(7·2 ± 0·7)	(7·91)
50	Sn	(8·5 ± 0·9)	(8·50)
53	I	(9·7 ± 1·0)	(10·5)

Table 2. Uncertainties in the quantities used to evaluate $\sigma_L(X)$ from (1).

Quantity	Nature of uncertainty	uncertainty
$n_L(X)$	Statistical	~1%
$\left[S(X)\cdot\frac{\omega_1}{4\pi}\cdot a(X)\cdot\frac{\omega_2}{4\pi}\cdot\varepsilon(x)\right]$	Statistical and due to errors in K-shell photoelectric cross sections, K-shell fluorescence yields and absorption coefficients etc.	~6%
$t_{\mathrm{eff}_L}(x)$	Due to errors in the absorption coefficients at incident and emitted photon energies etc.	~5%
$\bar{\omega}_L$	Estimated (Krause *et al* 1978).	~6%

The energies of the incident and the emitted x-rays and thickness of the targets used in the present measurements were such that the target behaved as infinitely thick. Under these conditions the effective thickness is given as

$$t_{\mathrm{eff}_L} = \sum_{i=1}^{n} p_i \frac{\cos\theta}{\mu_X + \mu_{ix}}.$$

The p_i values were taken from the tables of Storm and Israel (1970) while μ_X and μ_{ix} taken from the tables of Veigele (1973), θ in the present experiment was 45°. The factor

$$\left[S(X)\cdot\frac{\omega_1}{4\pi}\cdot a(X)\cdot\frac{\omega_2}{4\pi}\cdot\varepsilon(x)\right]$$

was measured experimentally in a separate comparison experiment in the same geometry. Its values were determined in terms of K-shell photoelectric cross-sections (Scofield 1973) and K-shell fluorescence yields (Krause *et al* 1978) of some low Z elements (Al, S, Cl, K, Ca, Ti and V) and plotted against the weighted average K-shell fluorescent x-ray energies of the elements. The values at the experimental target element L x-ray energies were read from figure 2 as explained earlier (Allawadhi *et al* 1978). The values of $\bar{\omega}_L$ were taken from the recent work of Krause *et al* (1978) and Krause (1980). $n_L(x)$ was determined from the area under the photopeak of L x-rays in the spectrum of radiation emitted from the target.

3. Results and discussion

The $\sigma_L(X)$ values as calculated from (1) are shown in table 1 for elements Zr, Nb, Mo, Ag, Cd, In, Sn and I. The uncertainties in the $\sigma_L(X)$ values are $\sim 10\%$ and are due to counting statistics and the uncertainties in the other quantities needed for its determination as explained in table 2. As no other experimental data are available, the comparison is made with the theoretical values of Scofield (1973) in which electrons are treated relativistically and as moving in Hartree–Slater central potential. In general the experimental and theoretical values agree proving the validity of the Scofield's calculations down to photon energy of 6 keV.

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