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Measurement of L_{III} subshell photoelectric cross-sections in high Z-elements

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Abstract. L_{III} subshell photoelectric cross-sections in lead, thorium and uranium at 13·596, 16·896 and 17·781 keV respectively have been determined. The results are found to agree well with theory.

Keywords. Photoelectric cross-section; target preparation; spectrum recording; Z-elements.

1. Introduction

Recently detailed calculations of photoelectric cross-sections for all the elements $1 \leqslant Z \leqslant 100$ at photon energies from 1—1500 keV using HFS potential have been made available (Pratt *et al* 1973) but the existing experimental data (Pratt *et al* 1973; Hubbell and Veigele 1976) are insufficient. Large gaps in various photon energy regions and Z values of the elements still remain to be covered by experiments. Though the work on K-shell cross-sections reported so far establishes fairly good agreement with theory, relatively less attention has been paid to the determination of L-shell cross-sections and further measurements are needed (Allawadhi *et al* 1978). Very little effort seems to have been made to measure subshell cross-sections; this is, perhaps, due to the reason that at high photon energies where suitable monoenergetic photon sources are easily available the subshell photon absorption cross-sections are so small that any significant experimental determination becomes extremely difficult and tedious. At low photon energies the subshell cross-sections are high but clean and strong sources are not available.

We have measured L_{III} cross-sections in Pb, Th and U at 13·596, 16·896 and 17·781 keV, respectively. The external conversion x-rays as proposed earlier (Allawadhi and Sood 1975) by two of the authors and later successfully used for the measurement of K and L shell photoelectric cross-sections (Allawadhi and Sood 1975, 1976; Arora *et al* 1980), have been used as the source of photons in the present measurements. The method involves irradiation of suitably selected primary targets with 59·5 keV gamma rays from ^{241}Am for producing K fluorescent x-rays that are made to interact with the secondary targets. The fluorescent x-ray measuring technique, employed here for the determination of the photoelectric cross-sections, is simpler and superior to high resolution electron spectroscopy

involved in the measurements of L-shell photoelectrons in the presence of Aüger electrons of comparable energies. The choice of primary target materials is determined by the requirement that the K-shell fluorescent x-rays of the primary target are able to excite selectively L_{III} subshells of the secondary target.

2. Method of measurement

Using the experimental arrangement similar to the one described in an earlier paper (Allawadhi and Sood 1975), 59·5 keV gamma rays coming from ^{241}Am, a disc source of strength of the order of 100 mC procured from Radio-chemical Centre, England, were collimated to fall on a primary target (P). The fluorescent K x-rays, from primary target produced as a result of the interaction of 59·5 keV photons with the target material were made to fall on the secondary target (S) resulting in the production of L x-rays that were counted by a proportional counter spectrometer. The primary targets of Rb, Nb and Mo were selected for the secondary targets of Pb, Th and U, respectively. The selection of a P target for a given S target satisfies the condition $E_S(L_{III}) < E_P(K) < E_S(L_{II})$ where $E_P(K)$ is the energy of any component of K x-rays from P target, $E_S(L_{II})$ and $E_S(L_{III})$ are edge energies of L_{II} and L_{III} subshells of the element of S target (Storm and Israel 1970). Consequently, only L_{III} subshell $M, N \ldots$ and higher shells got excited and the x-ray beam emerging out of the S target could be analysed by the detector to get only L_{III} x-ray yield.

For the experimental arrangement used $N_S(L_{III})$ the number of fluorescent L_{III} x-rays of S target as counted per second by the counter is given by

$$N_S(L_{III}) = N_P(K) \cdot \frac{N}{M_S} \cdot t_S \cdot \sigma_S(L_{III}) \cdot \beta_S(L_{III}) \cdot \omega_S(L_{III}) \cdot \frac{\omega_S}{4\pi} \cdot \epsilon_S(L_{III}) \tag{1}$$

where $N_P(K)$ is the number of K-shell x-ray of P target falling per second on the S target, N is Avogadro's number, M_S is atomic weight of the element of the S target, t_S is the thickness of S target, $\sigma_S(L_{III})$ is L_{III} photoelectric cross-section in the element of S target at the weighted mean energy of K x-rays from P target, $\beta_S(L_{III})$ is the factor that takes into account the absorption of incident and emerging x-rays from the S-target, $\omega_S(L_{III})$ is the L_{III} sub-shell fluorescent yield in S target, ω_S is secondary target to detector solid angle, and $\epsilon_S(L_{III})$ is the detector efficiency including absorption of L_{III} x-rays in the air column between S target and detector.

The S target is then replaced by a comparison target (C) of identical dimensions and is so chosen that

(i) its K-edge lies below the energy of any K x-ray component from the P-target;

(ii) the weighted mean energy of K x-rays emitted from it lies very close to the weighted mean energy of L_{III} x-rays from S target. Such a choice dispenses with the detector-efficiencies as shown later in (3).

The various primary, secondary and comparison targets along with their respective weighted mean x-ray energies are listed in table 1. $N_C(K)$ the number of

Table 1. Primary, secondary and comparison targets used in the measurements

Primary targets		Secondary targets		Comparison targets	
Element	Energy in keV ($\bar{K}_{\alpha,\beta}$)	Element	Energy in keV ($\bar{L}_{III}$)	Element	Energy in keV ($\bar{K}_{\alpha,\beta}$)
Rb	13·596	Pb	10·862	As	10·676
				Se	11·372
Nb	16·896	Th	13·409	Rb	13·596
Mo	17·781	U	14·091	Rb	13·596
				Sr	14·384

K x-rays, emerging from C target, counted per second by the counter is given by

$$N_C(K) = N_P(K) \cdot \frac{N}{M_C} \cdot t_C \cdot \sigma_C(K) \cdot \beta_C(K) \cdot \omega_C(K) \cdot \frac{\omega_C}{4\pi} \cdot \epsilon_C(K) \qquad (2)$$

where the various terms have the same meaning as already explained but correspond to the comparison target. But $\epsilon_S(L_{III}) \simeq \epsilon_C(K)$ because energies of L_{III} x-rays from S target are very close to K x-rays from C target and $\omega_S = \omega_C$ as the S and C targets are of identical dimensions. Therefore (1) and (2) lead to

$$\sigma_S(L_{III}) = \frac{N_S(L_{III})}{N_C(K)} \cdot \frac{M_S}{M_C} \cdot \frac{t_C}{t_S} \cdot \frac{\beta_C(K)}{\beta_S(L_{III})} \cdot \frac{\omega_C(K)}{\omega_S(L_{III})} \cdot \sigma_C(K) \qquad (3)$$

Obviously, the determination of $\sigma_S(L_{III})$ reduces to the measurement of the ratio of the counting rates $M_S(L_{III})/M_C(K)$ and computation of $\beta_C(K)$, $\beta_S(L_{III})$ and $\sigma_C(K)$.

3. Target preparation and spectrum recording

The targets of Mo, Pb, Th and U used in the present experiments were cut to the required size from thin metallic foils purchased from Reactor Experiments Inc., USA while the targets of Nb, Rb, Sr, Se and As were prepared from the metallic powders/salts by the method reported earlier (Allawadhi *et al* 1978).

The L_{III} K x-rays, produced due to interaction of K x-rays from P target with S/C target, were counted by Xe + CO_2 filled proportional counter with 5 mil Be window, purchased from Reuter Stokes, USA, coupled to ORTEC 142 PC preamplifier, ORTEC model 451 spectroscopy amplifier and ND 600 multichannel analyser. The 26 keV gamma rays and N_P L x-rays coming from the source were completely ($< 99{\cdot}9\%$) filtered out by graded absorber to avoid interference of their scattering component in the K x-ray beam emerging out of P-target. The scattering of 59·5 keV photons from P target was taken care of by subtracting background recorded with equivalent Al target (Allawadhi and Sood 1976) placed at the position of P

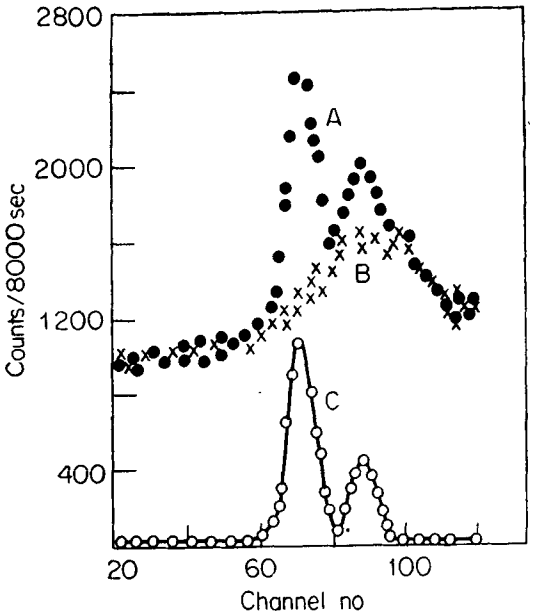

Figure 1. Secondary target spectra recorded with proportional counter spectrometer. A—Rb primary and Pb secondary. B—Eq. Al primary and Pb secondary. C—L_{III} x-rays of Pb ($=A-B$). Only the representative data points are shown on different curves for the sake of clarity.

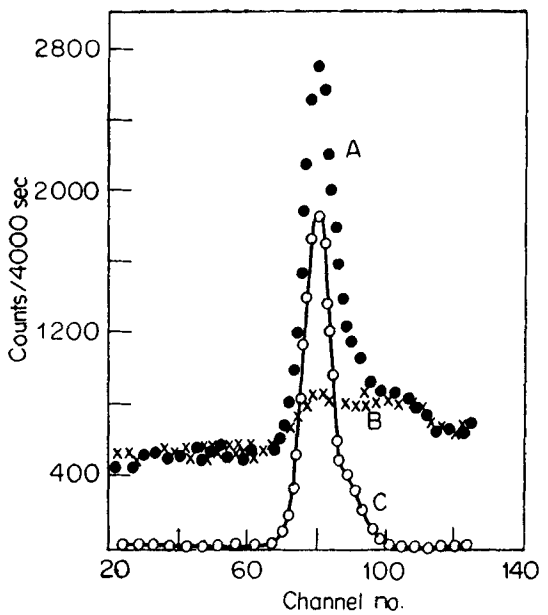

Figure 2. Comparison target spectra recorded with proportional counter spectrometer. A—Rb primary and Se comparison. B—Eq. Al primary and Se comparison. C—K x-rays of Se ($=A-B$). Only representative data points are shown on different curves for the sake of clarity.

target. The distances between the ^{241}Am source, primary target, secondary target and the detector were so adjusted as to get the best possible peak to the background ratio. The contribution, in the spectrum, arising due to natural radioactivity of Th and U targets got cancelled out while subtracting background with equivalent Al target from the spectrum. The direct radiation from source were prevented from reaching the S/C target by graded shielding consisting of Pb, Fe and Al. The contribution of the scattering of primary K x-rays from S/C target being insignificant as compared to L_{III} K x-ray production (Allawadhi and Sood 1976) was neglected. Sufficient number of runs ranging from 1000 to 8000 sec were taken to achieve statistical accuracy within 1–2%. A typical spectrum of Pb L_{III} x-rays and Se K x-rays are shown in figures 1 and 2 respectively. The values of $N_S(L_{III})$ and $N_C(K)$ were found by determining the areas under photopeaks of the respective spectra.

4. Results and Discussion

The L_{III} sub-shell photoelectric cross-sections in Pb, Th and U as calculated using equation (3) are listed in table 2. The value of $\omega_C(K)$ and $\omega_S(L_{III})$ were taken from Bambynek *et al* (1972). As described in an earlier paper (Allawadhi *et al* 1978) the correction factor $\beta_S(L_{III})$ was calculated using the relation

$$\beta_S(L_{III}) = \frac{1 - \exp\left[-\{\mu_i(K) + \mu_e(L_{III})\}\, t_S \cdot \sqrt{2}\right]}{\{\mu_i(K) + \mu_e(L_{III})\}\, t_S \cdot \sqrt{2}}$$

where $\mu_i(K)$ and $\mu_e(L_{III})$ are absorption coefficients in the element of the S target at the incident K x-ray energy and emerging L_{III} x-ray energy. In a similar manner $\beta_C(K)$ was calculated. The absorption coefficients used for such computations were calculated by finding the index to the power of energy with which absorption coefficients vary using various values of absorption coefficients from Veigele (1973). This avoids any graphical error that would otherwise enter if absorption coefficients are found from μ vs E plots. K shell photoelectric cross-sections were also calculated by the above method using Scofield's value (Scofield *et al* 1973). The total uncer-

Table 2. Measured values of L_{III} photoelectric cross-sections (σL_{III}) in Pb, Th and U compared with the theoretical values of Scofield (1973)

Element	Energy of measurements (keV)	L_{III} photoelectric cross-section	
		Present measurements	Theoretical value
Pb	13·596	29000 ± 3200[a]	29111
		31000 ± 3400[b]	
Th	16·896	22000 ± 2200	22889
U	17·781	22000 ± 2200[c]	21580
		23000 ± 2400[d]	

With comparison targets of [a]As, [b]Se, [c]Rb, [d]Sr.

tainty in the results is $\sim$ 10–11% and is mainly due to uncertainty in the fluorescent yields. The error in $\omega_S(L_{III})$ is $\sim 8\%$ while in $\omega_C(K)$ it varies from ~ 1 to 5%. The uncertainty in β has been estimated to be 2 to 4%. The counting rates $N_S(L_{III})$ and $N_C(K)$ were determined with statistical accuracy $\sim 1\%$. Since no other experimental data of L_{III} subshell cross-sections in Pb, Th and U at the said energies are available, the present measurements are compared with theoretical values of Scofield (1973). Evidently, within the quoted errors the results agree well with Scofield's calculations. It may be noted that more accurate and reliable experimental as well as theoretical data on shell/sub-shell fluorescence yields are needed to fully exploit the present method.

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References

Allawadhi K L and Sood B S 1975 *Nucl. Instrum. Meth.* **129** 493
Allawadhi K L and Sood B S 1976 *Phys. Rev.* **A13** 688
Allawadhi K L, Arora S K and Sood B S 1978 *Pramana* **10** 511
Allawadhi K L *et al* 1978 *Physica* **C95** 424
Arora S K, Allawadhi K L and Sood B S 1980 *J. Phys. B* (in press)
Bambynek W *et al* 1972 *Rev. Mod. Phys.* **44** 716
Hubbell J H and Veigele Wm J 1976 NBS Technical Note 901
Pratt R H, Ron A and Tseng H K 1973 *Rev. Mod. Phys.* **45** 273
Scofield J H 1973 Lawrence Livermore Lab. Report No. 51326 (Unpublished)
Storm E and Israel I 1970 *Nucl. Data Tables* **A7** 565
Veigele Wm J 1973 *Atomic Data Tables* **5** 51