

K_{β} to K_{α} Intensity Ratio and Total Vacancy Transfer Probabilities of Molybdenum and Silver

L. Francis Maria Anand¹, S. B. Gudennavar¹, Daisy Joseph^{2,*}, S. G. Bubbly¹

¹Department of Physics, Christ University, Bangalore-560029, India

²Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai-400085, India

*Corresponding Author: djoseph@barc.gov.in

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Abstract Using a simple method of targets of Mo and Ag being excited by a weak Cs137 γ -ray source it was possible to determine K shell X-ray intensity ratios ($I_{K\beta}/I_{K\alpha}$) and the total vacancy transfer probabilities (η_{KL}) of Mo and Ag. The targets of Mo and Ag were excited using barium K X-rays from a weak Cs137 γ -ray source. K shell X-rays were detected using Si (Li) X-ray detector coupled to 8k multichannel analyzer. The values of $I_{K\beta}$ to $I_{K\alpha}$ ratios and η_{KL} are compared with the theoretical values and experimental data of other experimentalists and the results are found to be in good agreement.

Keywords X-ray Intensity Ratio, Vacancy Transfer Probability, 2π Geometrical Configuration, Weak γ -Ray Source

Although the method is simple, it yields XRF parameter values comparable to the standard reflection geometry experiments (See, Horakeri et al., 1997, 1998; Gudennavar et al., 2003a, 2003b; Bennal et al., 2010; Horakeri et al., 2011). Recently Tursucu et al., (2012) have determined the K shell intensity ratios and total vacancy probabilities of 9 elements in the atomic range $40 \leq Z \leq 50$ employing this simple method and they report that the method yields the results comparable with the results of reflection geometry experiments. In the present work, we have determined the $I_{K\beta}/I_{K\alpha}$ intensity ratios and total vacancy probabilities of Mo and Ag by using Si(Li) detector coupled to a PC based 8k multichannel analyzer and a weak Cs¹³⁷ source. The targets of Mo and Ag were excited using barium K X-rays of energy 32.86 keV resulting in the Internal Conversion (IC) process in Cs¹³⁷.

1. Introduction

X-ray fluorescence (XRF) intensity ratios and vacancy transfer probabilities of elements and compounds have been found to have wide applications in many areas of diverse applications. These applications require the accurate values of K shell X-ray intensity ratios and vacancy transfer probabilities of elements. In the past few decades, several researchers have determined K shell X-ray intensity ratios and vacancy transfer probabilities of various elements and compounds by different methods (For e.g., Apaydin and Tiraşoğlu, 2012; Hopman et al., 2012; Cengiz et al., 2011, Cengiz et al., 2010). However these methods require strong γ -ray sources of the order of 100 to 200 mCi and hence require shielding from strong radiations. Our group has developed a simple method to determine K shell fluorescence parameters of elements and compounds by using 2π -geometrical configuration with weak γ -ray sources of the order of 1 μ Ci (Horakeri et al., 1997; Gudennavar et al., 2003b; Bennal et al., 2010). The method essentially involves placing the target between the detector and the source. Because of the wide solid angle, source strength requires could be as low as of the order of a few μ Ci.

2. Experimental

The experimental set up consists of a Si(Li) X-ray detector, spectroscopy amplifier, a high voltage bias supply and a PC based MCA to detect and measure the intensity of K X-rays emitted from Mo and Ag targets (Fig.1). The Si (Li) detector had an active surface area of 20 mm², 3.5 mm thick and Be window of 12.5 μ m thickness. The energy resolution of the detector is 140 eV at 5.9 keV Mn K X-ray. The Si (Li) X-ray detector spectrometer was calibrated using various gamma and X-ray sources. The target materials of pure molybdenum and silver, were purchased in the form of thin foil of required thickness from local company. The Mo and Ag targets were excited using the barium K X-rays of energy 32.86 keV resulting in the IC process of Cs¹³⁷. The weak point Cs¹³⁷ γ -ray source (2 μ Ci) prepared on a thin plastic disc was obtained from Radiopharmaceuticals Division, Therapeutic and Reference Sources Section, BARC, Mumbai.

The total K to L vacancy transfer probability is given (Schönfield and Janßen, 1996) by

$$\eta_{KL} = Z - Wk/Ik \quad (1)$$

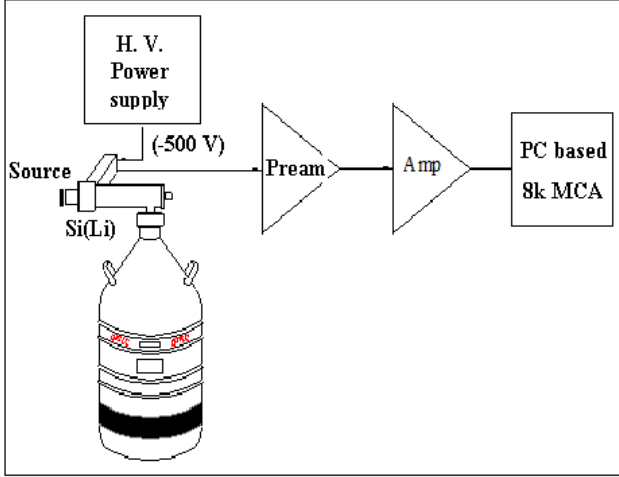


Figure 1. Experimental arrangement

The ratio of the intensity of the characteristic X-ray of type *i* to type *j* is given by

$$\frac{I(i)}{I(j)} = \frac{I'_i \varepsilon_j \beta_j \exp(-\mu_{xjw} t_w)}{I'_j \varepsilon_i \beta_i \exp(-\mu_{xiw} t_w)} \quad (2)$$

where $i = K_\beta$ and $j = K_\alpha$; I'_i and I'_j are the measured intensities of K shell X-ray of type *i* and *j* respectively, ε_i and ε_j are the efficiencies of the detector for K shell X-ray of type *i* and *j* respectively, $\exp(-\mu_{xiw} t_w)$ and $\exp(-\mu_{xjw} t_w)$ are the window attenuation correction factors for fluorescence X-rays of type *i* and *j* respectively; μ_{xiw} and μ_{xjw} are the mass attenuation coefficients of K shell X-rays of type *i* and *j* in the detector window of thickness t_w ; β_i and β_j are the self-attenuation correction factors for the K shell X-ray of

type *i* and type *j* respectively in the target material and are calculated using the eqn. (Horakeri et al., 1997; Gudennavar et al., 2003a),

$$\beta = \frac{1 - \exp[-(\mu_i + \mu_e)t]}{(\mu_i + \mu_e)t} \quad (3)$$

where μ_i and μ_e are the mass attenuation coefficients (cm^2/gm) of the incident and emitted K shell X-rays respectively in the target of thickness t (g/cm^2) and are computed using WinXcom software (Berger et al., 2005).

The intensities of K shell X-rays of Mo and Ag targets were measured as follows. The 'source spectrum with background' was acquired for the live time of 5000s by placing the source in front of the face of the detector window, as close as possible so as to have wide solid angle (Fig. 2). The target was then placed between the source and the detector window to acquire the 'transmitted spectrum with background' for the same duration of live time (Fig. 3). Subtraction of the former from the latter, gives a clean K shell X-ray fluorescence spectrum of the target element under investigation (Fig. 4). Each K shell X-ray peak is then fitted to a Gaussian distribution function using ORIGIN software and the area under the peak is estimated carefully. The area under each peak gives the intensity of K shell X-ray of given type, which is then corrected for self attenuation in the target, attenuation in the window and the efficiency of the detector to get the total number of K shell X-rays emitted in the forward hemisphere. The $I_{K\beta}/I_{K\alpha}$ intensity ratios and total vacancy probabilities of Mo and Ag are calculated using the following eqs. (2) and (1) respectively. The values of ω_k for the calculation of η_{KL} of Mo and Ag are taken from Hubbell tables (Hubbell, 1989)

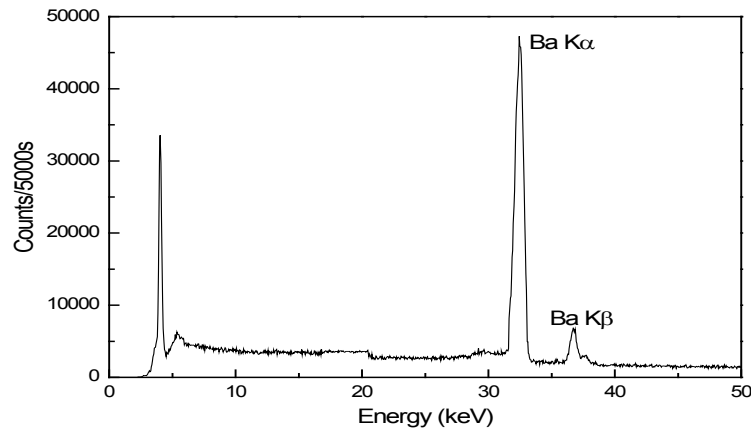


Figure 2. Source spectrum with background

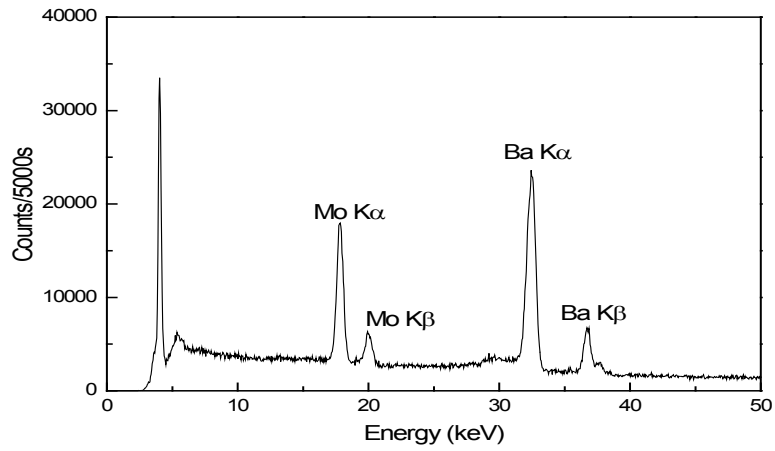


Figure 3. Transmitted spectrum with background

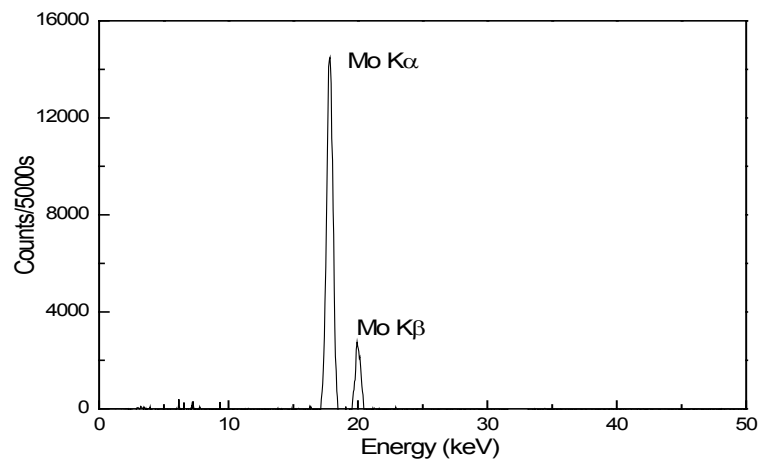


Figure 4. K shell X-ray fluorescence spectrum of molybdenum

3. Results and Discussion

The molybdenum and silver targets were excited using barium K x-rays of weighted energy of 32.86 keV from weak ¹³⁷Cs gamma source. The K x-rays emitted were detected using Si(Li) detector spectrometer. From the measured K shell X-ray intensity ratios and the ω_k values taken from Hubbell tables (Hubbell, 1989), the total vacancy transfer probabilities for pure molybdenum and silver have been determined. The results along with the theoretical values calculated by Scofield (1974) and others' experimental values obtained by adopting reflection geometry for these elements are presented in Table 1.

Table 1. The exp and theoretical values of K shell X-ray intensity ratios and vacancy transfer probabilities for Mo and Ag

Element	$\frac{I(K_{\beta})}{I(K_{\alpha})}$	Reference	η_{KL}	Reference
Molybdenum (42)				
Present	0.184 ±	---	1.04 ±	---
	0.007		0.006	
Theory	0.195	Khan and Karimi (1980)	1.029	Schönfeild and Janßen (1996)
	0.1809	Scofield (1974)	1.045	Scofield (1974)
			1.033	Rao et al. (1972)
Other's Experimental	0.1809	Turşucu et al. (2012)	1.047	Turşucu et al. (2012)
	0.185	Bennal et al. (2010)	1.039	Bennal et al. (2010)
	0.193	Ertuğral (2001)	1.026	Ertuğral et al. (2007)
			1.028	Öz (2006)
		1.033	Ertuğral (2001)	
Silver (47)				
Present	0.192 ±	---	0.981 ±	---
	0.005		0.006	
Theory	0.212	Khan and Karimi (1980)	0.964	Khan and Karimi (1980)
	0.1964	Scofield (1974)	0.971	Scofield (1974)
Other's experimental	0.1964	Turşucu et al. (2012)	0.977	Turşucu et al. (2012)
	0.198	Bennal et al. (2010)	0.973	Bennal et al. (2010)
	0.2096	Ertuğral et al. (2007)	0.9995	Simsek et al. (2003)
	0.217	Ertuğral et al. (2001)		

From the table, it is clear that our results agree with the theoretical and others' experimental values. Thus the present study shows that the simple 2π geometrical configuration method employing weak gamma source can be an alternate method

REFERENCES

- [1] Apaydin, G., Tıraşoğlu, E., 2012. Calculation of vacancy transfer probabilities from K to L shell using the x-ray fluorescence parameters. *Radiat. Phys. Chem.* 81, 1593-1594.
- [2] Bennal, A.S., Niranjan, K.M., Badiger, N.M., 2010. Determination of K to L shell total transfer probabilities using a weak gamma source. An alternative method. *J. Quant. Spect. Radiat. Trans.* 111, 1363-1371.
- [3] Berger, M.J., Hubbell, J.H., Seltzer, S.M., Chang, J., Coursey, J.S., Sukumar, R., Zucker, D.S., 2005. XCOM: Photon Cross Section Database (version 1.3). National Institute of Standards and Technology Gaithersburg MD.
- [4] Cengiz, E., Tıraşoğlu, E., Apaydin, G., Aylikci, V., Kıp Aylikci, N., Aksoy, C., 2011. K-shell x-ray fluorescence parameters of some heavy elements and compounds. *Radiat. Phys. Chem.* 80, 328-334.
- [5] Cengiz, E., Tıraşoğlu, E., Aylikci, V., Apaydin, G., 2010. The investigations on K and L x-ray fluorescence parameters of gold compounds. *Radiat. Phys. Chem.* 79, 809-815.
- [6] Ertuğral, B., Apaydin, G., Cevik, U., Ertuğral, M., Kobya, A.I., 2007. K_β/K_α x-ray intensity ratios for elements in the range 16 ≤ Z ≤ 92 excited by 5.9, 59.5 and 123.6 keV photons. *Radiat. Phys. Chem.* 76, 15-22.
- [7] Ertuğral, M., Söğüt, Ö., Şimsek, Ö., Büyükkasap, E., 2001. Measurement of K_β/K_α intensity ratios for elements in the range 22 ≤ Z ≤ 69 at 59.5 keV. *J. Phys. B: At. Mol. Opt. Phys.* 34, 909-914.
- [8] Gudennavar, S.B., Badiger, N.M., Thontadarya, S.R., Hanumaih, B., 2003a. K-shell fluorescence parameters of medium Z elements. *Radiat. Phys. Chem.* 68, 721-726.
- [9] Gudennavar, S.B., Badiger, N.M., Thontadarya, S.R., Hanumaih, B., 2003b. A method for measuring K-shell fluorescence parameters in a 2 geometrical configuration. *Radiat. Phys. Chem.* 68, 745-750.
- [10] Hopman, T.L., Heirwegh, C.M., Campbell, J.L., Krumrey, M., Scholze, F., 2012. An accurate determination of the K-shell x-ray fluorescence yield of Silicon. *X-ray Spectrom.* 41, 164-171.
- [11] Horakeri, L.D., Hanumaiah, B., Thontadarya, S.R., 1998. K-shell fluorescence yields of medium and heavy elements using a simple method. *X-Ray Spectrom.* 27, 344-348.
- [12] Horakeri, L.D., Bubbly, S.G., Gudennavar, S.B., 2011. K-shell fluorescence yields of barium and lanthanum. *Radiat. Phys. Chem.* 80, 626-628.
- [13] Horakeri, L.D., Hanumaiah, B., Thontadarya, S.R., 1997.

- Method for the determination of K-shell fluorescence yields. *X-ray Spectrom.* 26, 69-74.
- [14] Hubbell, J.H., 1989. Bibliography and current status of K, L, and higher shell fluorescence yields for computation of photon energy-absorption coefficients, National Institute of Standards and Technology Report. NISTIR. 89-4144.
- [15] Khan, M.R., Karimi, M., 1980. $K\beta/K\alpha$ ratios in energy-dispersive x-ray emission analysis. *X-ray Spectrom.* 9, 32-35.
- [16] Öz, E., 2006. Determination of ratios of emission probabilities of Auger electrons and K-L shell radiative vacancy transfer probabilities for 17 elements from Mn to Mo at 59.5 keV. *J. Quant. Spectrosc. Radiat. Transfer.* 97, 41-50.
- [17] Rao, P.V., Chen, M.H., Crasemann. B., 1972. Atomic Vacancy Distributions Produced by Inner- shell Ionization. *Phys. Rev. A.* 5, 997-1012.
- [18] Schönfield, E., Janben, H., 1996. Evaluation of Atomic shell Data. *Nucl. Instr. Meth. A.* 369, 527-533.
- [19] Scofield, J.H., 1974. Relativistic Hartree – Slater values for K and L x-ray emission rates, *Atom Data Tables.* 14, 121–137.
- [20] Şimşek, Ö., Karagöz, D., Ertugrul, M., 2003. Measurement of K to L shell vacancy transfer probabilities for the elements 46 Z 55 by photoionization. *Spectrochim. Acta Part B* 58, 1859–1865
- [21] Turşucu, A., Önder, P., Eroğlu, E., Demir, D., 2012. Determination of K- L total vacancy transfer probabilities using a weak gamma source in 2π geometrical configuration. *Appl. Radiat. Isot.* 70, 1509-1511.