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Measurements of Radiative Vacancy Transfer Probabilities for Some Elements Irradiated with Photons of 0.0208 Nanometer Wavelengths

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The radiative vacancy transfer probabilities of K to L_2, L_3, M_2, M_3 sub-shells were calculated using the experimental K level widths and theoretical partial radiative transitions. The targets were irradiated with photons of 0.0208 nm wavelength. It has been observed that the obtained values in the present study agree with theoretical results, theoretical predictions and the other available experimental values.

Keywords: Vacancy transfer probabilities, Level width.

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1. INRODUCTION

The knowledge obtained from experimental results of the fluorescence yields, the vacancy transfer probabilities, the level and line widths for different elements is very important in the study of some basic phenomena such as in atomic, molecular and radiation physics and in non-destructive trace element analysis of various sample using the energy dispersive X-ray fluorescence method. Both some nuclear process like orbital electron capture or internal conversion and interaction of photons or charged particles such as heavy ions and protons are create primer vacancies in the inner shells /sub-shells of the atoms. In this study, vacancies in atomic shells/sub-shells were created by using a photoionization method. In the K shell, one of the higher shell electrons will fall into the vacated orbital followed by the emission of either a K X-ray photon or an Auger electron from one of the higher shells. In the radiative transfer process, a vacancy in the shell is filled by the jump of an electron from the higher shell and the difference in energy of two shells/sub-shells is emitted in the form of characteristic X-ray. These radiation transitions, which obey a definite set of selection rules, are called allowed lines.

Ertuğral et al. [1] determined K to L shell vacancy transfer probabilities for 25 elements in the atomic range $58 \leq Z \leq 92$ by measuring the K X-ray yields from targets excited by 123.6 keV photons and using $I_{K\beta}/I_{K\alpha}$ intensity ratios. Santra et al. [2] measured K to L shell vacancy transfer probabilities (η_{KL}) of Mo, Pd, and Cd by successively exciting them with the K X-rays of Ni and Sn induced by the bremsstrahlung emanating from an X-ray tube. The radiative vacancy transfer probabilities from L_3 to M shell, $\eta_{L_3M}(R)$ and L_3 to N shell, $\eta_{L_3N}(R)$, have been determined for W, Re and Pb using synchrotron radiation by Bonzi [3]. The vacancy transfer probabilities of K to L_1, L_2 and L_3 shells measured for Ho and Er using L X-ray yields at 59.54 keV incident photons by Ertuğrul [4].

In this study, we determined K to L_2, L_3, M_2, M_3 sub-shells radiative vacancy transfer probabilities for some elements (V, Co, Zn, Se) by using the experimental K level widths and theoretical partial radiative transitions. The determined probabilities are compared with theoretical predictions, theoretical values and the other available experimental values.

2. EXPERIMENTAL AND CALCULATION PROCEDURES

2.1 Experimental Procedure For K X-Ray Fluorescence Cross Sections

The values of experimental K X-ray fluorescence cross-sections were calculated using the following equation:

$$\sigma_{K_i} = \frac{N_{K_i}}{I_0 G \varepsilon_{K_i} \beta_{K_i} t} \quad (I = \alpha, \beta) \tag{2.1}$$

where N_{K_i} is the number of counts per second under the corresponding K_i X-ray photopeak, I_0 is the intensity of the exciting radiation, G is the geometrical factor dependent on the source-sample-detector geometry, ε_{K_i} is the detector efficiency for K_i X-rays, t is the thickness of target in g/cm² unit and β_{K_i} is the self-absorption correction factor for the target material and is given by:

$$\beta_{K_i} = \frac{1 - \exp\left[-\left(\mu_i/\cos\theta_i + \mu_e/\cos\theta_e\right) t\right]}{\left(\mu_i/\cos\theta_i + \mu_e/\cos\theta_e\right) t} \tag{2.2}$$

where μ_i and μ_e are the total mass absorption coefficients of the target material at the incident photon (nano-wavelenght 0.0208 nm) and emitted K_i X-ray energies, respectively. The values of μ_i and μ_e were taken from WinXCom program [6]. The angles of θ_i and θ_e which correspond to incident and emission angles with sample surface were set to 45°, respectively.

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2.2 Experimental procedure for K shell fluorescence yields and K shell level widths and radiative vacancy transition probabilities

The experimental K shell fluorescence yields were calculated from using the following expression:

$$\omega_K = \frac{\sum \sigma_{K_i}}{\sigma_K(E)} \; (i = \alpha, \beta) \tag{2.3}$$

where $\sum \sigma_{K_i}$ is the total K X-ray fluorescence cross-section obtained experimentally, $\sigma_K(E)$ is the theoretical K-shell photoionization cross-section of a given element for the excitation energy taken from Scofield [7].

The experimental values of K shell level widths were evaluated from the following equation:

$$\Gamma_K = \frac{\Gamma_K(R)}{\omega_K}, \tag{2.4}$$

where $\Gamma_K(R)$ is radiative transition rate [8], ω_K is the K shell fluorescence yield obtained experimentally.

Some experimental radiative vacancy transition probabilities ($\eta_{X_iY_t}(R)$ $X = (K)$, $Y = (L_2, L_3\ M_2, M_3)$ and $t = (1, 2, 3, \ldots)$ from K shell to L, M sub-shells were evaluated from following equation:

$$\eta_{X_iY_t}(R) = \frac{\Gamma_{X_iY_t}(R)}{\Gamma_{X_i}}, \tag{2.5}$$

$\eta_{X_iY_t}(R)$ is the partial radiative transition rate and taken from Scofield [8], Γ_{X_i} is the level width obtained experimentally.

3. RESULT AND DISCUSSIONS

The experimental K_α, K_β and K_t X-ray fluorescence cross sections, K shell fluorescence yields, K shell level widths and K to L_2, L_3, M_2, M_3, sub-shells vacancy transfer probabilities were measured for some elements. The measured values of X-ray fluorescence cross sections, X-ray fluorescence yields and Γ_K level widths values were listed in Table 1. For the measured and calculated radiative vacancy transfer probabilities, eqs. (5) were used to include partial radiative transition rates [8] and level widths from Table 1. The measured values of K to $L_{2,3}$, $M_{2,3}$ radiative vacancy transfer probabilities were listed in Table 2 with the calculated values. The present results are generally in the good agreement with theoretical prediction and other experimental results can be obtained from literature.

Table 1 – Experimental and theoretical K_i ($i = \alpha, \beta, t$) X-ray fluorescence cross sections (barn/atom), X-ray fluorescence yields and Γ_K level widths (eV) values

Element	$\sigma_{K\alpha}$		$\sigma_{K\beta}$		σ_{Ktotal}		ω_K		Γ_K	
	Experimental	**Theoretical**	**Experimental**	**Theoretical**	**Experimental**	**Theoretical**	**Experimental**	**Theoretical**	**Experimental**	**Theoretical**
^{23}V	11.54±0.70	10.87	1.48±0.09	1.26	13.01±1.1	12.13	0.260±0.023	0.243[9]	0.88±0.08	1.01[10]
^{27}Co	35.12±1.99	32.46	4.73±0.28	3.95	39.85±3.21	36.41	0.408±0.033	0.373[9]	1.15±0.09	1.33[10]
^{30}Zn	62.18±3.53	63.39	8.70±0.52	7.87	70.88±5.77	71.26	0.471±0.038	0.474[9]	1.59±0.13	1.67[10]
^{34}Se	126.90±7.23	128.08	19.49±1.17	18.25	146.38±11.91	146.33	0.589±0.048	0.589[9]	2.22±0.18	2.33[10]

Table 2 – Experimental and theoretical K shell to L_2, L_3, M_2, M_3 sub-shells radiative vacancy transfer probability

Element	η_{KL2} (R)		η_{KL3} (R)		η_{KM2} (R)		η_{KM3} (R)	
	Experimental	**Theoretical**	**Experimental**	**Theoretical**	**Experimental**	**Theoretical**	**Experimental**	**Theoretical**
^{23}V	0.079±0.007	0.068[a] 0.076[11]	0.154±0.014	0.134[a] 0.151[11]	0.0091±0.0008	0.0079[a]	0.0179±0.0016	0.0156[a]
^{27}Co	0.123±0.010	0.106[a] 0.116[11]	0.241±0.019	0.0208[a] 0.228[11]	0.0149±0.0012	0.0129[a]	0.0293±0.0024	0.0253[a]
^{30}Zn	0.142±0.012	0.135[a] 0.142[11]	0.277±0.022	0.263[a] 0.278[11]	0.0176±0.0014	0.0167[a]	0.0344±0.0028	0.0326[a]
^{34}Se	0.176±0.014	0.167[a] 0.173[11]	0.340±0.028	0.323[a] 0.336[11]	0.0237±0.0019	0.0226[a]	0.0464±0.0038	0.0441[a]

[a] Theoretical calculation of radiative vacancy transfer probability from eq. (5) obtained theoretical level widths from Krause [10].

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