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Measurements of *K*-shell X-ray production cross-sections and fluorescence yields for some elements in the atomic number range $28 \leq Z \leq 40$

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HIGHLIGHTS

- K_α and K_β X-ray production cross-sections have been determined for the elements Cu, Ge, As, Br, and Rb at 16.896 keV.
- Fluorescence yields have been determined for the elements Cu, Ge, As, Br, and Rb.
- Results have been compared with results from experimental and theoretical studies.

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ABSTRACT

K shell X-ray production cross-sections ($\sigma_{K\alpha}$ and $\sigma_{K\beta}$) have been measured for some elements in the atomic number range $28 \leq Z \leq 40$. Measurements have been carried out at 16.896 keV excitation energy using secondary source. *K* X-rays emitted by samples have been counted by a Si(Li) detector with 160 eV resolution at 5.9 keV. The values of *K*-shell fluorescence yields (ω_K) have been evaluated for the same elements. The results obtained for *K* X-ray production cross-sections and fluorescence yields have been compared with the theoretically calculated values and other available semiempirical values.

1. Introduction

Experimental determination of X-ray production cross-sections and fluorescence yields (ω_K) are important in many practical applications like elemental analysis by X-ray emission technique, basic studies of nuclear and atomic processes leading to the emission of X-rays and Auger electrons and dosimetric computations for medical physics and irradiational processes. The de-excitation of an atom with an inner-shell *K* vacancy can proceed either by emission of an X-ray photon or by the ejection of Auger electrons. The de-excitation of an atomic shell is characterized by these fluorescence yields and is defined as the probability that a vacancy in the *K*-shell is filled through a radiative transition.

K X-ray production cross-sections and fluorescence yields for different elements have been investigated for many years. Earlier experimental *K* X-ray production cross-sections have been measured by Garg et al. (1985), and Rao et al (1993). *K* X-ray production cross-sections have been determined theoretically for all the elements at energies ranging from 10 to 60 keV (Krause et al.,1978). *K*-shell X-ray production cross-sections and fluorescence yields have been investigated for different elements (Kumar et al.,1987; Durak et al., 1998; Özdemir et al., 2002).

K- shell fluorescence yields ω_K were deduced from the measured cross-sections by using the theoretical photoionization cross-sections and fractional X-ray emission rates. *K* shell fluorescence yields for different elements have been investigated for many years. Bambynek et al. (1972) in review article have fitted their collection of selected most reliable experimental values in the $13 \geq Z \geq 92$ range. Krause (1979) present a table of ω_K adopted values for elements $5 \geq Z \geq 110$ by using all theoretical and experimental data on the parameter contributing to the *K*-shell fluorescence yields. Hubbel et al. (1994) have compiled more recent experimental values. Theoretical values of$\omega_K$were obtained using the Hartree- Fock-Slater model (Walters and Bhalla, 1971). Kostroun et al. (1971) present computations for elements in the range $10 \geq Z \geq 70$. *K*-shell fluorescence yields have been investigated for different elements (Araro et al., 1981; Pious et al.,

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1992, Şimşek et al., 2002). *K* shell X-ray production cross-sections and fluorescence yields for Cr, Mn, Fe and Co elements have been measured using secondary source by Yılmaz (2014).

In the present study, the *K* X-production cross-sections for some elements in the atomic number range $28 \leq Z \leq 40$ have measured at 16.896 keV . *K* shell is excited by the *K* X-rays of the secondary source excited by 59.5 keV photons emitted by the primary source. *K* - shell fluorescence yields were obtain by using the measured cross-sections, the theoretical photoionization cross-sections**,** and fractional X-ray emission rates. The results obtained for *K* X-ray production cross-sections and fluorescence yields are compared with the theoretically calculated values and other available semiempirical values.

2. Experimental

The experimental arrangement used in the present study has been described elsewhere (Yılmaz, 2012). The samples were excited by the *K* X-rays of secondary source excited at 59.5 keV γ-rays from a ^{241}Am point source. Fluorescent X-rays spectra were recorded by a calibrated Si(Li) X-ray spectrometer (FWHM = 160 eV at 5.96 keV, active area = 12.5 mm^2, sensitivity depth = 3.5 cm, Be window thickness = 12.5 μm) coupled to a Nuclear Data MCA system (ND66B) consisting of a 4096- channel analyzer and spectroscopy amplifier. The net peak areas of the *K* X-rays of each target were determined after background subtraction, talling and escape-peak corrections (Öz 2006). The secondary excitation source was pure Nb (99.99%). In secondary sources or secondary excitation method, the incident energies were calculated by taking the weighted average of K_α and K_β X-ray energies according to their intensity ratios(Storm and Israel, 1970) . We also have used the secondary excitation method applied by Baydaş et.al. (2002,2003) as in our previous and present studies (2012,2014). For Nb, weighted averages $K_{\alpha\beta}$ energy is 16.896 keV, (Storm and Israel, 1970).

3. Data analysis

The *K*-shell X-ray production cross-sections ($\sigma_{K\alpha}$ and $\sigma_{K\beta}$) required for the determination of *K* shell fluorescence yields were evaluated by measuring the characteristic *K* X- ray intensities for cited range of elements. The experimental *K* X-ray production cross-sections were measured using the relation.

$$\sigma_{Ki} = \frac{N_{Ki}}{I_0 G \varepsilon_{Ki} \beta t} \tag{1}$$

where N_{Ki}(($i = \alpha, \beta$) is the number of counts per unit time under the corresponding photopeak. A typical *K* X-ray spectrum for As is shown in Fig.1. I_0 is the intensity of exciting radiation , G is the geometrical factor,$\varepsilon_{Ki}$is the detector efficiency for the K_i X-rays, *t* is the mass of the sample in g /cm^2 and β is the self-absorption correction factor for the incident photons and emitted *K* X-ray photons. β is the calculated by using the relation (Yılmaz, 2014),

$$\beta = \frac{1 - \exp[-(\mu_1/\sin\theta + \mu_2/\sin\theta)t]}{(\mu_1/\sin\theta + \mu_2/\sin\theta)t} \tag{2}$$

where μ_1 and μ_2 are the absorption coefficients (cm^2/g) of incident photons and emitted characteristic X-Rays, respectively (Hubbell and Seltzer, 1995). The angle of incident photons and emitted X-rays, with respect to the normal at the surface of the sample, θ was equal to 45^0 in the present set-up In the present study, as shown in Fig. 2, the values of the factors $I_0 \varepsilon G$, which contain terms related to the incident photon flux, the efficiency of the X-ray detector and geometrical factor, were determined by collecting the *K* X-ray spectra of thin samples of Fe, Ga, Se, Sr and Zr , in the same geometry in which the *K* X- ray fluorescence cross-sections were measured and using the equation (Durak and Özdemir, 2001).

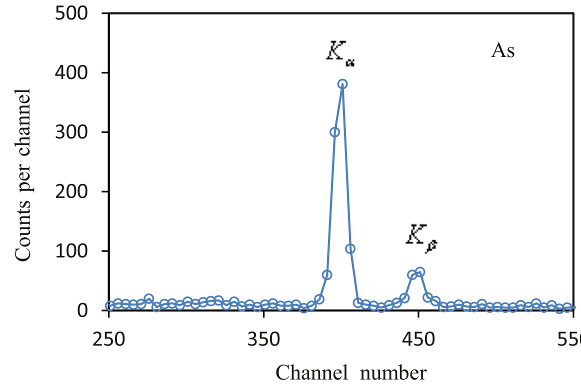

Fig. 1. *K* X-ray spectrum of As.

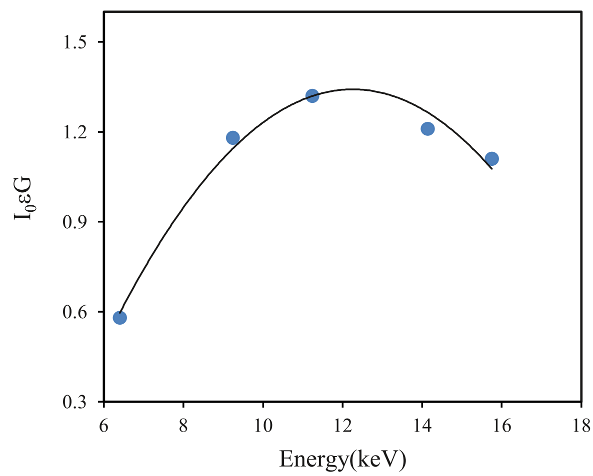

Fig. 2. $I_0\varepsilon G$ values versus *K* X- ray energy for Cu, Ge, As, Br and Rb elements.

Table 1
Experimental and theoretical K_α X- ray cross-sections (barns/atom).

Element	Excitation energy (keV)	Present Work	Theoretical predictions
^{29}Cu	16.896	2004 ± 148	1930.347
^{32}Ge	16.896	3233 ± 252	3273.372
^{33}As	16.896	3940 ± 264	4007.949
^{35}Br	16.896	4853 ± 346	5003.461
^{37}Rb	16.896	6237 ± 457	6389.019

Table 2
Experimental and theoretical K_β X- ray cross-sections (barns/atom).

Element	Exciation energy (keV)	Present Work	Theoretical predictions
^{29}Cu	16.896	243 ± 018	234.716
^{32}Ge	16.896	424 ± 033	429.877
^{33}As	16.896	539 ± 036	549.440
^{35}Br	16.896	721 ± 051	741.892
^{37}Rb	16.896	991 ± 073	1015.428