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Measurements of K- shell production cross-section and fluorescence yield for Y element

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Abstract: *K*- shell X- ray production cross-section have been measured for Y element. 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 yield has been evaluated for Y element. The results obtained for fluorescence yield and *K* X- ray production cross-section has been compared with the theoretically calculated values and other available semiempirical fits values.

Keywords: X-Ray Fluorescence, Fluorescence Yields, Cross-Sections

1. Introduction

K X-ray production cross-sections ($\sigma_{K\alpha}$) and fluorescence yields (ω_K) are important in a variety of fields such as atomic physics , nuclear physics , space physics, plasma physics, elemental analysis by X- ray emission technique, medical research, industrial processing. 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 [1,2]. *K* X-ray production cross-sections have been determined theoretically for all the elements at energies ranging from 10 to 60 keV [3]. *K*-shell X-ray production cross-sections and fluorescence yields have been investigated for different elements [4,5,6].

K shell fluorescence yields for different elements have been investigated for many years. Bambynek et al. have fitted their collection of selected most reliable experimental values in the $13 \geq Z \geq 92$ range[7]. Krause 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[8]. Hubbel et al. have compiled more recent experimental values[9]. Theoretical values of ω_K were obtained using the Hartree-Fock-Slater model [10]. Kostroun et al. present computations for elements in the range $10 \geq Z \geq 70$ [11]. *K*-shell fluorescence yields have been investigated for different elements [12,13,14]. *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 [15]. There is scarcely experimental *K*-shell fluorescence yield data for ^{39}Y.

The purpose of this study is to examine in low energy the *K* X-ray production cross-section of ^{39}Y. Measurements of fluorescence yilds for elements at various photoionization energies are important because of their widespread use.

In the present study, measurements have been carried out at 16.896 keV. *K* shell has been 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 geometry and the shielding arrangement of the experimental set-up employed in the present work are as shown in Fig.1. Also, it is available in our previous study [16]. As shown in Fig. 1., the sample (target) was placed at a 45^0 angle with respect to the direct beam from secondary source excited by 59.5 keV photons emitted by the primary source.

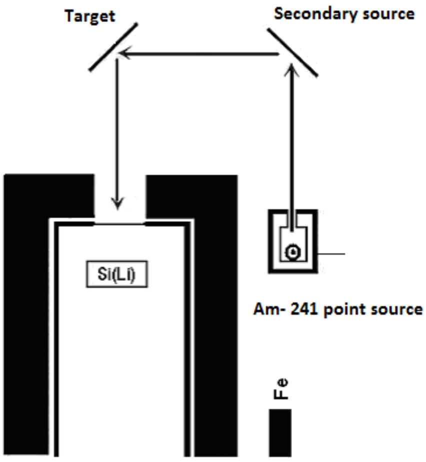

Fig . 1. *Experimental set-up used for measurements of production cross-section and yields.*

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. The *K* X-ray spectra from target was recorded by a calibrated Si(Li) X-ray spectrometer (full-width at half-maximum (FWHM) =160 eV at 5.96 keV, active area = 12.5 mm^2, sensitivity depth = 3.5 cm, Be window thickness = 12.5μm) 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, escape-peak corrections [17]. The secondary excitation source was pure Nb (99.99%). The excitation energy was taken as average of K_α and K_β X-ray energies. For Nb, weighted averages K_α , K_β , $K_{\alpha\beta}$ energies are 16.584 keV, 18.661 KeV and 16.896 keV, respectively [18].

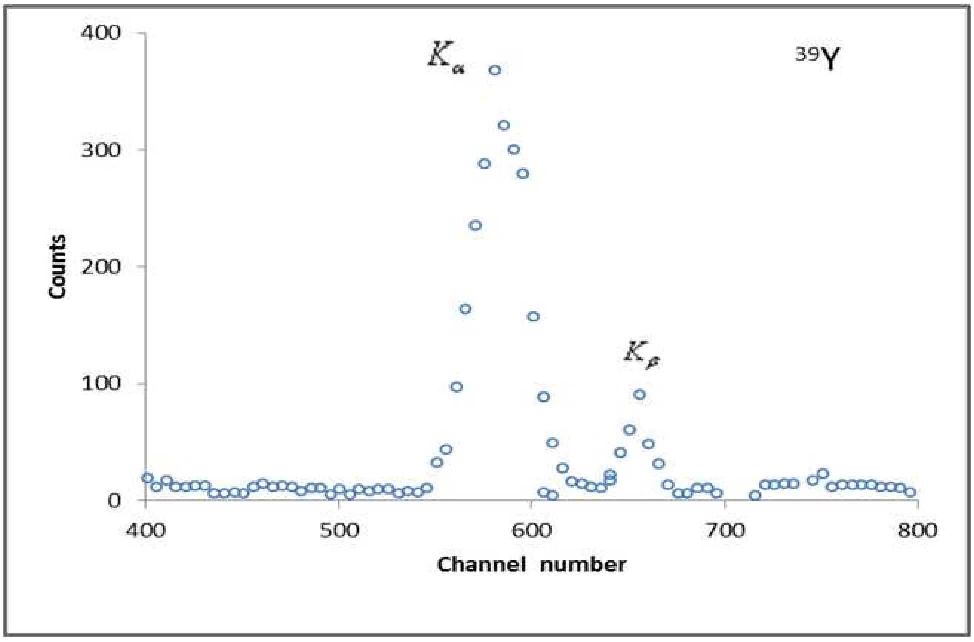

Fig. 2. *A typical K X-ray spectrum for ^{39}Y.*

3. Data Analysis

The *K*-shell X-ray production cross-section ($\sigma_{K\alpha}$) required for the determination of *K* shell fluorescence yield was evaluated by measuring the characteristic *K* X- ray intensities for ^{39}Y. 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 ^{39}Y is shown in Fig.2. I_0 is the intensity of exciting radiation , G is the geometrical factor, ε_{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[15],

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

where μ_1 and μ_2 are the absorption coefficients (cm^2/g) of incident photons and emitted characteristic X-Rays, respectively [9]. 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 3, the values of the factors $I_0\varepsilon G$, which contain terms related to the incident photon flux, geometrical factor and the efficiency of the X-ray detector, 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 [19].

$$I_0 G\varepsilon_{Ki} = \frac{N_{Ki}}{\sigma_{Ki}\beta t} \quad (3)$$

where N_{Ki} , β and t are as in Eq.(1).

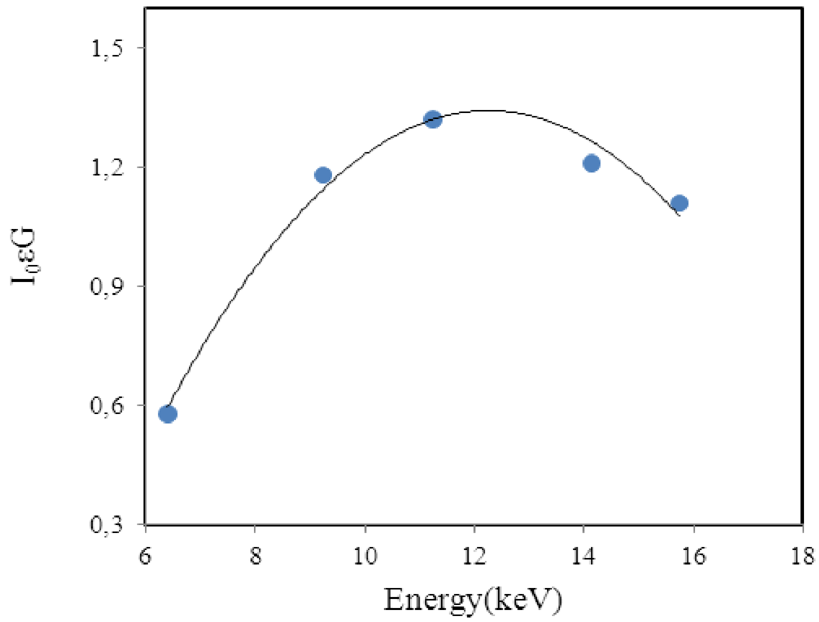

Fig. 3. *$I_0\varepsilon G$ vs. K X- ray energy.*

4. Theoretical Method

The theoretical values of K X-ray production cross-section $\sigma_{K\alpha}$ has been calculated using the following equation [5],

$$\sigma_{K\alpha} = \sigma_K^P(E)\omega_K f_{K\alpha} \quad (4)$$

Where $\sigma_K^P(E)$ is the K-shell photoionization cross-section for the given element at excitation energy E, ω_K is the K-shell fluorescence yield and $f_{K\alpha}$ is fractional X-ray emission rate for K_α X-rays and are defined as

$$f_{K\alpha} = (1+I_{K\beta}/I_{K\alpha})^{-1} \quad (5)$$

where $I_{K\beta}/I_{K\alpha}$ is the K_β to K_α X-ray intensity ratio. In the present calculations, the values of σ_K^P (E) were taken from Scofield [20] based on Hartree-Slater potential theory, and the values of ω_K were taken from the tables of Krause[8]. $I_{K\beta}/I_{K\alpha}$ values based on relativitic Hartree-Slater potential theory were used for the evaluation of theoretical K X-ray cross-sections [21].5. Results and Discussion

The experimental values of K shell X-ray production cross-section for ^{39}Y at 16.896 keV is listed in Table 1 together with the theoeretical value obtained using Eq.(4). The overall error in the present measurements is estimated to be <8%. This error is the quadrature sum of the uncertainties in the different parameters used to deduce K X-ray production cross-sections, namely, the error in the area evaluation under the K_α and K_β X-ray peak (2%), in the self-absorption correction factor ratio (<1%), the product $I_0\varepsilon G$(5%) and the other error in the non-uniform thickness(<1%). In this work , in order to reduce the absorption, thin sample was also used as the target. In order to reduce the statistical error, the spectra was recorded and about 6000 counts were collected under the K_α peak. It can be seen from Table 1 that our measured value is in good agreement, within the experimental uncertainties, with the calculated theoretical value.. The agreement between the presently measured *K* shell X-ray production cross-section and theoretical prediction is within % 3 for ^{39}Y element.

Table 1. *Experimental and theoretical* K_{α} *X- ray cross-sections (barns/atom) for* ^{39}*Y.*

Element	Excitation energy (keV)	Present Work	Theoretical predictions
^{39}Y	16.896	6002±468	6187.863

The present measured value of *K*-shell fluoresans yield(ω_K), deduced using Eq.(4) for ^{39}Y is compared with the other available calculated values, and semiempirical fits in Tables 2,3. In this study,our experimental result agree to the experimental result agree to <3.9% for ^{39}Y element with The K-shell fluorescence yields calculated using a semiemprical expression by Hubbell et al.[9] , Bambynek et al., [7] and Krause et al. [8]. The present measurement is in good agreement with the semiempirical values deduced by Hubbell et al.[9], with 0.4% (Table 3).

Table 2. *Comparison of the present K shell fluorescence yield (* ω_K *) and theoretical values for* ^{39}*Y.*

Element	Present work	Walters [10]	Kostroun [11]
^{39}Y	0.688±0.053	0.742	0.722

Table 3. *Present experimental result and semiempirical fits values of* ω_K *for* ^{39}*Yb*

Element	Present work	Bambynek [7]	Hubbell [9]	Krause [8]
^{39}Y	0.688±0.053	0.7155	0.685	0.710

As a result, the present agreement between the theoretical and present experimental values lead to the conclusion that the data presented here will benefit for analytical purpose and satisfactory for many other appilications employing the fundemental parameter approach. Also, secondary source are quite useful in low energy studies.

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