

K Shell X-Ray Fluorescence Yields for Elements in the Atomic Number Range $25 \leq Z \leq 50$ Excited by 59.54 Kev Gamma Rays

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Abstract: : K-shell fluorescence yields of low and medium Z elements were determined using Si-PIN diode detector employing reflection geometry set up. Target atoms were excited using 59.5 keV gamma rays emerging from Am-241 source of strength 300 mCi. Background radiation and multiple scattering effects were minimized by properly shielding the detector. The elemental foils of uniform thickness and 99.9% purity were used in the present investigation. The emitted fluorescent X-rays were detected using Si PIN diode detector. The fluorescent spectra were recorded in an 8 K multi channel analyzer. The data were carefully analyzed and total K-shell fluorescence yields were calculated. The resulting yield values are compared with the available experimental and theoretical values.

1. Introduction

The study of interaction of X-rays and gamma rays with matter has drawn wide range attention by virtue of their diverse applications in various fields like industry, agriculture, medicine and biology. Owing to their fundamental simplicity and due to small characteristic deviations shown by advanced experiments from the theoretical predictions, inner shell processes have become increasingly popular among various processes of 'interaction of gamma rays with matter'. One of the important parameters that play a vital role in experimental XRF studies is the K-shell fluorescence yield. K-shell X-ray fluorescence yields connect X-ray production cross sections with the theoretically calculated ionization cross sections and hence are important whenever comparing theory with experiment. The knowledge of

fluorescence yields is also required in the solution of many practical problems, such as standardization of radio isotopes, design of many radiation detecting devices and in the design of minimum weight graded or stacked shields for various engineering applications.

A literature survey on the K-shell fluorescence yields reveals the fact that there have been a number of theoretical estimations, semi empirical fits (Mc Guire 1969; Walters et al 1971; Kostrum et al 1971; Bambynek et al 1972; Krause 1979; Hubbel et al 1994) and some experimental investigations to measure these values in all atomic number region in the periodic table (Arora et al 1987; Al-Naser et al 1987; Siddu et al 1988; Pious et al 1991; Balakrishna et al 1994; Yashoda et al., 2002). In the present work, Si PIN diode detector is used to determine the K fluorescence yields.

2. Experimental method

Fluorescence yield is the probability that a vacancy in a shell or a sub shell is filled through a radiative transition. In the present work, K-shell fluorescence yield were determined by employing a straightforward method of measuring K X-ray emission rates and the number of primary K-shell vacancies. The target atoms were ionized using 59.54 keV gamma rays from 300 mCi Am-241 source. Experiments were carried out using reflection geometry setup employing a good collimating and shielding arrangements as shown in Fig 4. The targets employed were pure elemental foils of high purity, greater than 99.9%. The emitted fluorescent X-rays were detected using Si PIN diode detector. The spectra were recorded and analyzed using a 8 K multi channel analyzer. The area under the X-ray photo peak which gives N_k the total number of K X-ray fluorescent radiation is accurately determined and the K X-ray fluorescence yields ω_k were evaluated using the expression (Balakrishna, 1989)

$$\omega_k = \frac{16\pi^2 N_k r_1^2 r_2^2 [1 + \mu_k / \mu]}{S \varepsilon_D f_k A A_D [1 - \exp \{-(\mu + \mu_k) t \sqrt{2}\}]},$$

where r_1 is the distance between the source and the target; r_2 is the distance between the target and the detector; S is the source strength, ε_D is the detector efficiency, f_k is the fraction of the incident gamma ray flux that ionizes the K shell of the target fluorescer, A is the area of the target, A_D is the area of the detector, t is the thickness of the target. The attenuation coefficients μ and μ_k were taken from the literature (Hubbell 1982).

The fraction of the incident gamma ray flux that ionizes the K shell of the target fluorescer is given by

$$f_k = (\mu_+ - \mu_-) / \mu_+,$$

where μ_+ and μ_- are the attenuation coefficients immediately above and below the K edge respectively. The values of attenuation coefficients at different energies were taken from the literature (Hubbell 1982) and a graph of attenuation coefficients versus energy is plotted for all the elements investigated. Then the values of μ_+ and μ_- were read from this graph corresponding to the K absorption edge.

3. Errors and Corrections

Sufficiently thin foils were used in the present work, which will not only avoid the absorption of fluorescent X-rays in the target fluorescer, but also reduce the effect due to bremsstrahlung and multiple scattering. The errors owing to the uncertainty in the measurement of 'source to target' and 'target to detector' distances were negligibly small. The uncertainty in setting the fluorescer foil angle was about 0.9%. The statistical errors due to count rate were negligibly small as the spectra were recorded for a sufficiently long time interval so that sufficiently large number of counts was recorded under the X-ray peak. The errors associated in evaluating the K X-ray photo peak area for most of the foils were estimated to be about 1%. The estimated errors in determining the photo peak efficiency of the detector vary from 2-4%. There was a built in provision for dead time correction in the multi channel analyzer used in the present study. The percentage of dead time correction was always kept around 2%. Thus, the overall error in the present measurements was around 4-5%.

4. Results and Discussion

Sample spectra for some selected elements were shown in Figures 1 to 3. The results of K-shell fluorescence yields obtained in the present investigation are given in Table 1. The variation of ω_K with atomic number 'Z' is shown in Fig. 5. To compare the present value with other theoretical values ω_K is plotted against atomic number Z and is shown in Fig 6. A good agreement can be seen between the present experimental values and other theoretical values.

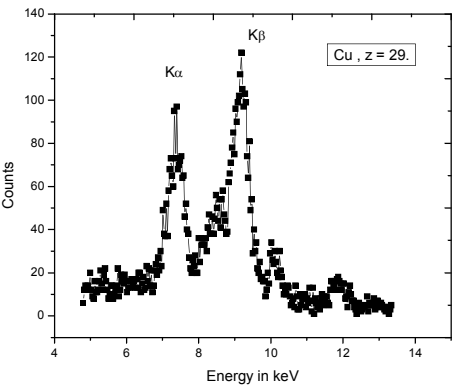


Figure 1. Spectrum of Cu

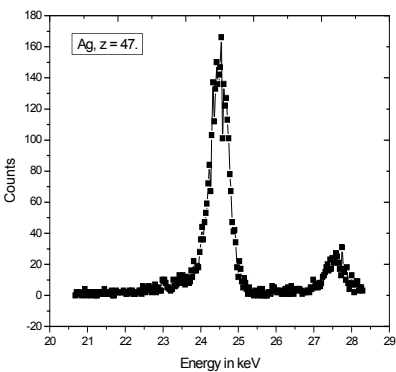


Figure 2. Spectrum of Ag

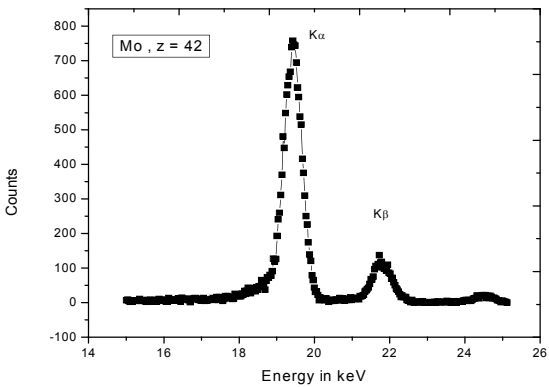


Figure 3. Spectrum of Mo

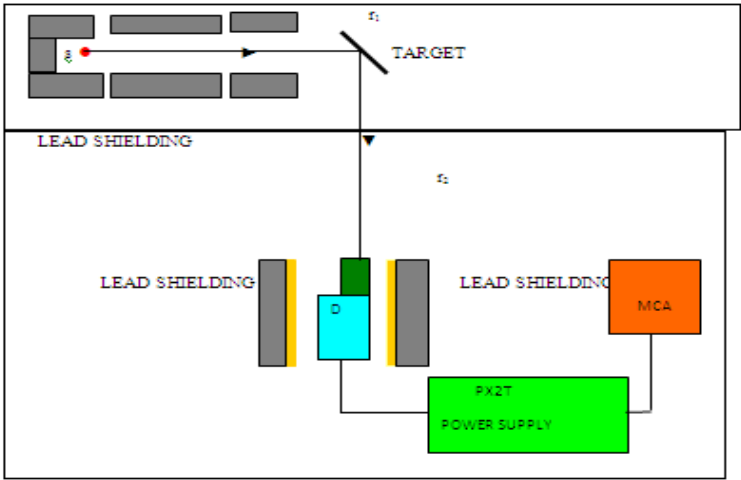
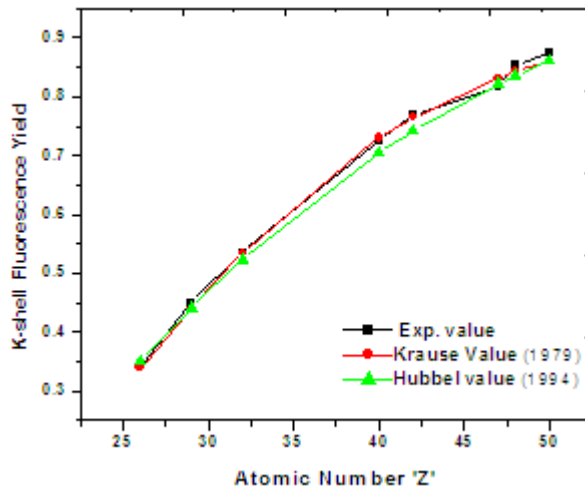


Fig .4 Geometry and shielding arrangement

Table 1. K-shell Fluorescence Yields using Si-PIN diode Detector

Element	ω_K (Present value)	ω_K (Other experimental value)	ω_K (Theory)
$_{25}\text{Fe}^{58.85}$	0.340 ± 0.013	$0.336 \pm 0.006^{(13)}$, $0.335 \pm 0.011^{(4)}$ $0.350 \pm 0.019^{(12)}$	$0.351^{(9)}$, $0.340^{(10)}$ $0.355^{(3)}$
$_{29}\text{Cu}^{63.54}$	0.450 ± 0.012	$0.448 \pm 0.010^{(1)}$, $0.440 \pm 0.018^{(2)}$ $0.425 \pm 0.021^{(12)}$, $0.452 \pm 0.003^{(6)}$ $0.443 \pm 0.020^{(11)}$	$0.441^{(9)}$, $0.440^{(10)}$ $0.454^{(3)}$
$_{32}\text{Ge}^{72.59}$	0.536 ± 0.013	$0.529 \pm 0.010^{(8)}$, $0.538 \pm 0.029^{(12)}$ $0.549 \pm 0.011^{(7)}$, $0.532 \pm 0.0164^{(5)}$	$0.523^{(9)}$, $0.535^{(10)}$ $0.546^{(3)}$
$_{40}\text{Zr}^{91.22}$	0.723 ± 0.012	$0.700 \pm 0.028^{(2)}$, $0.725 \pm 0.390^{(4)}$	$0.705^{(9)}$, $0.730^{(10)}$ $0.734^{(3)}$
$_{42}\text{Mo}^{95.94}$	0.769 ± 0.011	$0.746 \pm 0.041^{(1)}$, $0.740 \pm 0.01^{(11)*}$ $0.804 \pm 0.032^{(2)}$, $0.758 \pm 0.043^{(12)}$ $0.792 \pm 0.013^{(6)}$, $0.768 \pm 0.036^{(11)}$	$0.742^{(9)}$, $0.765^{(10)}$ $0.767^{(3)}$
$_{47}\text{Ag}^{107.87}$	0.817 ± 0.013	$0.843 \pm 0.046^{(1)=}$, $0.856 \pm 0.025^{(8)}$ $0.857 \pm 0.034^{(2)}$, $0.861 \pm 0.072^{(4)}$ $0.836 \pm 0.040^{(11)}$	$0.822^{(9)}$, $0.831^{(10)}$ $0.831^{(3)}$
$_{48}\text{Cd}^{112.40}$	0.853 ± 0.013	$0.874 \pm 0.048^{(1)}$, $0.856 \pm 0.075^{(4)}$ $0.853 \pm 0.013^{(6)}$	$0.836^{(9)}$ $0.843^{(10)}$
$_{50}\text{Sn}^{118.69}$	0.875 ± 0.013	$0.854 \pm 0.047^{(1)}$, $0.872 \pm 0.025^{(8)}$ $0.890 \pm 0.036^{(2)}$, $0.874 \pm 0.013^{(6)}$ $0.861 \pm 0.041^{(11)}$	$0.861^{(9)}$, $0.862^{(10)}$ $0.860^{(3)}$

Fig. 5. Variation of ω_K with Atomic number (Z)

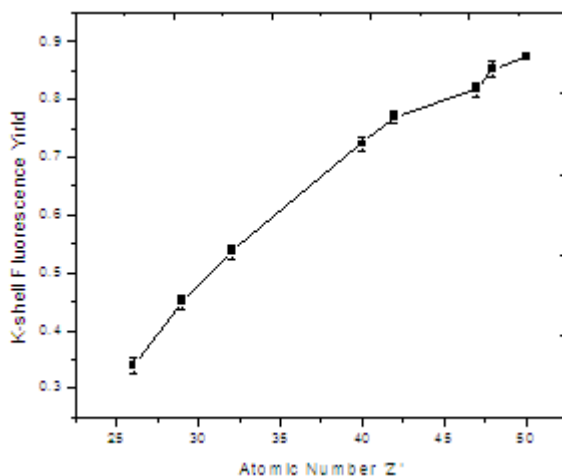


Fig. 6. Comparison of ω_K with Theoretical values

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