Measurement of K – shell x-ray intensity ratios in compounds of Barium

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Abstract. Intensity ratios of K X-rays generated by 59.6 keV gamma rays from Am-241 radioactive isotope are determined for Barium in two of its compounds using a high efficiency HpGe detector. The experimental results were compared with those of earlier investigators and theoretical estimates.

1. Introduction
X-ray intensity ratios have extensive applications in various areas of Physics and most predominantly in atomic, nuclear, molecular, radiation and health physics. An accurate knowledge of these ratios is very important in XRF techniques used for elemental analysis. Using these ratios, physical factors like the L/K electron capture ratio and photoionisation cross-section can be determined. They also find important applications in dosimetry, medicine and other irradiational processes. The measurement of these ratios is also important because, by comparison with theoretical predictions based on atomic models which stem from various inherent assumptions, there is a possibility of testing the validity of these models.

A large number of investigations dealing with evaluation of K X-ray intensity ratios for different elements have been reported earlier in the literature. The measured values were compared with theoretical evaluations based on Hartree-Fock theory and Hartree-Slater theory. The $K_\beta/K_\alpha$ yield ratio is essentially related to atomic potential. In the absence of multiple ionization of the target atom, the value of $K_\beta/K_\alpha$ is expected to be constant irrespective of the source of excitation used to create the vacancies in the K shell[1]. However in a number of recent studies, it has been demonstrated that the value of $K_\beta/K_\alpha$ depends on the method of X-ray generation [2-5] and chemical state of targets [6].

In the present investigations, X-rays are generated by exciting the samples using an intense source of gamma photons. Since efficiency plays an important role in the determination of fluorescent ratios, a detector whose efficiency characteristics are constant over a wide energy region is selected for the present investigations. A HpGe detector with constant efficiency characteristics is employed to study the variations in the value of $K_\beta/K_\alpha$ intensity ratios of Barium in two of its compounds namely Barium Sulphate and Barium Carbonate.
2. Theory
In the present studies, X-ray intensity ratios were calculated using the following relation

\[ \frac{I_{K_i}}{I_{K_j}} = \frac{N_{K_i} \beta_{K_i} \epsilon_{K_i}}{N_{K_j} \beta_{K_j} \epsilon_{K_j}} \]

where \( i \) and \( j \) corresponds to either \( \alpha \) or \( \beta \), \( N_{K_i} \) and \( N_{K_j} \) are the counts observed under the peaks corresponding to \( K_i \) and \( K_j \) peaks respectively, \( \beta_{K_i} \) and \( \beta_{K_j} \) are the target self – absorption correction factors and \( \epsilon_{K_i} \) and \( \epsilon_{K_j} \) are the efficiencies of the detector for the \( K_i \) and \( K_j \) series of X-rays.

The value of \( \beta_{K_i} \) is calculated using the formula

\[ \beta_{K_i} = \frac{1 - \exp\left[-\frac{\mu_{inc}}{\cos\theta_1} \left( \frac{\mu_{inc}}{\cos\theta_1} + \frac{\mu_{K_i}}{\cos\theta_1} \right) \right]}{\left( \frac{\mu_{inc}}{\cos\theta_1} + \frac{\mu_{K_i}}{\cos\theta_1} \right) t} \]

where \( \mu_{inc} \) is the mass attenuation coefficient of the sample at incident energy, \( \mu_{K_i} \) is the mass attenuation coefficient of the sample at the emitted \( K_i \) X-ray energy, \( \theta_1 \) is the angle made by the incident photon with the normal to the target surface, \( \theta_2 \) is the angle made by the emitted photon with the normal to the target surface and \( t \) is the mass thickness of the sample.

3. Experimental set up
The experimental arrangement employed for present studies is shown in Fig. 1. It consists of an HpGe detector and an electronic system to process the pulses and provide digital data for storage and analysis. The equipments included under the head of electronic system are a pre-amplifier, a spectroscopy amplifier, a multi channel analyzer and a personal computer. Photons from an annular source of \(^{241}\)Am are allowed to fall on the sample under investigation. These photons initiate the inner shell ionization process. The characteristic X-rays emitted as a result of filling up of vacancies in the inner shells by electrons from higher shells, are detected by the HpGe detector. The detected photons produce electronic pulses which are initially amplified by a pre-amplifier. The pulses thus amplified are processed by a spectroscopy amplifier and the output is passed on to a Multi channel analyzer (MCA). The MCA finally provides digital data for storage and further analysis. The digital data is analysed using a Quantitative X-ray Analysis System (QXAS) software package.

The effective incident photon flux (\( I_{G\epsilon} \)) over a wide energy range is determined and is plotted as shown in Fig - 2.
4. Results and Conclusions:
Since the term $I_0 \varepsilon$ is constant over the required energy range, the present experimental method eliminates the estimation of efficiencies of the detector for $K_\alpha$ and $K_\beta$ X-rays. K X-ray intensity ratios of Barium were determined in two of its compounds namely Barium Sulphate and Barium Carbonate and the results are as shown in table – I.

| Compound   | Present work      | Sogut [7]      | Scofield [8] | Scofield [9] |
|------------|-------------------|----------------|---------------|---------------|
| BaSO$_4$   | 0.2307±0.0058     | 0.2365±0.019   | 0.237         | 0.243         |
| BaCO$_3$   | 0.2331±0.0058     | -              | 0.237         | 0.243         |

The results are presented with an experimental accuracy of 2.5%. For Barium Sulphate, the results are in agreement with the earlier experimental values of Sogut[7] within the experimental errors. However the values deviate with the theoretical estimates of Scofield[8,9] by 0.2% and 2.7% respectively. The intensity ratios of Barium determined in Barium Carbonate deviates with the theoretical values of Scofield[9] by 1.7%. These deviations are very minor to state that there is a necessity to determine X-ray intensity of elements in compound form.

References

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