Charge state distribution of projectile ions inside the solid target using K-shell ionization cross-section

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Introduction

The subject of charge changing processes in an ion-atom collision is highly important and has been investigated in the laboratory with the availability of the accelerators in the laboratory since the 1950's. A significant difference of ionization in gas and the solid target was measured away from the target using a charge analyser [1] and vital role inside a target was put through a model associating the Auger processes which occur after the ions leave the solid [2]. Nevertheless, any direct measurement of the ionization phenomena inside the target was not possible to date. In this study, an experimental investigation on the charge state distribution measurement of the projectile ions inside the target with the help of the K-shell ionization cross-section measurements is demonstrated.

Experimental details

The experiment was performed in atomic physics beam line of 15 UD Pelletron witch is situated at Inter-University Accelerator Centre, New Delhi (India). *Si* ion beam of charge state 8+ (energy 84, 90, 98, 107 MeV) and charge state 12+ (118, 128, 140 MeV) was obtained from Pelletron to bombard the natural *Cu*, *Zn*, and *Ge* targets. The vacuum of the order of 10^{-6} was maintained in the chamber using turbo-molecular pump. Two silicon surface barrier detector were placed at ±7.5° with respect to beam direction to normalize the charge. A Si(Li) solid state detector was placed outside the chamber at 125° with respect to beam direction and distance of 170 mm from the target. A collimator of 5mm diameter was placed in front of the detector inside the chamber. The thickness of the Mylar window of the chamber for the detector was 6 μm. The specification of the detector (ORTEC, Oak Ridge, Tennessee, USA) is as follows: thickness 5 mm, diameter 10 mm, the thickness of Be window 25 μm and energy resolution 200 eV for $Mn\ K_\alpha$ x-rays. The data was acquired using a PC based software CANDLE developed at IUAC.

Result and Discussion

K x-ray production cross-section (σ_K^x) is related to the K shell ionisation cross-section (σ_K^I) by the relation;

$$\sigma_K^x = \omega_K \sigma_K^I. \qquad (1)$$

The measured σ_K^I are compared with the predictions of the ECUSAR [3] theory including simultaneous multiple ionization (SMI) effects through ω_K. With a great surprise, we see that the measured σ_K^I are at least a factor 2 higher than the ECUSAR predictions. The higher experimental ionization probability than the theoretical prediction provides a clear indication that the direct ionization including SMI is not at all enough to explain the K-shell ionization phenomenon in the present experimental conditions and another parallel

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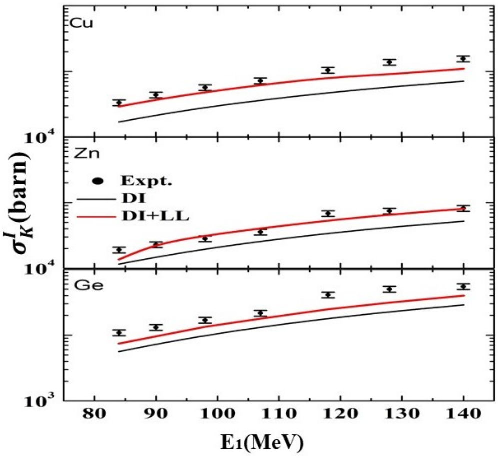

FIG. 1: Comparison of experimental K-shell ionization cross-sections with the ECUSAR (DI) and the sum of the ECUSAR (DI) and K-K capture cross-section (EC) predictions for different targets bombarded by the ^{28}Si ions are given as function of ion-beam energies.

K-shell ionization process must be involved. Such a possibility can arise from K-K electron capture phenomena. It can only be feasible if the K-shell of the projectile is either fully or partially vacant, i.e., for this case, Si^{13+} and Si^{14+} must be present inside the target. If such condition is met, the target K-electron may be captured by the vacant K-shell of the projectile ions and then the K-shell ionization of the target atoms will include the K-K capture process along with the direct Coulomb ionization.

To calculate the K-K electron capture cross-sections we have used the theory of Lapicki and Losonsky [4] which is based on the Oppenheimer-Brinkman-Kramers (OBK) approximation with binding and Coulomb deflection corrections at low velocities. Due to certain CSD inside the target, effective capture contribution will be $F(q) \times \sigma^{OBK}_{2K\to K}(\theta_K)$, for q = 13 and 14. Here $F(q)$ is the charge state fraction for a specific q. To obtain the $F(q)$, in the first step, we have used the following Fermi gas model based empirical formula for evaluating mean charge state (q_m) inside the target

$$q_m = Z_1(1 - \frac{v_F}{v_1}) \qquad (2)$$

where Z_1 and v_F are the projectile atomic number and Fermi velocity of target electrons, respectively. In second step, the q_m-values inside the target are substituted in the Lorentzian charge state distribution to obtain the F(q) as follows

$$F(q) = \frac{1}{\pi}\frac{\frac{\Gamma}{2}}{(q-q_m)^2 + (\frac{\Gamma}{2})^2} \text{ and } \sum_q F(q) = 1 \qquad (3)$$

where distribution width Γ is taken from Novikov and Teplova [5]. At this instance, the excitation function curve of the sum of direct and K-K capture cross-sections almost overlie on the corresponding experimental cross-sections.

Conclusion

The sum of these theoretically calculated direct ionization cross-section and K-K capture cross-section represent pretty well the experimentally measured values. Hence, in this study, we have not only succeeded in measuring the charge state distribution inside the targets but also found a suitable empirical formula, which could be utilized to estimate the theoretical charge state distributions inside the target materials.

Acknowledgments

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