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Measurement of L X-Ray Production Cross-Sections of Au, Ho, Bi and K-X-Ray Cross Sections of Nb, Sn, Sb by Using Protons of Energy 4 MeV

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Abstract

L X-ray production cross-sections for the elements Au, Ho, Bi and K X-ray production cross-sections for the Nb, Sn, Sb have been measured using proton beam of energy 4MeV. The experimentally measured cross sections using PIXE (Proton Induced X-ray Emission) and RBS (Rutherford Backscattering Spectrometry) have been compared with the values obtained by the theoretical predictions of ECPSSR model and they are in agreement within an experimental error of 10%.

Keywords: PIXE, RBS, protons, X-ray production cross sections, FOTIA.

1. Introduction

As is well known X-ray emission is a phenomenon whereby atoms when bombarded by charged particles or electromagnetic radiation gives the elemental signature of the target. The potential of X-ray emission studies are well known [1-3]. Compared to X-ray excitation (X-ray fluorescence) the product of beam intensity and

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cross section of X-ray production being larger, Proton Induced X-ray Emission (PIXE) technique has a higher sensitivity [4]-meaning that for protons the variation of X-ray production cross section is higher for low Z as compared to higher Z. Also the beam flux being larger for protons the sensitivity which takes into account the X-ray cross section and beam flux is higher especially for low Z as compared to higher Z. The X-ray spectra measured routinely in PIXE consists mainly of K and L X-rays whose intensities are proportional to the concentration of the elements of the sample. However one of the most essential factors used to quantitatively compute the concentration of an element is the production cross section of the considered X-ray line. We have measured L X-ray production cross sections of Au, Bi, Ho and K X-ray production cross sections for Nb, Sn and Sb. These results are compared with the Energy-Loss Coulomb-Repulsion Perturbed-Stationary-State Relativistic Theory (ECPSSR). The ECPSSR theory accounts for the projectile energy loss (E) and Coulomb deflection (C) as well as the perturbed-stationary-state (PSS) and relativistic (R) effects in the treatment of target inner shells. It is the most recent theory for dealing with cross section calculations [5, 6]. Most of the measurements of X-ray production cross sections carried out previously are with protons of energy 2-3 MeV [7, 8]. Very few measurements are with a proton beam of 4 MeV energy.

We present here the experimental method and the results of X-ray production cross sections measured with protons from the recently commissioned Folded Tandem Vandegraaff Accelerator (FOTIA) at BARC, Trombay, Mumbai [9, 10].

2. Experimental

LX-ray production cross sections of Au (0.1 mil thin) and Au (0.5 mil thin), Bi and Ho and K X-ray production cross sections of Nb, Sn and Sb were measured with protons of energy 4 MeV with Folded Tandem Accelerator (FOTIA) at BARC, Trombay, Mumbai. Thin targets Ho, Bi, Nb, Sn and Sb of 200 ug/cm2 thickness on carbon backing of 25 ug/cm2 were prepared by resistive heating evaporation technique. They were placed on aluminum holders which were then mounted on an aluminum ladder. The ladder was then housed inside a PIXE chamber which was maintained at a vacuum of 10^{-6} mm of Hg by a turbo molecular pump. X-ray spectra were collected simultaneously with the protons elastically scattered from the targets by a surface barrier detector. Characteristic X-rays were detected using a Si (Li) detector with Be window of thickness 25.4 μm and an energy resolution of 170 eV at 5.9 KeV. The detector with an active area of 30 mm^2 was mounted inside the chamber perpendicular to the beam axis (Fig. 1). A Mylar film of 0.3 micron was positioned in front of the detector, which separated the chamber from vacuum and air. Protons elastically scattered from the target were detected with a silicon surface barrier detector positioned at an angle of 155° relative to the beam direction.

3. Results and discussion

In Fig. 1, we give the experimental setup of X-ray cross section measurement by PIXE. In Fig. 2a and 2b, we give the L X-ray spectrum of Au and RBS spectrum of Au target 3a and 3b are PIXE spectrum of Bi and the RBS spectrum of Bi target. The L X-ray cross sections σ_{Lx} were determined from the X-ray yields, by normalization to the measured proton backscattered intensity and using the following equation.

$$\sigma_{LX} = \frac{4\pi Y_X \sigma_{RBS} \Omega_{RBS}}{Y_{RBS}\, \varepsilon\, \Omega_X}$$

Where Y_x and Y_{RBS} is the X-ray and backscattered proton intensities, ε is the detector efficiency for respective elements. Ωx and Ω_{RBS} are detector solid angles for X-ray and protons, σ_{RBS} is the differential elastic scattering cross section.

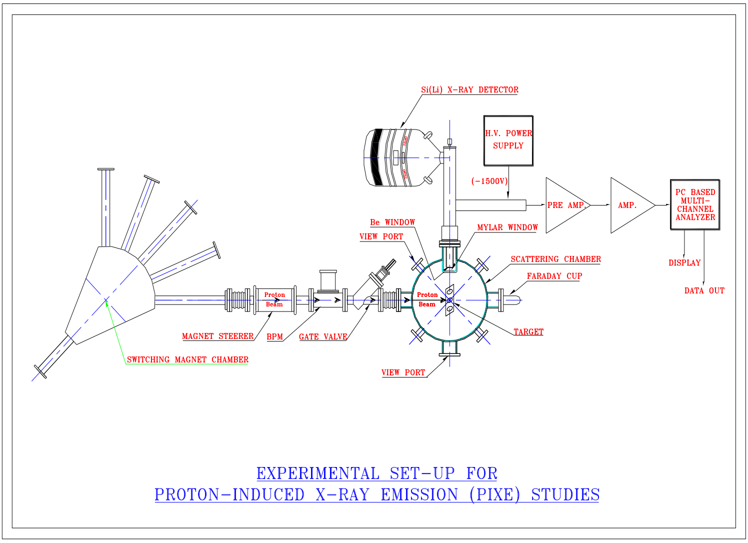

Fig. 1. Experimental set up for PIXE for X-ray cross section measurements.

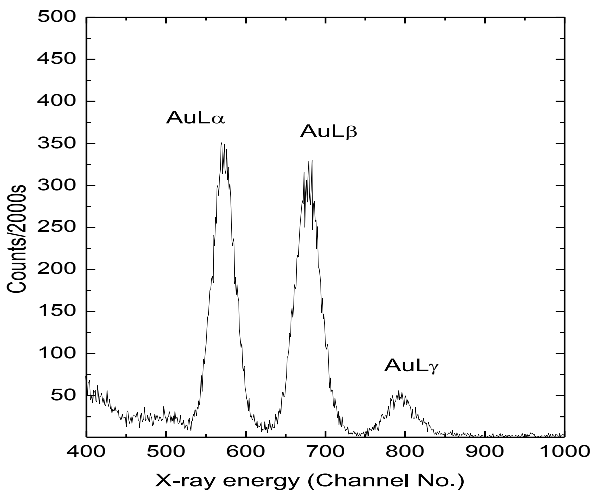

Fig. 2a. L x-ray spectrum of thin gold foil

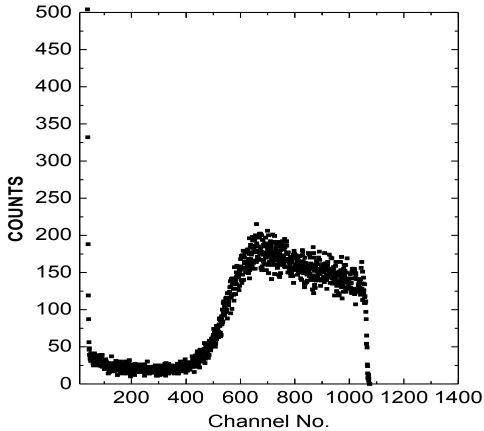

Fig. 2b. RBS spectrum of a thick gold foil

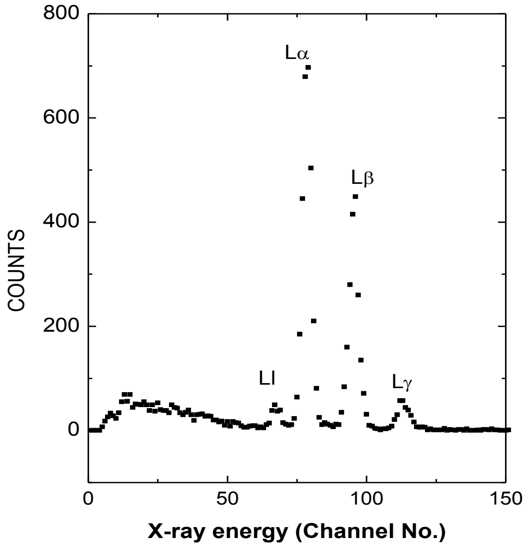

Fig. 3a. L X-ray spectrum of Bi target

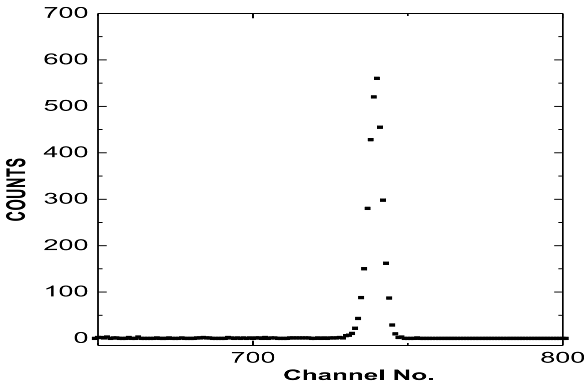

Fig. 3b. RBS spectrum of Bi target

Each X-ray spectrum was collected for a time of 2000 seconds. Table 1 gives the values for L X-ray production cross section for Au thin (0.1 mil) as well as thick targets (0.5 mil), Bi and Ho targets and the K X-ray production cross sections for Nb, Sn and Sb targets. It is seen that the target number dependence for the cross sections follow a similar trend in all cases.

Element	Z	X-ray energy (keV)	σ_{expt} (barns)	σ_{theor} (barns)
Ho	67	6.7	254.12±0.05	284
Au (thin)	79	9.7	103.53±0.018	111
Au (thick)	79	9.7	51.52±0.015	61
Bi	83	10.83	1.387±0.011	1.5
Nb	41	16.6	23.74±0.018	18
Sn	50	25.27	1002±0.01	1167
Sb	51	26.35	985±0.033	1026

Table 1: X-ray production cross sections by protons of energy 4MeV

4. Conclusion

It is seen that our experimental measurements for cross section deviate from the theoretical predictions of ECPSSR by about 10%. With proton energy of 4 MeV, it was possible to measure X-ray cross sections for the above mentioned elements, which is reported for the first time experimentally.

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