

L₃ sub-shell X-ray production cross sections for ⁷⁶Os at incident photon energies 10.9-12.7 keV using synchrotron photoionization method

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Abstract— The X-ray production cross sections for L₃ sub-shell X-rays L_k (k=1, α, β₆, β_{2,5,7,15}) have been measured at different incident photon energies ranging 10.9-12.7 keV for ⁷⁶Os using synchrotron radiation induced photoionization method in order to check the reliability of the IPA models at these incident photon energies. The measured values have been compared with the theoretical set of values calculated using the non-relativistic Hartree-Fock-Slater (HFS) model based photoionization cross sections [6] tabulated by Scofield (1973), the Dirac-Fock (DF) model based X-ray emission rates [7] provided by Campbell and Wang (1989), and the Dirac-Hartree-Slater (DHS) model based fluorescence (ω_i) and Coster-Kronig (f_{ij}) yields [8] tabulated by Puri et al (1993). The present measured L_k (k=1, α, β₆, β_{2,5,7,15}) X-ray production cross sections for ⁷⁶Os at different incident photon energies ranging 10.9-12.7 keV exhibit significant differences with the theoretical set values.

Index Terms— Synchrotron radiation, X-ray production cross sections.

I. INTRODUCTION

The measurements of X-ray production (XRP) cross sections are important for a variety of applications in the field of atomic and radiation physics including radiation shielding, radiation dosimetry, medical diagnosis and therapy, and elemental composition analysis using X-ray emission techniques (EDXRF and PIXE). The XRP cross sections can be evaluated from the physical parameters, namely, the X-ray emission rates, the photoionization cross sections, fluorescence and Coster-Kronig (CK) yields. There are numerous reports on experimental and theoretical investigations of the photon induced L-shell X-ray production cross sections available in literature. Most of these reports pertain to measurements of the L_i (i=1-3) sub-shell X-ray

production cross sections at incident photon energies much above the L_i (i=1-3) sub-shell absorption edge energies [2]-[5] performed to test the reliability of the IPA models [1]. However, to the best of our knowledge similar investigations at incident photon energies in vicinity of the L_i (i=2, 3) sub-shell ionization threshold of heavy elements are not available in literature.

In the present work, the cross sections for production of the L_k (k=1, α, β₆, β_{2,5,7,15}) X-rays from L₃ sub-shell vacancies have been measured at incident photon energies ranging 10.9-12.7 keV, just above the L_i (i=2,3) sub-shell ionization thresholds of ⁷⁶Os employing synchrotron radiation induced photoionization method. The measured values have been compared with the theoretical set of values calculated using the non-relativistic Hartree-Fock-Slater (HFS) model based photoionization cross sections[6], the Dirac-Fock (DF) model based X-ray emission rates [7], and the Dirac-Hartree-Slater (DHS) model based fluorescence (ω_i) and Coster-Kronig (f_{ij}) yields [8].

II. EXPERIMENTAL DETAILS

The present measurements were performed using the micro-focus X-ray fluorescence beam-line (BL-16) of INDUS-2 synchrotron radiation facility. The salient features of beam-line BL-16 and details of the X-ray fluorescence (XRF) setup are described elsewhere [9]. The electron storage ring at INDUS-2 was operated at 2.53 GeV with a nominal current of 100 mA. A Si (111) double crystal monochromator (DCM) capable of tuning the photon energy in the range 4-15 keV with energy resolution $\sim 10^{-3}$ - 10^{-4} was used to obtain a monochromatic photon beam of desired energy on the sample position. The size of the X-ray beam at the target position was controlled using JJ slit having size $\sim 800 \mu\text{m}$ (H) \times $200 \mu\text{m}$ (V). The target holder was placed at 45° with respect to the incident beam direction. The monochromatic beam was allowed to pass through an ionization chamber (aperture size: 10 mm \times 6 mm; FMB OXFORD, UK) before reaching the target in order to monitor the incident photon beam intensity (I₀). The Vortex-EX90 silicon drift detector (50 mm² \times 350 μm , FWHM \sim 140 eV at 5.89 keV, Be window thickness \sim 1 mil, SII Nano Tech. Inc., USA) coupled to a digital pulse processor

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(XIA LLC, USA) was placed at 90° with respect to the incident beam direction to detect emitted X-rays. Spectroscopically, thick pressed pellet (1 inch diameter) of ^{76}Os having mass thickness 193 mg/cm² procured from Sigma-Aldrich was used as the target. The L X-rays were excited using monochromatic X-ray beam by varying its energy in small steps over the range 10.9-12.7 keV just above its L₂ ionization threshold (12.395 keV) and L₃ ionization threshold (10.882 keV) energies of ^{76}Os . Typical L X-ray spectrum recorded using a ^{76}Os target at 10.900 keV incident photon energy (E_{inc}) is shown in Fig. 1

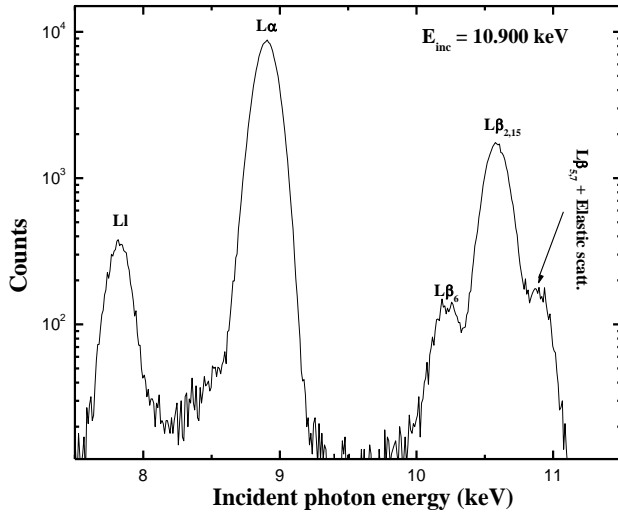


Fig. 1: A typical spectrum of ^{76}Os target at 10.900 keV incident photon energy depicting the L₃ sub-shell fluorescent X-rays.

III. EVALUATION PROCEDURE

The experimental L_k (k=1, α, β₆, β_{2,5,7,15}) X-ray production (XRP) cross sections, $\sigma_{Lk}(exp)$, at different incident photon energies (E_{inc}) have been evaluated using the relation

$$\sigma_{Lk}(exp) = N_{Lk} / (I_0 G \epsilon_{Lk} \beta_{Lk} m)$$

where N_{Lk} represents the counts per unit time under the L_k photo-peak, $I_0 G$ is the incident photon intensity falling on the area of the target visible to the detector, ϵ is the detector efficiency at the L_k X-ray energy, m is the mass thickness (gm/cm²) of the target and β_{Lk} is the self-absorption correction factor which accounts for the absorption of incident and emitted photons in the target.

The values of self-absorption correction factor (β_{Lk}) have been evaluated as explained in our earlier reference [2]. In these evaluations, the values of mass-attenuation coefficients for the incident and emitted X-rays were taken from the computer code XCOM [10]. Each spectrum was analyzed for peak areas, N_{Lk} , using software package ORIGIN 6.0 in which a non-linear least squares fitting routine based on chi-square minimization using Marquardt's algorithm [11] has been implemented. The peak fitting for different L X-ray spectra were performed as explained in our earlier references [2, 4, 5, 12]. The

product $G\epsilon$ was determined as explained in our earlier reference [12] by measuring the K X-ray yields excited by 13 keV incident photons from self-supporting thick pressed pellets (1 inch diameter) of ZnS, GeO₂, Se, As₂O₃ and metallic foils of Ti, Co, Fe, Ni, Cu in the same geometrical set up. In these evaluations, the theoretical values of the K X-ray production (XRP) cross sections, $\sigma_{K\alpha}^x$, were taken from reference [13].

The current status of different L_i (i=1-3) sub-shell physical parameters, namely, the photoionization cross sections, X-ray emission rates, fluorescence and CK yields, required to evaluate XRP cross sections / intensity ratios has been discussed in our earlier reference [14]. In the present work, experimental XRP cross sections have been compared with the theoretical set values of the L_k (k=1, α, β₆, β_{2,5,7,15}) XRP cross sections, $\sigma_{Lk}(Thr.)$, which have been calculated using the non-relativistic Hartree-Fock-Slater (HFS) model based photoionization cross sections[6], Dirac-Fock (DF) model based X-ray emission rates[7], the Dirac-Hartree-Slater (DHS) model based fluorescence (ω_i) and Coster-Kronig (f_{ij}) yields [8].

IV. RESULTS AND DISCUSSIONS

The present measured L_k (k=1, α, β_{2,5,6,7,15}) XRP cross sections, $\sigma_{Lk}(exp)$, have been compared with theoretical set values, $\sigma_{Lk}(Thr.)$, by plotting the ratios [$\sigma_{Lk}(exp)/\sigma_{Lk}(Thr.)$] as a function of incident photon energies over the range 10.9-12.7 keV in Fig. 2. The overall error in the present measured cross sections is estimated to be 6-9% and is obtained as quadrature sum of the uncertainties in different parameters used to evaluate these cross sections, namely, the evaluation of photo peak areas (1-4%), I₀Gε product (~5-7%), target thickness (< 2%) and in the absorption correction factor (<4%).

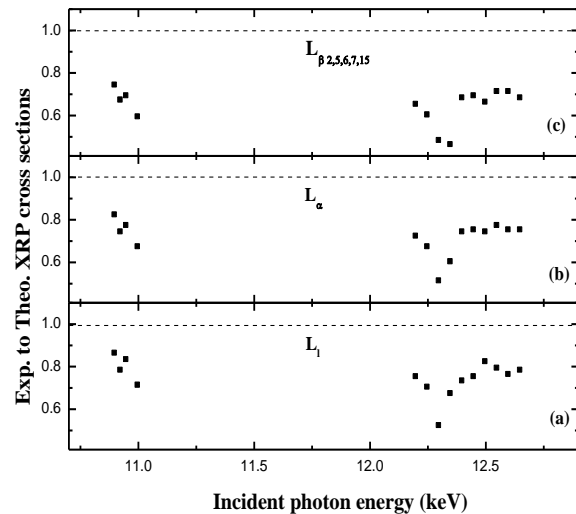


Fig. 2: A plot of ratios of the present measured (a) the L1 (b) the Lα (c) the Lβ_{2,5,6,7,15} XRP cross sections to the theoretical values [$\sigma_{Lk}(Th.)$; k = 1, α, β_{2,5,6,7,15}] for ^{76}Os as a function of incident photon energy.

The present measured cross sections, $\sigma_{Lk}(\text{exp})$, L_k ($k=1, \alpha, \beta_{2,5,6,7,15}$) from the decay of L_3 sub shell vacancies of ${}_{76}\text{Os}$ are found to be, on average, lower by up to 54% of the theoretical values $\sigma_{Lk}(\text{Thr.})$ at energies ranging $E_{L3} < E_{\text{inc}} < E_{L2}$ and about 34% at energies ranging $E_{L2} < E_{\text{inc}} < E_{L1}$ (Fig. 1). The present measured L_k ($k=1, \alpha, \beta_{2,5,6,7,15}$) XRF cross sections, $\sigma_{Lk}(\text{exp})$, for ${}_{76}\text{Os}$ at different incident photon energies ranging 10.9-12.7 keV in vicinity of the L_i ($i=2,3$) ionization threshold energies exhibit significant differences with theoretical values, $\sigma_{Lk}(\text{Thr.})$.

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