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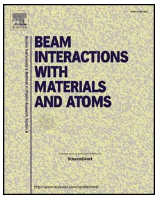
BEAM INTERACTIONS WITH MATERIALS AND ATOMS

Employing X-ray absorption technique for better detector resolution and measurement of low cross-section events

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ABSTRACT

The versatility of X-ray absorption technique is experimentally employed for enhancing the detector resolution and to rejuvenate the low probable transitions obscured in the pile-up region, during a beam-foil spectroscopy experiment. The multiple aluminum absorber layers (10 µm each) are used to suppress the pile-up contribution drastically and to restore a weak transition which is about 1.38×10^4 times weaker than a one-electron-one-photon transitions viz. K_α and K^h_α. The weak line is possibly originating from a two-electron-one-photon transition in He-like Ti. Further, the transitions, which were obscured in the spectra due to high intensity ratio, are revived by dissimilar line intensity attenuation using this technique. The measured lifetimes of K_α line with and without intensity attenuation match well within error bar. The present technique finds potential implications in understanding the structure of multiple-core-vacant ions and other low cross section processes in ion-solid collisions.

1. Introduction

The formation of two K-shell vacancies either in the target atoms or the projectile ions is often seen in the energetic heavy ion-solid collisions [1]. These two vacancies are mostly filled sequentially by emitting a $K_{\alpha h}$ or $K_{\beta h}$ (hypersatelite) line and another K_α or K_β line [2]. However, there is a small probability that the two vacancies can be filled simultaneously by two electrons resulting in an emission of a single photon of nearly twice the energy of K_α or K_β [2–5] line. Therefore, the signature of the two-electron-one-photon (TEOP) transitions ($K_{\alpha\alpha}$, $K_{\alpha\beta}$) is mostly buried in the spectral region affected by the pile-up phenomenon. Several pile-up rejection techniques such as pulse shape discrimination [6], pile-up rejection circuits, reduction of the counting rates [7–9], and use of selective filters [10–14] are well known. The relative yield for $K_{\alpha\alpha}/K_\alpha$ is of the order of 10^{-4} in Ar atom [15]. This ratio improves for the lighter atoms and deteriorates further for the heavier atoms [3]. Therefore, the detection of such processes requires sufficiently high **count** rate of TEOP transitions, which can be enhanced by increasing the number of incident ions. However, this will further increase the one-electron-one-photon (OEOP) transition count rate leading to more pile-up events in the spectrum. As a solution, the techniques capable of handling high counting rates and elimination of pile-up simultaneously, can only be used for such experiments. Nevertheless, the commonly used electronic techniques [7–9] cannot completely reject the pile-up contributions. Rate of pile-up rejection depends on $n^2\tau$, where n is the true counting rate and τ is the system dead time, which has certain limiting value. Thus, an elegant method of solving the problem requires limited event rate in the detector even though count rate is high in the experiment. The absorption technique abruptly decreases the count rate of intense X-ray transitions (which is main cause of the pile-up) on low energy side, but barely attenuates the low intensity transitions lying on the high energy side. Hence, it increases the effective count rate for the low intensity processes by decreasing the pile-up contributions to an extreme limit.

The maximum resolution of any detector is characterized by least overlapping of the peaks. This overlapping can be minimized by either, (i) increasing the spectral separation between the peaks or (ii) improving the spectral width of the transition. This overlapping depends on the intensities of the adjacent peaks and minimum for the identical intensities. Therefore, it is possible that the two transitions existing within the resolution of the detector may not be experimentally resolved. The high resolution spectroscopy method [17] help resolving them, but it requires absorber with specific K or L absorption edge. Note that such transitions can be resolved in a delayed spectrum [16] if the lifetimes of the excited levels corresponding to the different lines differ significantly. In this paper, we have used the absorption technique to validate our earlier theoretical studies (i) to improve the resolution for closely separated transitions having different intensities and (ii) to

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detect a low cross section TEOP process in the pile-up affected spectrum of a beam-foil spectroscopy (BFS) experiment [18].

2. Experiment

The present experiment was done at IUAC, New Delhi, India using the 15UD Pelletron accelerator. An ion beam of 110 MeV Ti^{8+} is allowed to pass through the carbon target of thickness 80 µg/cm^2 to create various excited states in the highly charged projectile ions. The thickness of the target was measured using the energy loss of alpha particle in the carbon target. The energy of the Ti beam was chosen to overcome the Coulomb barrier so that the X-ray of the projectile-like ions can also be produced along with the other different lines including the TEOP transition. The self-supported carbon foils prepared using the electron gun evaporation technique were further annealed at 900 K in the N_2 environment to obtain better uniformity and mechanical stability. The carbon target on an aluminum holder was mounted on a lifetime measurement assembly having translational measurement accuracy better than 1 µm, which is equivalent to a delay of 0.047 ps. The target can be moved to and fro up to a 50 mm distance along the beam axis from the detector window. Two low energy germanium X-ray detectors were placed outside the vacuum chamber at an angle of ± 90° to the beam direction. The X-ray produced at the beam-foil interaction region were collected through a 6 µm thick mylar window. The absorption of X-ray in the mylar has been taken into consideration in the calculations. A Faraday cage was used to normalize the X-ray spectra during the lifetime measurements. An electron suppressor ring at a potential of −1 kV was used before the Faraday cage to avoid the charge collection due to stray electrons for better normalization. Thin multiple layers of aluminum absorbers of 10 µm each were used in front of the X-ray detectors to attenuate the intensity accordingly. The thickness of the aluminum layers were confirmed by weighing and the energy loss method. During the experiment, the pressure of about 10^{-7} torr was maintained in the vacuum chamber. The schematic of the experimental set up used is shown in Fig. 1.

3. Results and discussions

Fig. 2 shows the X-ray spectra with different numbers of aluminum absorbers. Multiple layers of 10.0 ± 0.2 µm thick aluminum filters are used to modify the X-ray intensities. A broad peak with a hump at the pulse pile-up region is seen when absorber is not used. With increasing the number of the absorber foils, the broad peak and the peak at the pile-up region get resolved with reasonable intensities. We have also measured the intensity decay as a function of the distance upstream the beam direction.

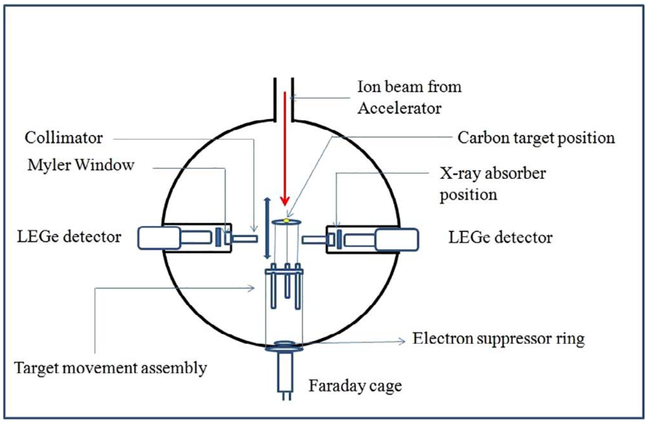

Fig. 1. The schematic of the experimental set up. The target movement assembly was used for measuring the atomic lifetimes by changing the target position with respect to the detector window.

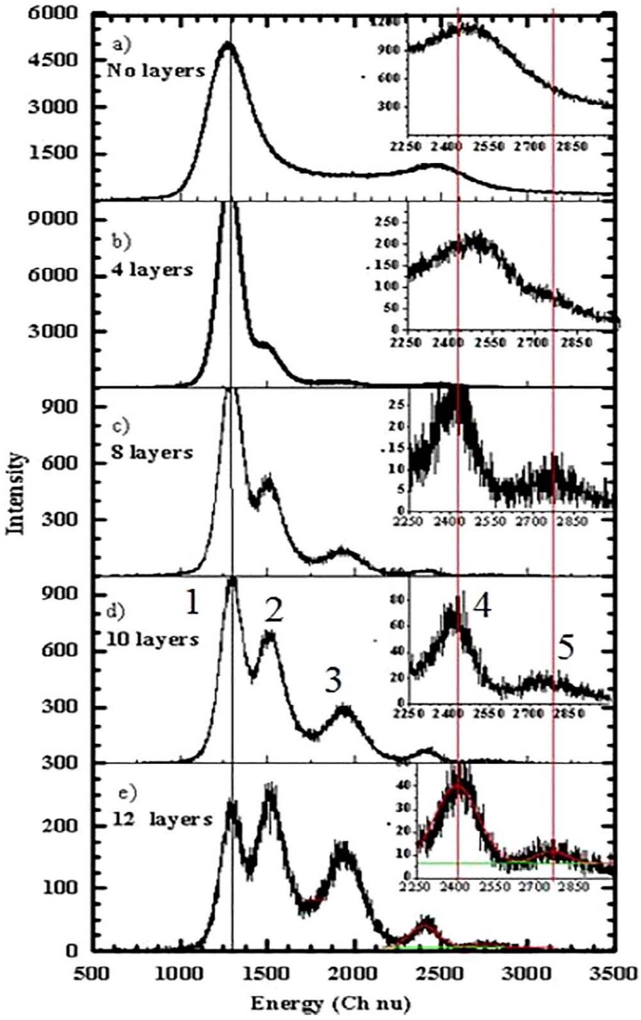

Fig. 2. The X-ray spectra with the different numbers of absorbers: Figures (a)–(e) represent the spectra taken with different numbers of Al absorber foils. The measured spectra show improved resolution with increasing total thickness of absorber foils. Peaks marked with 1, 2, 3 and 4 represent Kα, Kβ, REC and TEOP transitions of He-like Ti at 4.73 keV, 5.5 keV, 7.36 keV, 9.34 keV, respectively. The transition marked as 5 at 10.72 keV belongs also to TEOP category.

The intensities, centroid and full width at half maximum (FWHM) of the peaks are consistent with different numbers of the aluminum layers realizing that the fundamental properties have not been modified by introducing the absorbers. It is important to note that all the peaks lie within the energy range of 4–11 keV and the efficiency of the detector remains constant in this range [19]. Still we have accounted for the efficiency of the detector as well as the absorption in the air and mylar of the exit port for X-ray window. The Beer-Lambert equation for X-ray absorption is used to evaluate the original intensity in the absence of absorber. The attenuation coefficient (µ) values for the calculations are taken from National institute of standard and technology [20] and the thickness of absorber (t) is measured using the weighing method; µ and t are utilized for further calculations. The intensity correction for ten absorber layers is shown in Table 1.

As seen from Table 1, the most intense peak in Fig. 2(a) is suppressed by introducing ten layers thick Al absorber. Also, the gradual elimination of the pile-up effect is seen in Fig. 2(c)–(e). These spectra represent the real transitions taking place in the ion-solid collisions with attenuated intensities. The first two peaks observed can be assigned to K_α and K_β from He-like Ti projectile ions. Whereas the third peak is mainly due to radiative electron capture (REC), but little admixture from H-like Co ions is possible. The Hartree-Fock calculations

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خدمت به شما فرهیختگان جامعه علمی کشور، مایه سرافرازی ما در دنیا و آخرت است▯

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