Spectra of Ho Lα x rays emitted in collisions with 6 MeV/amu Heavy Ions

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It is well known that fast heavy ions provide an efficient means for creating multiple inner-shell vacancies in small impact parameter atomic collisions. In general, the presence of multiple vacancies results in a complex and mostly unresolvable multiplet structure which appears above the diagram (single vacancy) lines in the x-ray spectrum. Over the past thirty years, numerous spectroscopic investigations of Kα x-ray satellites and hypersatellites have led to a detailed understanding of the L spectator vacancy states produced in K-shell ionizing collisions. However, comparatively little work has been devoted to the spectroscopy of L x-ray satellites arising from M spectator vacancies [1-3]. This is primarily due to the fact that the multiplet structure associated with L plus M vacancy states is much more complicated than that for K plus L vacancy states. In addition, the average energy separations between the diagram lines and the L x-rays are smaller than those for the corresponding K x-ray satellites. For example, the Kα₁ transition energy in Co is 6930 eV and its energy separation from the KL⁺ satellite is 30 eV, whereas the Lα₁ transition energy in Ho is 6722 eV and its energy separation from the LM⁺ satellite is 21 eV.

In the present work, the Lα x-ray satellite structure of holmium has been examined using 6 MeV/amu C, Ne, Ar and Kr ions. Spectra for a metallic Ho target were obtained by means of a curved crystal (Johansson) spectrometer employing second order diffraction from a LiF crystal. The spectrometer energy resolution for the Ho Lα₁ line excited by 10 keV electron bombardment was determined to be 9.0 eV (FWHM). Spectra of Ho Lα x rays obtained with the three heavy ion projectiles are compared in Fig. 1. The spectra contain the single vacancy (diagram) Lα₂ and Lα₁ lines at 6679 eV and 6722 eV, respectively, and extensive satellite structure arising from Lα x-rays emitted in the presence of spectator M vacancies. The diagram lines originate from single L₃ vacancies produced both in ion-atom collisions and secondary ionization processes involving x rays and electrons. The diagram lines arising from ion-atom collisions are broadened and slightly shifted up in energy relative to those from secondary ionization. As the projectile atomic number increases, relative intensity of the ion-atom collision contribution decreases and the relative intensity of the secondary ionization contribution increases. In the spectrum obtained with Ar ions, for example, almost all of the Lα₁,2 intensity is attributable to secondary ionization.

A simplified preliminary analysis has been performed on the spectra shown in Fig. 1. In this analysis, the manifold of multiplet transitions for a specified number n of M vacancies was represented by two Voigt functions - one representing the L₃Mⁿ → M₄Mⁿ multiplet transitions (Lα₂ satellites) and one representing the L₃Mⁿ → M₅Mⁿ multiplet transitions (Lα₁ satellites). In the least-squares fitting process, the energy separation of the two peaks in each set was fixed at the diagram Lα₁-Lα₂ separation value, but the average energy of each set was allowed to vary. In addition, the intensity ratio of the two peaks in each set was assumed to be the same as that for the diagram lines and the total intensity contribution of each peak set to the spectrum was constrained to follow a binomial distribution, as predicted by the independent electron approximation. The results are shown by the thin solid curves in Fig. 1. Each contributing LMⁿ manifold is shown by a dashed curve and the secondary ionization diagram lines are shown by thick solid curves. It is evident from the fits shown in Fig. 1 that the highest contributing value
of \( n \) (the number of spectator M vacancies) is four for C ions, six for Ne ions, and nine for Ar ions. In the case of the Ar spectrum, additional components attributed to L hypersatellites (double L vacancy initial states) have been included in the fits. The fitted values of the energy centroids for the \( \text{L}_{\alpha_1} \) satellite peaks

**Figure 1.** Spectra of Ho \( \text{L}_{\alpha} \) x rays emitted under bombardment by 6 MeV/amu C, Ne, and Ar ions.
are in good agreement (within 3 eV on average) with the Dirac-Fock average of configurations energies (see preceding report) if additional energy shifts of 7 eV (C spectrum), 13 eV (Ne spectrum), and 21 eV (Ar spectrum) are assumed to be present due to N-shell vacancies.

The energy calibrations were performed by measuring the Kα x-ray spectra of Co, Ni, and Cu. These calibration spectra, which also contained the Kα satellites, provided an opportunity to compare the average probability of L vacancy production in K-shell ionizing collisions, $P_L$, with the average probability of M vacancy production in L-shell ionizing collisions, $P_M$, for atoms having similar x-ray transition energies. The average spectator vacancy probabilities were determined by dividing the average numbers of satellite vacancies (calculated from the satellite relative intensities) by the corresponding shell occupation numbers (i.e., eight for the L shell and 18 for the M shell). This comparison is shown in Fig. 2. It appears that the M spectator vacancy probability is systematically lower than the L spectator vacancy probability.

![Figure 2](image-url)  

**Figure 2.** Comparison of the average probabilities of producing spectator L- and M-shell spectator vacancies in K- and L-shell ionizing collisions, respectively, for Co, Ni, Cu and Ho.

References