**Systematics of *L* x-ray satellite spectra**

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Systematic analysis of the spectra of $K\alpha$ x rays emitted from thick solid targets under bombardment by fast heavy ions [1] has established that the apparent average fraction of $L$ vacancies at the time of $K$ x-ray emission can be described by a semiempirical function of the "universal variable" [2]. Presented here is an extension of this analysis to the spectra of $L$ x rays. The targets used in the study contained elements with atomic numbers ranging from 49 (In) to 67 (Ho).

Texas A&M's K-500 cyclotron was used to produce the beams of Ne, Ar, Kr, and Xe ions, at 6, 10, and 15 MeV/amu. Target $L$ x rays were measured in high resolution using a Johansson-type curved crystal spectrometer employing a LiF crystal. The spectra were measured in the first order of reflection.

The dependence of the spectral features on the target atomic number is illustrated in Figure 1. To facilitate comparison of the spectra, the horizontal axis has been scaled such that the $L\alpha_1$ and $L\beta_2$ energies correspond to the values of 1 and 2, respectively.

Centroids of the peaks due to $L\alpha_1$ and $L\beta_2$ diagram transitions are indicated by the vertical dashed lines. The prominent narrow peak between the two corresponds to the $L\beta_1$ diagram transitions. Peaks due to the other diagram transitions, such as $L\beta_3$ and $L\beta_4$, are hardly noticeable. The diagram transitions are a consequence of $L$-shell ionization by secondary processes [1].

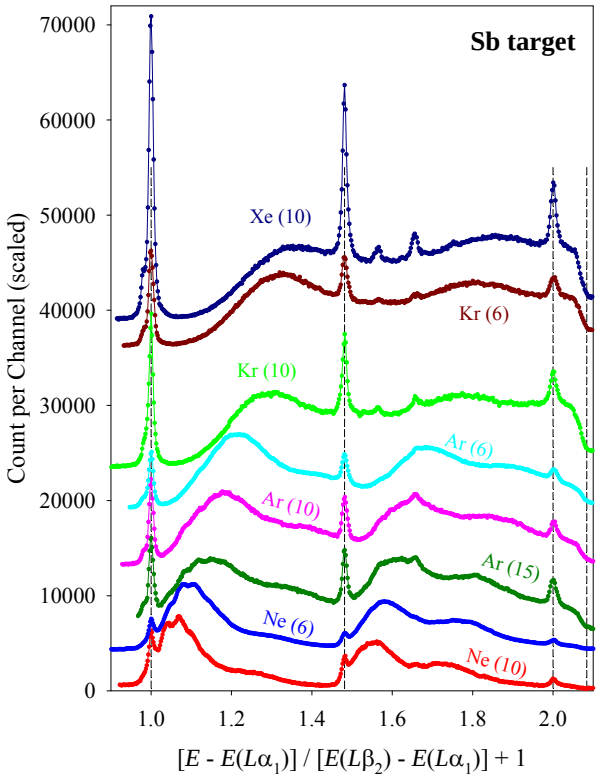


**Figure 2.** Spectra of $L$ x rays emitted from thick solid target of Sb under bombardment by fast heavy ions. The projectile species is indicated along with its energy in MeV/amu enclosed in parenthesis. The vertical dashed lines indicate, respectively, the positions of the $L\alpha_1$, $L\beta_1$, and $L\beta_2$ diagram transitions as well as the $L_3$ absorption edge (at the high-energy end).

The broad distributions on the high-energy sides of the diagram peaks, known as satellite peaks, are due to multiple $M$-shell ionization caused by the projectiles. The centroid energies of these distributions increase with the degree of $M$-shell ionization, while their widths depend mostly on the energy spread of the underlying unresolved peaks.

The degree of $M$-shell ionization at the time of $L$ x-ray emission can be described in terms of the apparent average fraction of $M$ vacancies ($p_M$). From Figure 1 it can be concluded that this parameter increases as the target atomic number decreases. Figure 2, on the other hand, shows the

dependence of the spectral features on the projectile atomic number. It is apparent that $p_M$ increases with the projectile atomic number, but decreases as the projectile energy increases. The value of $p_M$ was determined from the measured spectra in a least squares curve-fitting procedure similar to that described in ref.[3].

The dependence of the measured $p_M$ values on the universal variable [2] is given in Figure 3. The solid line in Figure 3 is a logistic curve that has been fit to the data points. It is given by

$$p_M^x = a/[1+(b/X_n)^c], \qquad (1)$$

where $a = 0.530 \pm 0.012$, $b = 1.507 \pm 0.044$, and $c = 2.15 \pm 0.12$. The standard deviation of the residuals was found to be 0.013. Chemical effects are believed to be the main cause for the deviations of the data points from the fitted curve. This assertion was supported by the results of measurements involving the same target element in different chemical states. Specifically, Sn targets were prepared in the form of a thick metallic foil, $SnO_2$, and $SnCl_2$. It was found that the variations in the values of $p_M$ determined from the spectra of Sn $L$ x rays emitted from these targets under bombardment by 6 MeV/amu Kr projectiles were comparable to the residuals shown in the insert of Figure 3.

The curve given by eq.(1) lies slightly above the one established previously [1] for the apparent average fraction of $L$ vacancies at the time of $K$ x-ray emission ($p_L$).

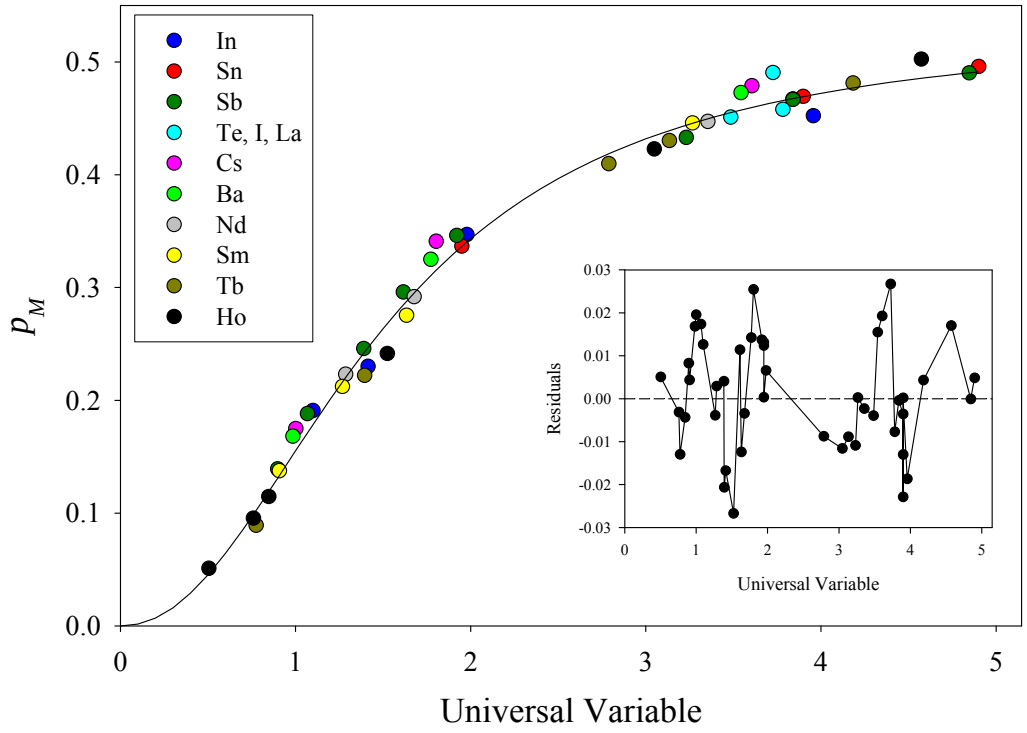


**Figure 3.** Apparent average fraction of *M*-shell vacancies at the time of L x-ray emission ($p_M$) as a function of the universal variable [2] for various targets employed in the measurements. The solid curve represents the best fit of a logistic curve to the data points. The insert shows the residuals, i.e. the deviations of the data points from the fitted curve.


[1] V. Horvat, R. L. Watson, J. M. Blackadar, A. N. Perumal, and Yong Peng, Phys. Rev. A **74**, 022718 (2006).

[2] B. Sulik, I. Kadar, S. Ricz, D. Varga, J. Vegh, G. Hock, and D. Berenyi, Nucl. Instrum. Methods Phys. Res. **B28**, 509 (1987).

[3] V. Horvat, R. L. Watson, J. M. Blackadar, A. N. Perumal, and Yong Peng, Phys. Rev. A **71**, 062709 (2005).