Kα hypersatellite x-ray energy systematics

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X rays known as the Kα hypersatellites are emitted in transitions between the 2p and 1s levels of atoms with doubly ionized K-shells. Such exotic initial states, which are only rarely produced by photoionization as a consequence of the shake-off mechanism, are of considerable interest because the energies and relative intensities of the associated hypersatellite x rays are quite sensitive to relativistic effects in general and to the Breit interaction in particular [1, 2]. In fast heavy-ion-atom collisions, the probability of double K-shell ionization is much larger than in photoionization, with the cross section for double K-vacancy production typically being 10 % or more of the cross section for single K-vacancy production. Furthermore, because the projectile must pass through the L-shell to remove one or both of the K-electrons, the simultaneous removal of multiple L-electrons is also highly probable. The net result is that the spectrum of Kα hypersatellite x-rays excited in heavy-ion-atom collisions generally displays a series of up to eight complex peaks containing the most probable transitions from initial states having two K-vacancies and zero to seven L-vacancies. In the most commonly used notation, each Kα hypersatellite peak is labeled by its associated number of initial state K- and L-shell vacancies (e.g., K^2L^0 through K^2L^7).

In the course of our recent studies of the projectile Z_1 dependence of K-vacancy production in heavy ion collisions, we have performed high resolution measurements of the Kα satellite and hypersatellite spectra of Al, Ca, Mn, and Cu [3, 4]. These new results, together with the results of previous measurements performed at Texas A&M over the past 17 years, provide a database that may be used to examine the energy systematics of the Kα hypersatellites over the target atomic number range Z_2 = 9 to 29. Shown in Fig. 1 are the Kα hypersatellite energy shifts, measured relative to the normal (single vacancy) $K\alpha_{1,2}$ diagram line energies, as a function of Z_2. The error bars on some of the data points for Z_2 = 20, 25, and 29 indicate the variation of the energy shifts for 10 AMeV projectiles ranging from Ne (lower bar) to Ar (upper bar). The Kα hypersatellites of aluminum (Z_2 = 13) did not display any significant variation over this same range of Z_1. The cause of the energy shift variations for the higher Z_2 targets is thought to be associated with an increase in the degree of M-shell ionization as the projectile atomic number increases. The effect increases with target atomic number because the number of M-electrons

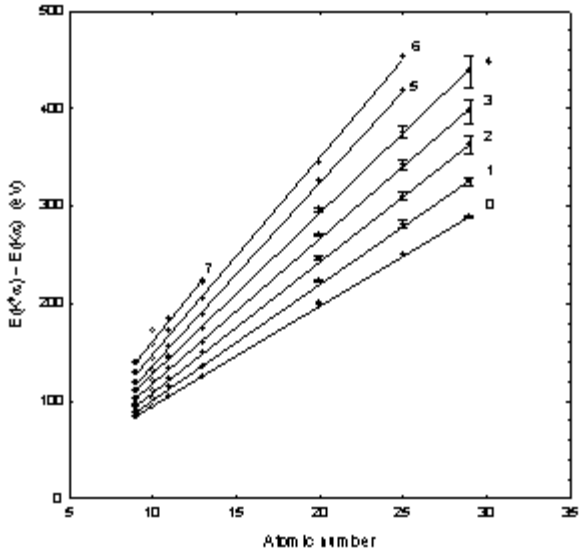

Figure 1. Dependence of the K^2L^n Kα hypersatellite x-ray energy shifts on target atomic number. The number labels indicate the value of n. The empty circles are for the gas target Ne. See text for an explanation of the error bars.

available for removal increases with Z_2. As the linear regression lines show, the (average) energy shifts increase linearly with Z_2. This behavior is in qualitative agreement with the predictions of a simple model proposed by Burch et al. [4] based on the change in the K- and L-shell electrostatic potentials accompanying the removal of an L-shell electron. The slopes and intercepts of the regression lines are listed in Table 1. Another noteworthy observation is that the higher order Kα hypersatellite energy shifts for Ne, the only gas target examined (shown by the empty circles in Fig. 1), display relatively large deviations from the regression lines. This suggests that additional screening effects are important in a solid state environment.

Table 1. Slopes (a) and intercepts (b) of the linear regression lines in Fig. 1.

n	a	b
0	10.33	− 8.79
1	11.94	−18.34
2	13.41	−24.81
3	14.82	−29.90
4	16.51	−37.89
5	18.80	−52.14
6	20.15	−53.27

References

[1] M. H. Chen, B. Crasemann, and H. Mark, Phys. Rev. A**25**, 391 (1982).

[2] R. Diamont, S. Huotari, K. Hämäläinen, C. C. Kao, and M. Deutsch, Phys. Rev. Lett. **84**, 3278 (2000).

[3] R. L. Watson, J. M. Blackadar, and V. Horvat, Phys. Rev. A**60**, 2959 (1999).

[4] R. L. Watson, V. Horvat, J. M. Blackadar, and K. E. Zaharakis, Phys. Rev. (Submitted).

[5] D. Burch, L. Wilets, and W. E. Meyerhof, Phys. Rev. A**9**, 1007 (1974).