Molecular Orbital Effects in Near-symmetric Collisions of 10 A MeV Heavy Ions with Solid Targets

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Cross sections for target atom K vacancy production have been measured recently, using solid targets of Cu, Mo, Ag, Sn, Sm, and Ta bombarded by 10 A MeV beams of H, Ne, Ar, Cr, Kr, Xe, and Bi [1]. It was found that the target K x-ray production cross section becomes enhanced as the target atomic number Z_2 approaches the atomic number Z_1 of the projectile. The purpose of the work presented here is to explain this enhancement in terms of the existing theories for K-vacancy production.

An increase in the x-ray production cross section as $|Z_1 - Z_2|$ decreases is a characteristic of the molecular-orbital (MO) mechanism, in which the target K vacancy production is due to interactive level crossings that occur as the two collision partners dynamically combine to form a quasi-molecule. This mechanism is expected to be predominant in slow collisions (i.e., when the projectile speed v_1 is significantly less than the orbital speed v_2 of the target electron). For 10 A MeV projectiles, v_1 / v_2 ranges from 0.3 for the Ta target (Z_2 = 73) to 0.8 for the Cu target (Z_2 = 29). The contribution from the MO mechanism was calculated using the diffusion model of Mittleman and Wilets [2], which describes the ionization process as a gradual vacancy diffusion from the continuum into the ground state as the molecule is being formed, followed by the migration of the vacancy into the K shell of one collision partner as the molecule dissociates.

Other processes may also contribute to target K-vacancy production. These include direct ionization of the target electron in a binary collision with the projectile (DI) and capture of the target electron to a projectile bound state (EC). The contributions from DI and EC are typically calculated using the ECPSSR theory [3]. However, this theory for DI is expected to be valid only when 0.03 # Z_1 / Z_2 # 0.3, which means that it does not apply in the near-symmetric region. Indeed, it was found, for projectiles with Z_1∃36 on Cu and Mo targets, that the ECPSSR cross sections for DI alone are significantly larger than those obtained from the measurements. A theory of DI that would be valid for near-symmetric collisions involving heavy projectiles is not presently available. The contributions from EC were also calculated using the ECPSSR theory, taking into account the availability of projectile states for capture while the projectile is inside the target. It was found that these cross sections for the copper target overestimate the measured cross sections in the near-symmetric collision region, while for the other targets they account for only a small fraction of the measured cross sections.

Therefore, the measured cross sections were compared with those calculated using the MO approach assuming that all other contributing processes can be represented by a second-order polynomial in Z_1. This comparison is shown in Fig. 1. It is evident that a good overall representation of the data is achieved and the regions of enhanced cross sections are well reproduced by the calculated MO contributions.

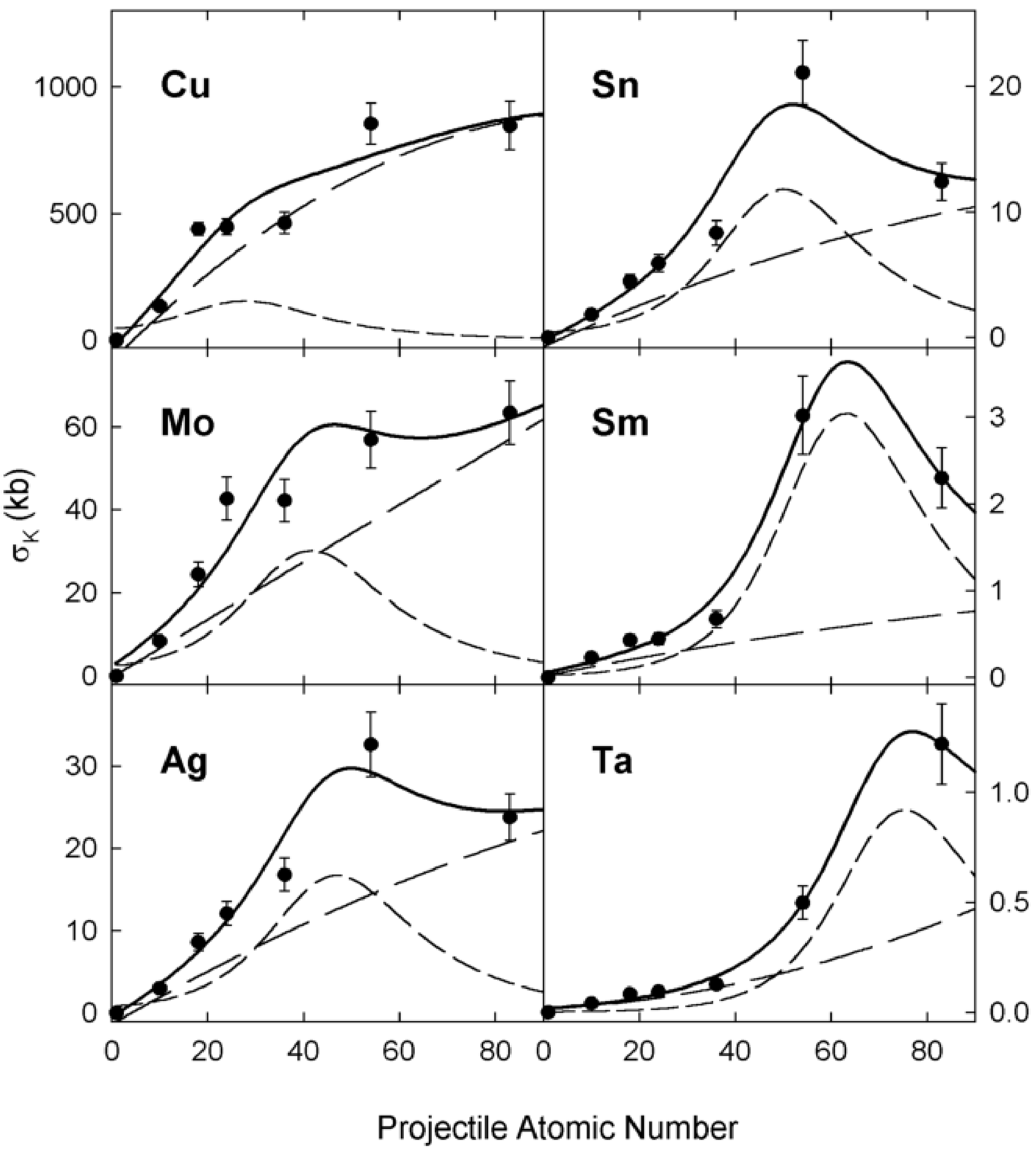

Figure 1: Cross sections for K vacancy production in thick solid targets of Cu, Mo, Ag, Sn, Sm, and Ta under bombardment by 10 A MeV projectiles. Solid circles represent the measured values. The short-dashed line represents the calculated contribution from the MO mechanism. The long-dashed line represents the best parabolic fit to the residuals. The sum of the two is represented by the thick solid line.

References

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