ASYMPTOTIC REGION K-SHELL IONIZATION

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A considerable simplification in the description of the collisionally-produced inner-shell ionization process is possible if the projectile ($M > M_e$) is "structureless" (i.e.; carries no electrons into the collision) and has a velocity much greater than the velocity of the electron in the shell to be ionized ($V_{proj} >> V_k$, for the K shell). Straightforward measurements of the K X-ray yield can be converted to total ionization cross sections which then can be compared to a very simple theoretical expression valid for the asymptotic region.[1] As originally derived by Bethe (for relativistic particles), the total ionization cross section σ_k, is:

$$\sigma_k = \frac{8\pi a^2{}_o}{\theta} \frac{Z_1{}^2}{Z_2{}^4} \frac{1}{T/R} \{ M^2_{TOT} [\ln(\gamma^2 - \beta^2) - \beta^2] + C_{TOT} \}$$

where $Z_1(Z_2)$ is the projectile (target) charge, Θ the target screening constant, T is the projectile kinetic energy scaled by M_e/M, R is the K-shell binding energy, and $\gamma^2 = \beta^2/(1 - \beta^2)$, $\beta = V/C$. The quantity $M^2{}_{TOT}$ is the sum of the dipole matrix elements squared for ionization and excitation (although the latter doesn't contribute much) from the K shell, and C_{TOT} is a parameter associated with the energy transfer during the collision. Thus, in a high-energy, but not appreciably relativistic regime, the shape of the measured total ionization cross section over a wide energy range should tend toward a $\ln E/E$ fall-off with increasing bombarding and energy (E) according to the Bethe theory.

A straight line fit to a plot of $(T/R)\sigma_k/(8\pi a_o^2\ Z_1{}^2/Z_2{}^2)$ vs $\ln(\gamma^2 - \beta^2)$ in this region enables one to directly determine M^2_{TOT} and C_{TOT}, and thereby constrain calculations of the dipole matrix elements in this atomic region. These dipole matrix elements in turn are important in the deduction of oscillator strengths and other salient features of the ionization process.[1] In addition, certain of the approximate theories used in describing data obtained at lower bombarding energies, should asymptotically approach the Bethe predictions in the high velocity limit. Cross-section measurements for a range of targets at relatively high energies thus provides a check on the applicability of Bethe theory as well as a normalization for, and test of, the energy dependence predicted by approximate theories used more extensively at lower relative velocities.

Only a handful of measurements with projectiles heavier than the electron have been made in the asymptotic region[3,4] mostly on low-Z targets[3]. We have proposed to measure K-shell X-ray cross sections for selected targets from oxygen to calcium. Proton bombarding energies will range from 30 to 200 MeV and thus significantly probe the energy dependence and the behavior in the asymptotic region for a number of different target Z's ($V_{proj}/V_k \lesssim 15$). Preliminary tests with low-background conditions have been made in the "gamma cave". A Kevex Si(Li) detector[5] $30mm^2 \times 3mm$ was operated in essentially a windowless mode; a 8000 Å Parylene window kept pump oil from condensing on the detector with virtually no attenation of the lowest energy X-rays. The detector assembly and collimating slits were attached to the standard scattering chamber at 135° to the beam direction. At a proton bombarding energy of 195 MeV, electronic noise and beam-related low-energy backgrounds could be reduced to $\lesssim$ 350 eV. Thus, oxygen X-rays were seen to be clearly resolved from low-energy background in several test runs proving the feasibility of the experiment as proposed. Further tests of the detector efficiency for low-energy X-rays are planned before in-beam data-taking will procede.

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2) D. Madison and E. Merzbacher in "Atomic Inner-Shell Processes" Vol. I, B. Crasemann, ed., (N.Y., 1975), and references therein.

3) G. Bissinger, J.M. Joyce, B.L. Doyle, W.W. Jacobs, and S.M. Shafroth, Phys. Rev. A16 (1977) 443, and references therein.

4) R. Anholt et al., Phys. Rev. A14 (1976) 2103.

5) Kevex Corporation, Model 3050 S.