Charge Transfer to the Continuum by Heavy Ions in Atomic Hydrogen

I. A. Sellin

University of Tennessee, Knoxville TN 37916 and
Oak Ridge National Laboratory, Oak Ridge TN 37830

The charge transfer process is an essential ingredient of any attempt to understand the ionization of gaseous media traversed by highly-charged energetic ions. Surprisingly, a sometimes dominant contribution to such ionization remained undiscovered until the past decade.[1] This process, known as charge transfer to the continuum, involves the ionization of electrons from the target species into unbound states closely matched in exit direction and speed to the charged particles which generate them.

Subsequent measurements of the resultant forward electron production, performed by University of Tennessee researchers at Oak Ridge and Brookhaven National Laboratories,[2] were unique in employing more highly charged projectiles than previously. One outcome of those measurements was a realization that the actual spectrum of forward-ejected electrons produced by swift ($\sim$ 2 MeV/u) ions traversing gases, predicted to have a characteristic symmetric "cusp" shape,[3] was in fact strongly asymmetric for highly-charged projectiles and skewed toward electron speeds lower than that of the projectiles. In addition, the total production rate of forward electrons, predicted to scale as the third power of projectile nuclear charge, actually scaled more as the square ($Z_p^{2.2 \pm 0.2}$). An important contribution made by Shakeshaft and Spruch[4] suggested that the observed asymmetry and Z_p-dependence was a first experimental indication of the importance of second-order Born series amplitudes relative to the first Born term, even though the impact velocities involved were appreciably below those necessary to assure dominance of second-Born terms in the total cross sections. Although other explanations of the asymmetry have been made,[5] more recent experiments[6] by the University of Tennessee group, in collaboration with colleagues at Lawrence Berkeley Laboratory, are in better agreement with the predictions of Shakeshaft and Spruch.

One difficulty with the interpretation of the asymmetry in terms of a second Born amplitude origin arises from the many-electron nature of the targets employed to date (He, Ne, Ar). The bulk of the second Born term can be identified with the double-scattering mechanism originally proposed by Thomas,[7] which is of importance to bound state capture as well. The presence of target electrons in addition to the one to be captured opens additional double-scattering channels which are difficult to handle theoretically, so that detailed calculations exist only for one-electron targets. Consequently, we have begun a program to study charge transfer to the continuum with atomic hydrogen targets.

The long-recognized problems associated with the construction of a reliable static atomic hydrogen target is compounded in the present case by the requirement that the electron spectrometer employed in charge transfer to continuum studies reside in a low ambient magnetic field. Common oven designs use high-current resistive heating techniques and as a result produce rather severe inhomogeneous stray fields. Although it is possible to pulse the heating current and acquire spectral data during the off portion of the heating cycle, we have chosen a low-current, high-voltage ($\sim$ 2 a. @ $\sim$ 5 kV) electron impact heating design with coaxial current paths to further minimize stray fields. Somewhat in excess of one year has been spent in the design and fabrication of several prototypes. As might be expected, the major problems encountered have involved the selection of suitable high-temperature materials, especially for insulators required in the electron gun, the difficulty of machining such materials, and the minimization of radiative oven heat loss.

The present design consists of a tungsten gas cell (mass ∿ 25 g) having internal dimensions of 4 mm dia x 1 cm long terminated by ∿ 1 mm apertures. The oven functions as the central portion of a Pierce extraction lens used in the electron gun. This design has been successfully operated at temperatures ∿ 2500 to 2600 K, as measured by a calibrated optical pyrometer. A water-cooled copper heat sink surrounds the oven assembly to protect a 180-degree spherical sector electron spectrometer which will be located a few cm from the oven.

The oven was recently installed at the ORNL EN tandem facility in an ultra-high vacuum beam line and equipped with a magnetic charge-state analysis system down-beam of the oven. At the time of this writing, preparations are under way to measure dissociation fractions by monitoring single to double electron capture ratios with beams of ∿ 2 MeV/u C^{6+} and O^{8+} at various oven temperatures. With these same beams and at the same time, it will also be possible to observe the charge transfer to continuum "cusp" spectra produced.

This work was partially supported by the Fundamental Interactions Branch, Division of Chemical Sciences, Office of Basic Energy Sciences, U. S. Department of Energy, under contract W-7405-eng-26.

References

1 G. B. Crooks and M. E. Rudd, Phys. Rev. Lett. 25, 1599 (1970).

2 C. R. Vane, I. A. Sellin, M. Suter, G. D. Alton, S. B. Elston, P. M. Griffin, and R. S. Thoe, Phys. Rev. Lett. 40, 1020 (1978).

3 K. Dettmann, K. G. Harrison, and M. W. Lucas, J. Phys. B 7, 269 (1974).

4 R. Shakeshaft and L. Spruch, Phys. Rev. Lett. 41, 1037 (1978).

5 F. T. Chan and J. Eichler, Phys. Rev. A 20, 367 (1979); K. C. R. Chiu, W. Meckbach, G. Sanchez Sarmiento, and J. E. McGowan, J. Phys. B 12, L147 (1979).

6 M. Breinig, S. B. Elston, I. A. Sellin, L. Liljeby, R. S. Thoe, C. R. Vane, H. Gould, R. Marrus and R. Laubert, Phys. Rev. Lett. 45, 1689 (1980).

7 L. H. Thomas, Proc. R. Soc. 114, 561 (1927).