A.1.2. Low Velocity Collisions: COLTRIMS Measurements of Electron Spectra from Low Energy Ionization of Light Targets--*H. Wolf, W.Wolff, M.Abdallah, E. Edgu and C.L.Cocke*

Despite several decades of the study of ionizing collisions, continuum electron emission from simple atomic and molecular targets is still poorly understood in the projectile velocity range below matching velocity, i.e., in the capture-dominated velocity region. This is true for both singly- and multiply-charged projectiles. (A more complete literature survey is given in Publications #6, 9 and 57.) We have used Cold-Target Recoil Ion Momentum Spectroscopy (COLTRIMS) to study the soft electron spectra generated in such collisions for projectiles of H^+, He^+, He^{++}, Ne^+ and C^{6+} on targets of He, H_2 and Ne under conditions which allow the experimental determination of the reaction plane and transverse momentum transfer. The latter can be translated into an impact parameter when the appropriate effective potential is known, since the major transverse momentum transfer is between target and projectile core. All measured electron spectra show a preference for the electron momentum to lie in the collision plane, near the saddle between projectile and target for singly and doubly charged projectiles. When viewed looking down on the collision plane, the electron spectra for singly- and doubly-charged projectiles show striking structures which can be interpreted in terms of the character of a single dominant molecular orbital promoted into the continuum during the collision. For example, for both He and H_2 targets, and H^+; He^+, and He^{++} projectiles, evidence for a nodal line in the electron spectra along the internuclear axis is seen.

An example of the results is shown in Fig. 1, where the electron distribution for He^+ on He and H_2 , as viewed looking down on the collision plane, is seen for several values of the transverse momentum transfer. This behavior can be interpreted as being due to the dominance of the promotion of a $2p\pi$ orbital into the continuum. It is interesting and perhaps surprising that the atomic and molecular targets show such similar patterns.

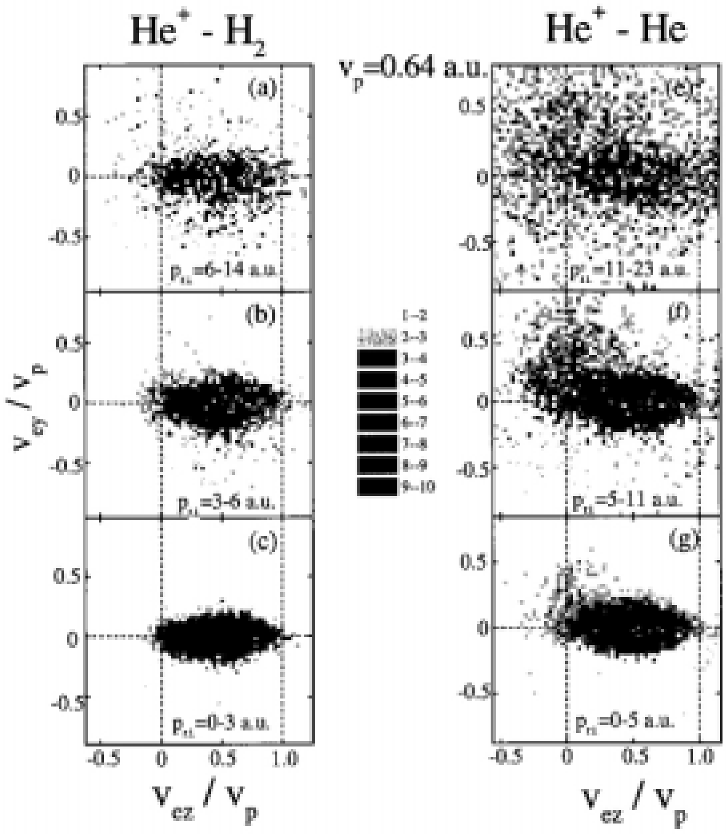

Figure 1. Electron momentum distributions seen looking down on the collision plane for 0.64 a.u. He^+ ions incident on H_2 (left column) and He (right column). The π structure is seen in the quasi-nodal line seen running along the direction of the beam.

The impact parameter dependences for both targets show that the “molecular window” extends over a finite velocity range, from about 0.1 a.u. in projectile velocity to near 1 a.u. Above this window, a transition of the reaction mechanism into a direct kinematic ionization begins to occur; below it, some as yet unidentified mechanism seems to enter. The impact parameter dependence in the promotion window region is consistent with the calculations performed on the assumption of dominance by the rotational coupling model. Evidence for the presence of σ and δ amplitudes is also seen in the data, however, and no specific model is available for calculating the relative contributions of these for the collision systems investigated to date.

For collisions involving Ne, the nodal structure is replaced by an anti-nodal peak along the internuclear axis, a behavior attributable to promotion of a $3d\sigma$ orbital into the continuum.

The clear difference between sigma and pi promotion is shown in Fig. 2 and illustrates that the COLTRIMS electron images are direct reflections of major promoted orbitals.

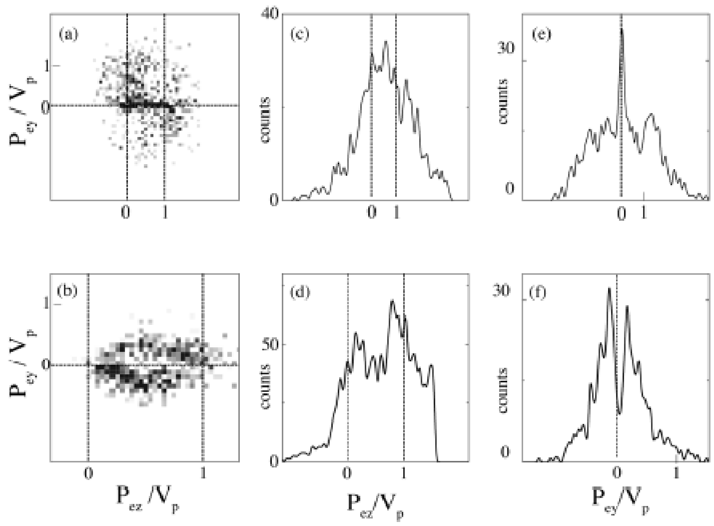

Figure 2. Electron momentum distributions for: (a) .45 a.u. Ne+ on Ne at a transverse recoil momentum of 15 a.u., and (b) .9 a.u. He^+ on He at a transverse recoil momentum of 7 a.u.. Figures (c) through (f) are slices in the x and y directions through the centers of the two dimensional plots. The distributions are viewed looking down on the collision plane. The He^+ case shows the image of a promoted σ orbital, while the Ne^+ case shows a promoted π orbital. Figure from Publication #92.

The evolution of the ionization process from the low-energy molecular-orbital dominated velocity region into the high energy perturbative region has also been studied for the case of H^+ on He up to a projectile velocity of 2 a.u. Over this velocity region the low energy nodal and saddle point structure of the electron spectra gradually evolves into a target-centered velocity distribution with little structure. The spectra are consistent with the LINAC results discussed in the high energy ionization section of this report.

The major theoretical interpretation of these data comes from the hidden crossing and Sturmian basis approach of Macek and Ovchinnikov [1,2] as well as an innovative momentum space approach carried out in this laboratory by Sidky and Lin (see Publications #56 and 76). The basic difficulty lies with a correct description of the electron continuum. As discussed in the proposal section, while the data are for multielectron systems, the theory is only possible for single electron systems so far, and gives enough problems already for that system. See proposal for further detail on the continuation of this work.

The results of this project are reported in Publications #6, 9, 57, 58, 88, 91, 92 and a comprehensive PRA article summarizing the light ion results, Accepted Publication #3, has been accepted by Phys. Rev. A.