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Shaofeng Zhang

J. Suske

Daniel Fischer
Missouri University of Science and Technology, fischerda@mst.edu

K. U. Kuehnel

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/phys_facwork/783

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Electron angular distributions in He single ionization impact by H_2^+ ions at 1 MeV

Shaofeng Zhang[1,2,5], J Suske[2], D Fischer[2,4], K U Kuehnel[2], S Hagmann[3], A Voitkiv[2], B Najjaril[2], A Krauss[2], R Moshammer[2], J Ullrich[2], Xinwen Ma[1,5]

[1]Institute of Modern Physics, CAS, Lanzhou 730000, China
[2]Max-Planck-Institut für KernPhysik, Saupfercheckweg 1, 69117 Heidelberg
[3]Gesellschaft für Schwerionenforschung, Planckstr. 1, 64291 Darmstadt, Germany
[4]Stockholm University, AlbaNova University Centre, 10691 Stockholm, Sweden
[5]Graduate University of Chinese Academy of Sciences, Beijing 100049 China

zhangshf@impcas.ac.cn

Abstract. For the first time we investigated in a kinematically complete experiment the ionization of helium in collisions with H_2^+-molecular ions at 1 MeV. Using two separate detectors, the orientation of the projectile H_2^+-molecular ions was determined at the instance of the collision. The electron angular distribution was measured by a "Reaction Microscope". The observed structures are found in agreement with theoretical calculations, indicating that the ionized electron of He shows a slight preferential emission direction parallel to the molecular axis.

1. Introduction

Studies of particle-induced dissociation of H_2, the simplest molecule composed of two atoms, have been reported extensively last decade. Particular attention is devoted to spatial effects in target ionization since the two centers are indistinguishable, where the contributions from each center add coherently. Early studies of collisionally induced fragmentation of H_2 mainly focused on the processes of electron capture[1, 2] and photoionization[3-5]. The following theoretical work was developed quite rapidly[6], whereas more experimental work mainly focused on the heavier molecules with synchrotron radiation[7, 8]. Up to now, little has been done for the collision experiments with H_2^+ as projectiles, which is the simplest molecular system in the nature, in despite of the advances in the collision experimental[9, 10] and theoretical work[11-13] with H_2 as a target. In a kinematically complete experiment the spatial effects in the ionization of helium induced by the molecular ion H_2^+ are investigated. In this work the orientation and internuclear distance of the molecular ion at the instance of the collision could be determined by momentum imaging technique. The phenomena resulting from the two-center potential of the molecular projectile in the dissociation channel were found.

2. Experimental setup

In our experiment, we employed a Recoil-Ion Momentum Spectroscopy (RIMS)[14] , which is suitable for the investigation of any kind of atomic reaction dynamics. The features of the experimental setup concerning molecular ion impact are presented. Briefly, the H_2^+ ion beam (1 MeV) was delivered by a

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linear accelerator at Max-Planck institute for nuclear physics. After collimation the ion beam entered the interaction chamber through a 0.5 mm diameter hole and crossed a cold localized gas-jet target. The outgoing projectile was charge selected by a dipole magnet, the neutral and the proton produced in the dissociation channel were delivered to different directions and detected by two separate position sensitive detectors respectively, while the primary beam was directed into a Faraday cup. The ejected electrons and the recoils produced in target ionization were extracted and accelerated by a 3 V/cm electric field from the interaction region, and then they were projected onto the detectors, respectively. In order to achieve a high acceptance together with a good resolution for both electrons and recoil-ions in coincidence, a weak homogenous magnetic field (generated by a pair of large Helmholtz coils) was superimposed along the spectrometer axis effectively confining the electron motion in space (figure 1).

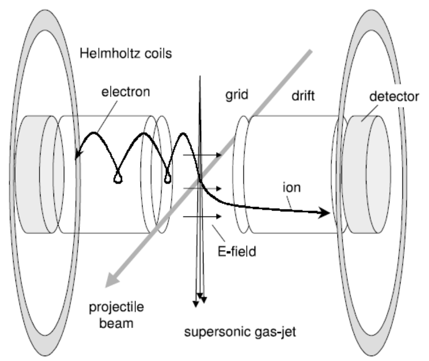

Figure 1. Schematics of an reaction microscope

The reaction channel of interest in the present experiment is the target ionization and simultaneous dissociation of the projectile molecular ion,

$$H_2^+ + He \rightarrow H + p + He^+ + e \qquad (1)$$

Here, four-fold coincidence measurements between the ionized electron, the recoil ion He^+, the projectile fragments (the neutral hydrogen atom H and the proton p) were performed, the data were recorded in event-by-event mode.

3. Results and discussion

The momenta of the four particles in eq. (1) were reconstructed according to their time and position on the detectors. The kinetic energy release (KER) of the projectile molecular H_2^+, were illustrated in the left panel in figure 2. By selecting specific KER the nuclear distance of the molecular ion can be determined. The right panel in figure 2 shows the projection of the spherical shell of the molecular ion with the KER condition around 10 eV.

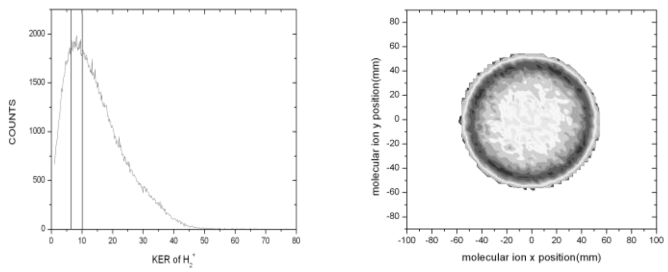

Figure 2. Left: The kinetic Energy Release (KER) spectrum of the H_2^+ ion in dissociation channel; Right: The projection of spherical shell of the fragments when the events between the two straight lines of the left plot are selected.

The theoretical electron angular distribution with respect to the molecular axis was obtained under the axial recoil approximation[15], which holds that when a diatomic molecular ion is formed in a dissociative state, the atoms produced in the dissociation process will move outward along the straight line defined by the internuclear axis of the molecule. From the estimation below it is clear that this approximation works well in our case. If we treat the diatomic molecule as a rotating dumbbell composed of two point masses with a distance R, its rotational energy is given by

$$\frac{1}{2}I_0\omega_0{}^2 = J(J+1)\frac{\hbar^2}{2I_0} \tag{2}$$

where ω_0 is the initial angular velocity of the molecular ion, and I_0 is its moment of inertia. Taking the rotational temperature of the gas to be 300 K, the final rotation angle can be written as below, by neglecting other aspects which can contribute to the rotational angle[16].

$$\Delta\varphi = \frac{8R_0\sqrt{E_\omega E_c}}{q^2} \tag{3}$$

where E_c is the coulomb potential energy, E_ω the rotational energy, R_0 the initial nuclear distance, and q the charge of the fragment. In our case, R_0=1, q=1, E_c=0.2, and E_ω=0.001 (in atomic units), we finally get $\Delta\varphi$=6.3°, which is sufficiently accurate to account for the data in our work.

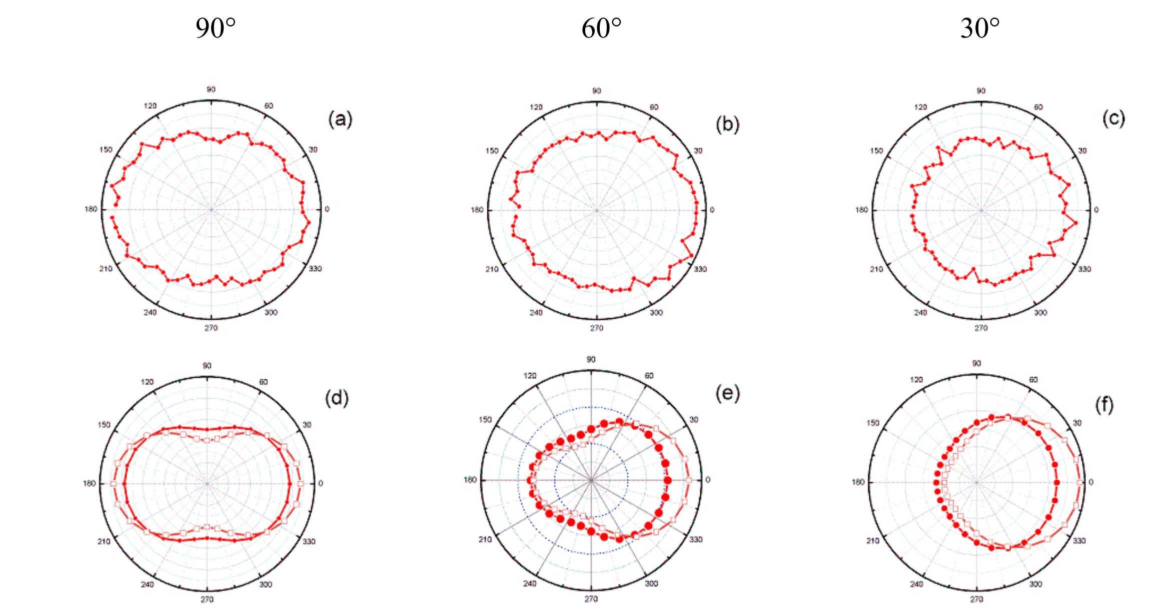

Figure 3. Electron angular distributions corresponding to three different molecular axis angles with respect to the projectile direction (from left to right the angles are 90°, 60°, and 30°, respectively). Upper row: experimental (a, b, c), lower row: theoretical (d, e, f).

Since the orientation of the H_2^+ axis can be reconstructed for each event, the electron angular distributions with respect to molecular axis can be obtained. Both experimental (upper row) and theoretical (lower row) results of the electron angular distributions are shown in figure 3. The projection plane in figure 3 is perpendicular to the beam propagation direction (the propagation direction is looking down into the figure). Plot (a) shows the electron angular distribution when the molecular axis is perpendicular to the beam propagation and plot (d) shows the theoretical results under the same situation. Plot (b) and (e) as well as plot (c) and (f) present the experimental and theoretical electron angular distributions for the molecular axis angle 60° and 30° with respect to projectile direction, respectively.

The experimental data show that the emission of the ionized electron from the target has a slight preference along the molecular axis. Theoretical calculations from the quantum plane-wave Born approximation show more pronounced structure variation while the direction of the molecular axis changes. This phenomenon indicates the structured projectile does have some impacts on the collision reaction.

4. Summary

The first successful experiment for projectile-orientation-reconstruction in high energies (1 MeV) collisions was performed. The experiment was precisely organized to study the spatial effects in ionization of helium by the hydrogen molecular ion impact in dissociation channel: $H_2^+ + He \rightarrow H + p + He^+ + e$. The experimental results show less pronounced structure effects than the quantum plane-wave Born approximation predictions.

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