4 - 4 Double-slit Interferences Observed in Dielectronic Transitions in Collisions of H_2^+ on Helium*

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Young's double-slit interference is a clear manifestation of the wave character of light. The feasibility of an atomic version of Young's double slit experiment for matter waves in ion-atom collisions was first discussed theoretically by Tuan and Gerjuoy in 1960[1]. They studied capture processes in collisions of protons with H_2 and suggested that diffraction of the protons from the two atomic centers of the molecule could lead to interference effects. Such interference effects are more difficult to observe in ionization processes, since there the final state of the collision involves at least three unbound particles. The experimental observation of this process is particularly challenging because the determination of the phase angle in such processes is not straightforward.

An atomic-collision version of Young double-slit experiment in collisions of H_2^+ on He was thus proposed and achieved recently[2]

$$H_2^+ + He \rightarrow H^+ + H + He^+ + e \ .$$

The experiment was performed in an inverse kinematic manner where H_2^+ acts as the moving double-slit and collides on helium atom. During the collision, H_2^+ molecule dissociated into a neutral hydrogen atom and a positively charged proton. These two projectile fragments were further discriminated by the dipole magnet after the reaction microscopes, and then were detected by their corresponding detectors. Meanwhile, helium atom was singly ionized so that the momentum transfer could be monitored with conventional reaction microscopes. These four detectors were set in the coincidence mode to extract the information of orientation-dependent momentum transfer for each collision event. In the rest frame of hydrogen molecular ion interference structures are expected in the momentum spectra of scattered helium atom.

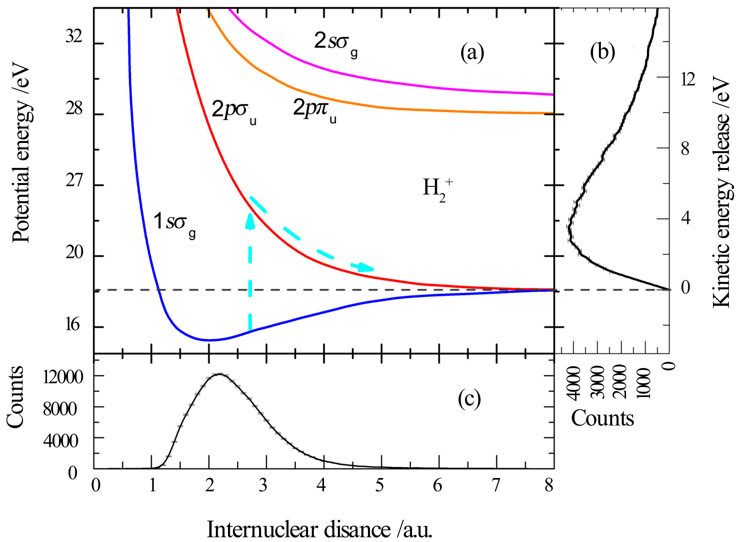

Fig. 1 (color online) (a) Molecular potential curves of H_2^+, taken from Ref. [2]. (b) Experimental kinetic energy release (KER). (c) Internuclear distance distributions calculated from the KER, assuming that only the $2p\sigma_u$ state is populated.

In the commllisions, the molecular ions are excited from the initial $1s\sigma_g$ state to the final dissociative states, at which the potential energy is converted to a certain KER (see Fig. 1). If only one potential curve is populated, each KER corresponds classically to a specific internuclear distance (neglecting the vibrational energy). For this collision system, excitation to the $2p\sigma_u$ state is the dominant channel because the required relatively low energy transfer is favored in ion-atom collisions. Using the potential curve of the $2p\sigma_u$ state, molecular internuclear distance distributions (Fig. 1(c)) are finally calculated from the measured KER distributions.

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In Fig. 2, the projection of the momentum transfer distributions on the azimuthal plane are shown for $|\phi_e - \phi_r| < 120°$. ϕ_e and ϕ_r are azimuthal angles of the ejected electron and that of the recoil ion, respectively. Different internuclear distances of the molecular ion were chosen by selecting KERs smaller than 2.5 eV in Fig. 2(a) and larger than 8 eV in Fig. 2(b) corresponding to internuclear distances of $\varrho \geq 3.2$ a.u. and $\varrho \leq 2$ a.u. approximately (see Fig. 1). In Fig. 2(c) these cross sections are integrated over the y-direction of the momentum transfer. For both KERs a clear minimum at $p_x = 0$ is observed and this minimum gets broader with increasing KER corresponding to decreasing ϱ. Qualitatively, this is in accordance with our simple model, however, the positions of the maxima are at slightly smaller values of p_x than expected. This might be explained considering the steep dropping of the atomic cross section σ_A with the momentum transfer $\boldsymbol{q}$.

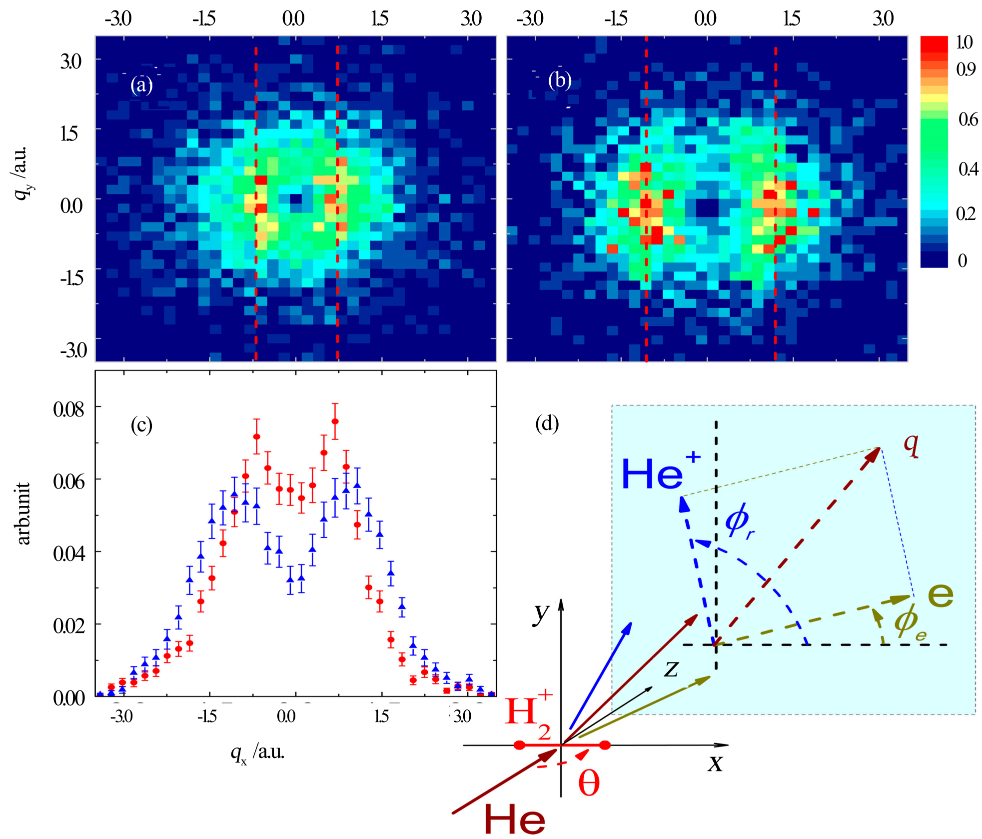

Fig. 2 (color online) Two-dimensional momentum transfer distributions in the transverse plane under different conditions of internuclear distances. Molecular axis perpendicular to the beam direction: (a) KER < 2.5 eV; (b) KER > 8 eV; (c) their q_x distributions: ● for (a), and ▲ for (b). (d) sketch of the molecular frame and corresponding definitions.

In the spectra, minimum distributions were found at $p_x \approx 0$ where maximum distributions are usually found in the conventional optical Young double-slit experiments. Such phenomena indicate symmetric flips occurred in our experiment. In the collision process, hydrogen molecular ion jumps from the ground state $1s\sigma_g$ to the first excited state $2p\sigma_u$ and its parity changes from even to odd accordingly. Due to the principle of parity conservation, the other part of the system (helium atom) has to change its parity eventually. The flip is a strong evidence that the double-slit and the scattering particle entangle with each other.

In conclusion, we have investigated simultaneous dissociation and target ionization in collisions between H_2^+ molecular ions and helium atoms in a kinematically complete experiment. We have observed a dependence of the differential cross sections on the orientation of the projectile molecular ion. Compared to earlier studies on Young-type interference in atomic collisions, the present collision system features more degrees of freedom, because it represents an effective 5-body system, consisting of the two active electrons, the two protons in the molecule, and the He^+ core. However, in spite of this rather complex collision system, the two contributing mechanisms can be separated by choosing appropriate kinematic conditions revealing clear interference structures.

References

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[3] T. E. Sharp, Atomic Data, 2(1970)19.