Laser Induced Rescattering Photoelectron Spectroscopy on Hydrocarbon Molecules

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Abstract: We have extracted field-free differential cross sections of electron scattering from $C_2H_4^+$ and $C_2H_6^+$ ions from rescattering photoelectron spectra of C_2H_4 and C_2H_6 induced by ultrashort intense infrared laser pulses at 1300 and 1650 nm.
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1. Introduction

When a molecule is exposed to the linearly polarized intense laser field, an electron is released from the molecule by tunnel ionization. The oscillating electric field of the laser forces a fraction of the emitted electron wave packet back to the parent ion. The re-colliding electron rescatters off the ion. This electron rescattering may be regarded as electron diffraction. It has been demonstrated theoretically and experimentally that elastic differential cross sections (DCSs) for scattering of **free** electrons from **atomic** ions [1,2] can be extracted from the momentum distributions of high-energy rescattering photoelectrons. The DCSs completely encapsulate electron-ion scattering and thus, this method offers the possibility of determining the target structure with the benefit of achieving femtosecond temporal resolutions offered by the short laser pulses. We have recently reported study on recattering photoelectron spectroscopy of O_2, CO_2 [3], and C_2H_4 [4] measured by 800 nm wavelength laser pulses and extracted differential cross-section (DCS) of electron scattering from target ions. In the present study, we extend our observations to a wider range of recattering photoelectron momentum using longer wavelength laser pulses at 1300 and 1650 nm. Target molecules are C_2H_4 and C_2H_6 as an initial step towards the investigations of dynamical structure for organic and bio-related molecules.

2. Experiment

We have measured angle-resolved RPS spectra of randomly oriented C_2H_4 and C_2H_6. The electron spectra are measured using a 264 mm long electron time-of-flight spectrometer. Emitted electrons are detected at arbitrary angles with respect to the laser polarization, which is controlled by a rotating half-wave plate. Infrared laser pulses at 1300 and 1650 nm wavelength are generated by an optical parametric amplifier from 100-fs Titanium-Sapphire laser pulses at 800 nm. The sample gas is introduced as an effusive beam into a vacuum chamber, where the laser pulses are focused by a spherical mirror.

3. Results and discussions

The extraction procedure of the DCSs from the RPSs for molecules are shown elsewhere [3]. The key point is the factorization of the rescattering electron yield into a product of the electron scattering DCS and a "wave packet" representing the momentum distribution of the returning electron $(S(\mathbf{p}))$ as

$$S(\mathbf{p}) = \overline{W}(p_r)\overline{\sigma}(p_r, \theta_r), \qquad (1)$$

where $\overline{\sigma}(p_r, \theta_r)$ is the DCS convoluted over the alignment angles of the molecule with respect to the laser polarization direction, and p_r and θ_r represent the momentum of rescattered electron at the time of recollision. After the recollision, the backward-rescattered electron receives additional drift momentum ($\mathbf{A_r}$) from the electric field, and then is ejected as a high-energy plateau photoelectron. Here the ratio of the absolute value of the recollision momentum (p_r) to that of the drift momentum (A_r) is approximated as 1.26 ($=p_r / A_r$) assuming a monochromatic field. Since the "wave packet" does not depend on the scattering angle $(=\overline{W}(p_r))$, angular DCSs can be extracted from the RPS spectra as a function of p_r.

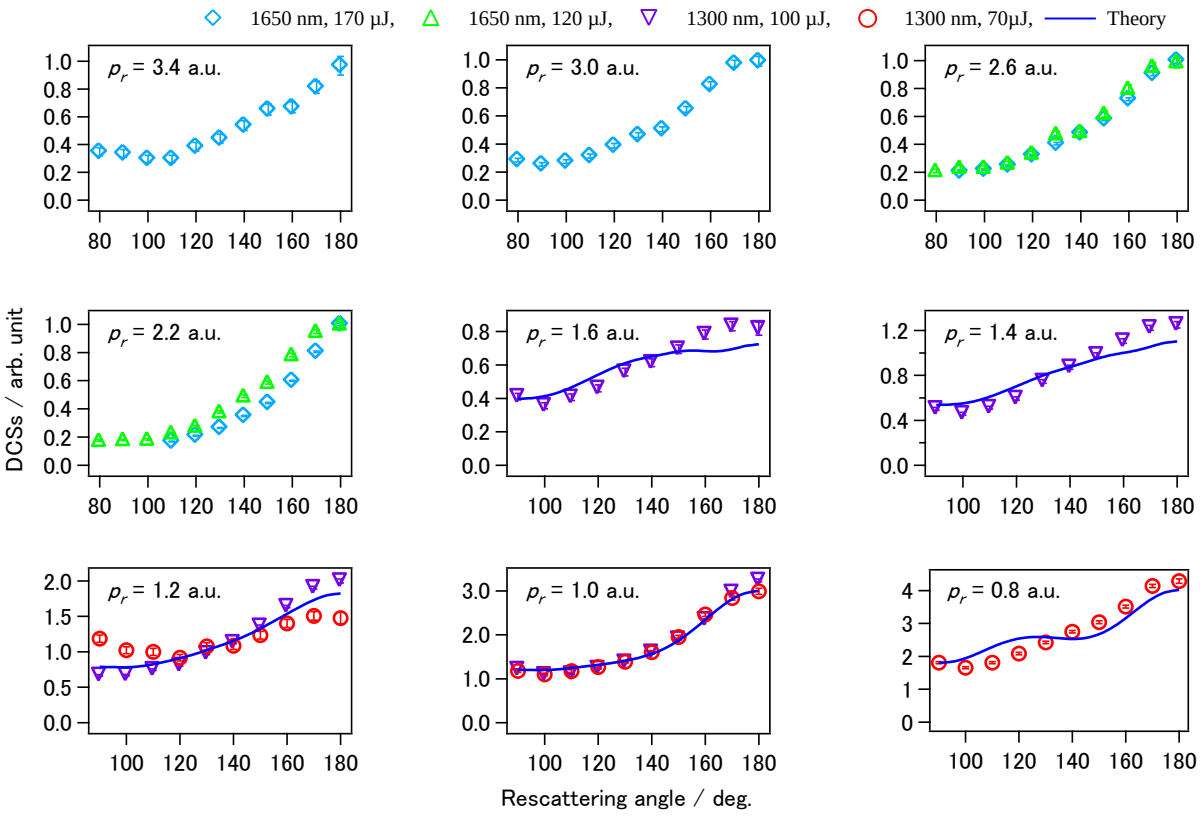

Fig. 1 Experimental DCSs of electron scattering from $C_2H_4^+$ extracted from RPS at several different laser parameters, and the theoretical calculations of the DCSs for $C_2H_4^+$.

Fig. 1 shows experimentally extracted DCSs from the RPS of measured by 1300 and 1650 nm laser pulses of C_2H_4. Theoretical calculations of the field-free DCSs of electron scattering from $C_2H_4^+$ ion are also included. In the calculations, we use the angle-dependent ionization rate calculated from the weak-field asymptotic theory [5,6]. We found that the experimental DCSs extracted from several RPS with different laser conditions agree well. Furthermore, the DCS of $C_2H_4^+$ extracted from RPS and the theoretical calculation also show good agreement. These finding indicate the validity of the present extraction procedure of the DCSs from RPS based on the factorization formula.

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