

# Accurate Retrieval of Structural Information of Atoms and Molecules from Laser-Induced Photoelectron and High-Order Harmonic Spectra by Intense Laser Pulses

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**Synopsis:** By analyzing accurate theoretical results as well as experimental results, we established the general conclusion that laser-generated high-energy electron momentum spectra and high-order harmonic spectra can be used to extract accurate differential elastic scattering and photo-recombination cross sections of the target ion with *free* electrons, respectively. Since both electron scattering and photoionization are the conventional means for interrogating the structure of atoms and molecules, this result implies that existing few-cycle infrared lasers can be implemented for ultrafast imaging of transient molecules with temporal resolution of a few femtoseconds.

When an atom or a molecule is exposed to an intense infrared laser, the atom is first tunnel ionized with the release of an electron. This electron is placed in the oscillating electric field of the laser and may be driven back to revisit its parent ion. This reencounter incurs various elastic and inelastic electron-ion collision phenomena where the structural information of the target is embedded. The possibility of using such laser-induced returning electrons for self-imaging molecules has been discussed frequently in the past. By analyzing accurate theoretical results from the solution of the time-dependent Schrödinger equation for rare gas atoms in few-cycle intense laser pulses, we established the general conclusion that the high-energy photoelectron momentum spectra and the high-order harmonics spectra can be simply expressed as the following factorization formula[1],

$$S = \sigma W,$$

where  $S$  is the photoelectron spectrum or the high-order harmonic spectrum, and  $\sigma$  is the elastic or photo-recombination cross section of the target ion by *free* electrons. Here,  $W$  is interpreted as the momentum distribution of the

returning electron wave packet which depends only on the laser parameters.

That conventional electron scattering as well as photorecombination cross sections yield structural information of the atoms and molecules implies that returning electrons induced by existing few-cycle infrared laser pulses can be indeed used for implementation of temporal resolution from a few femtoseconds down to sub-femtoseconds[2].

We will present recent experimental results for extracting a wide range of angular and momentum distributions of the photoelectron cross sections [3] and photo-recombination cross sections [4] of rare gas atoms. We will also discuss several developments, including theoretical and experimental results for molecular targets as well as a detailed structure of the factorization formula based on an adiabatic theory for rescattering processes [5].

## References

- [1] T. Morishita, A.-T. Le, Z. Chen, and C. D. Lin, Phys. Rev.Lett. **100**, 013902 (2008).
- [2] T. Morishita A.-T. Le, Z. Chen, and C. D. Lin, New J.Phys. **10**, 025011 (2008).
- [3] T. Morishita, *et al.*, J. Phys. B. **42**, 105205 (2009).
- [4] S. Minemot, *et al.*, Phys. Rev. A **78**, 061402 (2008).
- [5] O. I. Tolstikhin and T. Morishita, *et al.*, in preparation.