

Rescattering dynamics in strong-field ionization of atomic and molecular targets beyond the dipole approximation

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Abstract

We study photoelectron angular distributions (PADs) from strong-field ionization of noble gases and small molecules with mid-infrared few-cycle pulses. We isolate electrons below the cutoff energy for multiple revisits before rescattering. We observe that their peaks are shifted opposite to the beam propagation direction. This is in contrast to the high-energy part of the electron spectrum above this cutoff.

In strong-field ionization with linearly polarized pulses, the rescattering picture is an important concept that forms the basis for the generation of high-harmonic radiation and attosecond pulses as well as time-resolved molecular structure imaging with photoelectrons. Recently, in a strong-field ionization experiment beyond the long wavelength limit of the dipole approximation, a counterintuitive shift opposite to the beam propagation direction of the maximum of the photoelectron distribution projected onto the beam propagation axis was observed [1].

To access the long-wavelength limit of the dipole approximation, we developed a state-of-the-art optical parametric chirped-pulse amplifier system based on chirped quasi-phase-matching devices. This system delivers laser pulses with a duration of 44 fs, and a pulse energy of 21.8 μJ at a center wavelength of 3.4 μm , with a high repetition rate of 50 kHz [2]. The PADs were extracted from photoelectron momentum images that were recorded with a velocity-map imaging spectrometer.

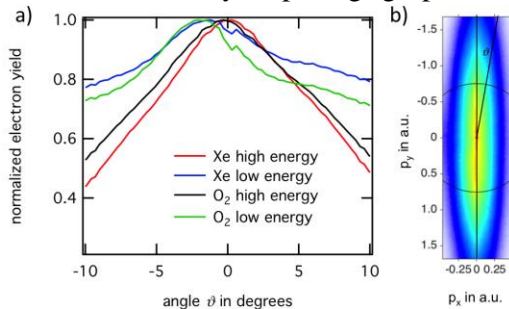


Fig. 1. a) PADs of xenon and oxygen recorded at an intensity of $8 \times 10^{13} \text{ W/cm}^2$. Different momentum ranges ‘high’ and ‘low’ are divided by the black circle indicated in the photoelectron momentum image from xenon in b). The laser is polarized along the y-axis and propagates along the x-axis

To develop a deeper understanding of the processes underlying our earlier observations in Ref. [1] we select the photoelectrons from atomic and molecular targets that stem from multiple revisiting and rescattering processes and compare their angular distributions with the ones that revisit the ion core only once [3], as indicated in Fig 1 b).

The photoelectrons that revisit only once end up in the high energy part above the classical cutoff energy of multiple revisits whereas the photoelectrons in the low energy range of the spectrum below that cutoff energy revisit the core at least twice before rescattering.

The peak of the PAD of electrons from the high-energy part of the spectrum does not show a measurable deviation from the polarization axis. Only the electrons from the low-energy part of the photoelectron images exhibit peaks of the PADs shifted opposite to the beam propagation direction.

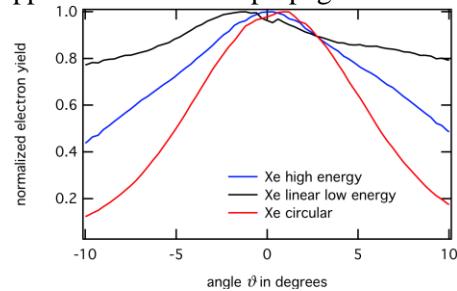


Fig. 2. PADs of xenon recorded at an intensity of $8 \times 10^{13} \text{ W/cm}^2$. The low and high energy parts are plotted for the case of linearly polarized and the full energy range for circularly polarized pulses.

In the case of circularly polarized pulses, shown in Fig. 2, where the spectrum is dominated by direct electrons we observe a shift of the peak of the PAD in beam propagation direction that is in agreement with a SFA-prediction [4].

Furthermore, we compare the PADs from the noble gases xenon and argon and diatomic molecules with nearly the same field-free ionization potential (N_2 and O_2) to study the role of the exact shape of the scattering potential. As we do not see a significant difference between the PADs from the atomic and the molecular target we conclude that our observations are not sensitive to the exact shape of the rescattering potential.

References

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