What's Different and Why for Photoelectrons and Elastic Scattering When Changing from the Strong to Ultrastrong Fields

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Abstract

We report photoelectron energy spectra and angular distributions for ionization with elastic scattering in ultrastrong laser fields. Semi-classical calculations quantify the response for hydrogen-like and selected noble gas species and fields from 10^{16} W/cm^2 to 10^{19} W/cm^2. The relativistic extension of a three-step recollision model using Hartree-Fock scattering potentials is compared to experimental results. The agreement is good for the energy resolved yield but poorer for the energy, angle resolved electron distributions. An update is provided on recent efforts to quantify the ultimate rescattering cutoff in ultrastrong fields.

The three-step model of ionization has provided a framework to understand strong field processes [1] such as electron dynamics, collisional excitation of electrons, high-harmonic generation of coherent attosecond x-ray light, and scattering for molecular tomography. This three-step analysis is traditionally limited to non-relativistic, dipole interactions (0.17 a.u. of field, intensities of 10^{15} W/cm^2) where the energy scale of the interaction, i.e the ponderomotive energy $U_p=e^2|E|^2/(4m\omega^2)$ for an electron charge –e, oscillating in an electric field E at a frequency ω, is far less than the electron rest mass m. As the intensity is increased to "ultrastrong" fields, nonrelativistic and dipole approximations are no longer accurate. The external magnetic field B can deflect the rescattering photoelectron and cause it to miss the parent ion. The ratio of the Lorentz deflection distance to the spatial width of the returning electron wave is indicated by a Lorentz deflection parameter in atomic units [2,3], $\Gamma_r= U_p^{3/2}V_{IP}/(3c^2\omega)$ for ionization from a binding energy V_{IP}. When $\Gamma_r=1$, the deflection of the returning electron is equal to its spatial extent.

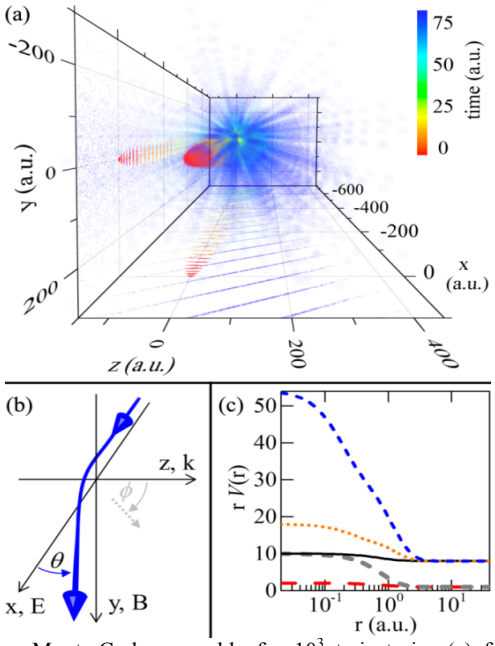

Fig. 1. : Monte-Carlo ensemble for 10^3 trajectories (a) from ionization at 1.3×10^{17} W/cm^2 to rescattering with the core 70 a.u. later (see propagation time color map). The coordinate system (b) and Hartree Fock scattering potentials are shown (c) for Ne^+, Ne^{8+}, Ar^{8+}, and Xe^{8+}. Atomic units (a.u.) are used.

Elastic scattering is a primary mechanism by which the field converts energy into particle motion, a process that is critical to realizing many long term dreams in science including laser fusion. In ultrastrong fields the electron can quickly become relativistic and traverse a large portion, or even exit, the laser focus during a femtosecond laser pulse. Spatial and temporal integration of the interaction region are an integral part of understanding the forces experienced by the photoelectron on the way to the detector. We use Monte-Carlo trajectory ensemble photoionization calculations (Fig. 1) to model photoelectron energy and angle distributions from Ne, Ar, and Xe across strong and ultrastrong fields. We compare these angular distributions to experiments to help quantify how the field-atom interaction changes when entering ultrastrong fields and whether several assumptions in ultrastrong field models are correct, such as a lack of multielectron excitation.

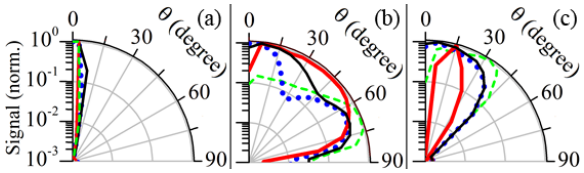

Fig. 2: Photoelectron angular distributions calculated with the full field, relativistically for Ne^+ (solid, black), Xe^{8+} (dotted, blue), Ar^{8+} (dash, green), Ne^{8+} (thick solid, red) at energies of (a) $U_p \pm 0.5\ U_p$, (b) $3\ U_p \pm U_p$, and (c) $7\ U_p \pm U_p$.

References

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