Since the discovery of multiphoton, multiply charged ionization 35 years ago, the study of double ionization in intense laser fields has been foundational in the development of strong-field physics. In the rescattering model, the Coulomb potential of the atom is distorted by the laser field, leading to liberation of an electron through tunneling. This electron gains energy from the laser field and is driven back to the ion, where it can help free a second electron via impact ionization. Since this process relies on trajectories that bring the first electron back to the ion, it is most effective with linear polarization, and is reduced significantly with increased ellipticity. But it has been shown that a bicircular laser pulse, generated by combining two colors with counter-rotating circular polarization, can also lead to effective double ionization. We recently investigated the dynamics of these processes with a computational study utilizing a classical ensemble [Physical Review Letters 116, 143005 (2016)]. Here, we present new results generated with a high-performance computational cluster, uncovering novel patterns in recollision timing, identifying classes of complex trajectories that contribute to double ionization, and demonstrating that rescattering can occur even in co-rotating fields.

**Abstract**

**High-Intensity Lasers**

The atomic unit of intensity is determined by setting the amplitude of the electric field in a pulse of light equal to the electric field magnitude that binds the electron to the proton in a hydrogen atom. At those high intensities, atoms can be ionized even for low photon energies, in defiance of Einstein's description of the photoelectric effect.

**Atoms in Strong Fields**

The fundamental physical process in strong-field laser science is the nonsequential double ionization of atoms via a strongly correlated electron-electron mechanism known as “rescattering.” This phenomena relies crucially on a laser-driven electron returning to the ion, which is efficient for linear polarization and impossible for circular polarization. But a laser pulse composed of two colors (typically at 8 and 2ω) of circularly polarized light can also lead to rescattering. We study this process computationally for co- and counter-rotating fields.

**Computational Method**

Classical model atoms are used to study the intense laser-atom interaction. By using a “softened” Coulomb potential, stable atoms are generated (above). Their interaction with the laser pulse can be visualized with trajectories, giving insight into the overall behavior, or individually, allowing for the development of an intuitive physical picture of rescattering electron trajectories. The UNC High Performance Computational Cluster (below) is used to generate massive data sets, allowing for high-resolution analysis and visualization of very low probability events.

**Double Ionization in Counter-Rotating Fields**

A counter-rotating 2ω:ω = 2:1 bicircular field (left) generates an electric field pattern (white) that can drive an electron in a triangular closed loop trajectory (red). This simple trajectory results from the laser exciting the electron at the peak of the field and ignoring the effects of the other electron or the ion. But the full simulation shows how rescattering occurs across a wide range of amplitude ratios, giving rise to looped, triangular, and even fish-shaped trajectories. The images of sample trajectories (below right) each show 100 events, with some events highlighted for each case (the width of each image is indicated).

**Double Ionization in Co-Rotating Fields**

A co-rotating 2ω:ω = 2:1 bicircular field (left) generates an electric field pattern (white) that can drive an electron in a looping clover loop trajectory (red). But in contrast to the counter-rotating case, this trajectory occurs for release of the electron at a minimum in the intensity. This is much less likely to occur, since the atomic Coulomb potential is barely suppressed at low intensities. Nevertheless, the full simulation shows how rescattering still occurs across a wide range of amplitude ratios, albeit at a much lower rate (right). The timing of the rescattering trajectories that lead to double ionization (below) varies significantly as a function of amplitude ratio, giving rise to a variety of looping trajectories.

**Double Ionization in Counter-Rotating Fields**

A counter-rotating 2ω:ω = 2:1 bicircular field (left) generates an electric field pattern (white) that can drive an electron in a triangular closed loop trajectory (red). This simple trajectory results from the laser exciting the electron at the peak of the field and ignoring the effects of the other electron or the ion. But the full simulation shows how rescattering occurs across a wide range of amplitude ratios, giving rise to looped, triangular, and even fish-shaped trajectories. The images of sample trajectories (below right) each show 100 events, with some events highlighted for each case (the width of each image is indicated).

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