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Pulse-shape effects in strong-field atomic ionization by an XUV pulse

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Synopsis Achieving a significant displacement, defined as a time integral of the vector potential taken over the pulse duration, in strong-field atomic ionization critically depends on the envelope function used for the electric field. Due to the sensitivity of theoretical predictions to the pulse details, an experimental realization of the effect appears to be a major challenge.

In a recent paper [1], strong-field ionization of atomic hydrogen as well as lithium driven by a short extreme ultraviolet (XUV) pulse was studied. The key results of the paper were some peculiar effects in the angular-momentum distribution of the ejected electron, provided the pulse alone caused a significant non-zero displacement of the electron without it leaving the laser focus. The displacement is defined as the time integral of the pulse vector potential taken over the pulse duration, i.e., essentially the second integral over time of the electric field. These effects should be visible in the photoelectron angular distribution [1].

Further examination [2] of the origin of the displacement, however, shows that its value critically depends on the assumption of a plateau in the envelope function of the electric field, and that the ramp-on is fine-tuned, via its length and/or the carrier envelope phase (CEP), in such a way that a drift velocity generated during the ramp-on phase can increase this displacement further. Seemingly minor variations in the electric field cause significant changes in the final results.

Specifically, we investigate n_1-n_2-n_3 pulses, where n_1, n_2, and n_3 denote the number of cycles in the sine-squared ramp-on, plateau, and sine-squared ramp-off phases of the pulse, respectively. Furthermore, we either set the envelope function of the electric field (**E**) or the vector potential (**A**) and then calculate the respective other field using the relationship $\mathbf{E}(t) = -d/dt\,(\mathbf{A}(t)/c)$.

Figure 1 shows the effects of two very similar pulses, which nevertheless differ slightly, since the envelope function of the electric field was set in the left panels while that for the vector potential was set on the right. Due to this variation, obtaining different results does not violate the principle of gauge invariance. For one of the cases, the displacement becomes significant and essentially grows proportional to the length of the plateau. In that case, indeed, there is a significant probability to find angular momenta of the ejected electron other than the expected p-character for a one-photon transition.

As usual, these theoretical predictions were obtained with idealized pulses, which do fulfill the basic requirements of Maxwell's equations for electromagnetic waves propagating in vacuum. In light of the sensitivity of the results, an experimental verification of the displacement effects appears to be very challenging.

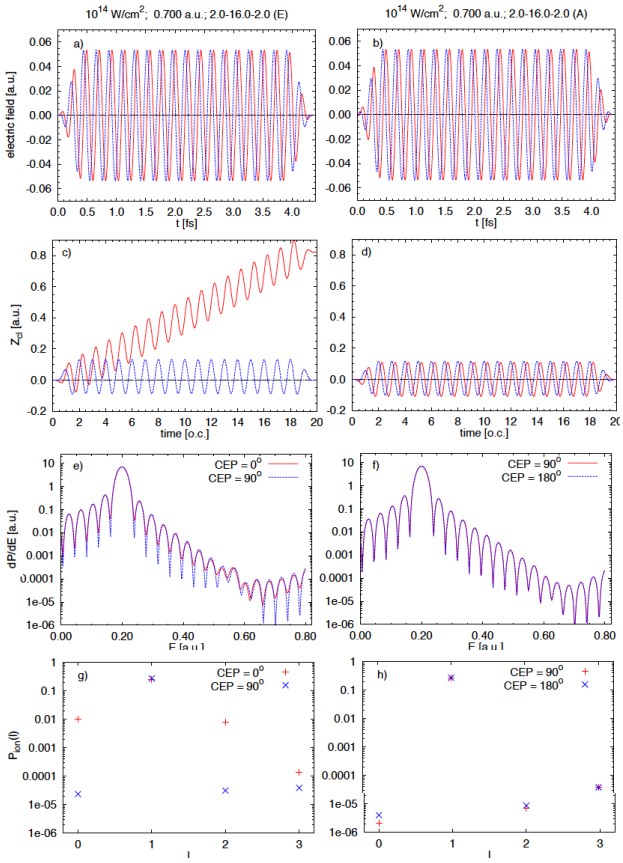

Figure 1. Electric field, classical displacement, energy-differential ionization probability, and l-decomposition for ionization of atomic hydrogen by a 2.0-16.0-2.0 pulse with a central frequency of 0.7 a.u. and a peak intensity of 10^{14} W/cm^2. In the left (right) panels, the envelope function of the electric field (vector potential) is set. The CEP used for panels a)-f) is indicated in panels e) and f).

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