Electron Interference in Atomic Ionization by Two Crossing Polarized Ultrashort Pulses

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Abstract: The formation of geometrically regular interference patterns in the photoelectron momentum distributions produced by photoionization of atoms using two single-color, crossing ultrashort pulses is investigated both analytically and numerically using quantum approaches [1].

Ab initio first-order perturbation theory (PT) and time-dependent Schrödinger equation (TDSE) calculations are used to gain more insight for the ionization process of atoms by two single-color crossing ultrashort pulses. Our theoretical analyses revealed that in contrast to photoionization by monochromatic pulses, the photoelectron momentum distributions (PMDs) for ionization by crossing and copropagating broadband pulses are essentially different, unless both pulses are linearly polarized. Here, for the illustrative cases of H and He atoms we exemplify this study by considering two orthogonal pulse configurations.

First, when one pulse is linearly polarized (LP) along the propagation direction $\boldsymbol{k}$ of the circularly polarized (CP) pulse, interference maxima (minima) of the ionization probability are found to have the form of three-dimensional *single-arm* regular spirals, which are wound along $\boldsymbol{k}$. However, this pattern emerges when detecting the photoelectron along the surface of any of the two mirror-image cones whose axis is defined by $\boldsymbol{k}$, as shown in Fig. 1(a) for a cone with semi-angle $\theta_0 = 55^o$ fixed by the ratio of the electric field strengths. It is important that this pattern does not emerge when electron is detected in the polarization plane of the CP pulse. No ring-shaped patterns (Newton's rings) can be observed in the PMD produced by LP and CP pulses. Neither Newton's rings nor spiral patterns occur for *copropagating* LP and CP pulses. Also, the origin of this single-arm spiral pattern differs from the one created in [2] in the polarization plane from 1- and 2-photon ionization using copropagating two-color time-delayed pulses.

Second, when a pair of time-delayed orthogonal elliptically polarized pulses are used, the interference maxima (minima) of the ionization probability are found to have the form of either Newton's rings or two-arm Fermat spirals depending on the position of a detection plane. For the case where the two pulses have the same ellipticity, Fig. 1(b) shows an example for a detection plane tilted by an angle $\psi = -\pi/4$ with respect to the *xz* plane. Remarkably, these regular patterns occur only for certain values of the pulse ellipticities, and they become distorted for CP pulses.

The production of such spiral patterns by crossing pulses is really unusual since such patterns are never formed when using copropagating pulses with the same helicity [3]. Also, spiral patterns occurring for copropagating elliptically-polarized pulses with opposite helicity [3] are always distorted, not regular as those produced here by crossing pulses.

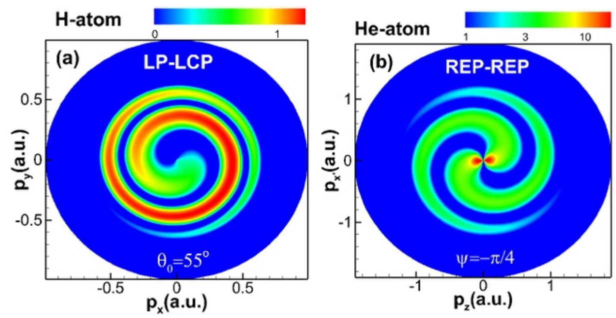

Figure 1: (a) Single-arm spiral pattern exhibited by the PMD in single-photon ionization of H atom by a pair of orthogonal linear/left-circularly polarized (LP-LCP) pulses delayed in time by $\boldsymbol{\tau = 1.6}$ fs. Each 6-cycle cosine-squared pulse with zero CEP has a carrier frequency of **16** eV. (b) Two-arm counterclockwise spiral from photoionization of He atom by a pair of time-delayed orthogonal right-elliptically/right-elliptically polarized (REP-REP) pulses for $\boldsymbol{\tau = 334}$ as. Each 3-cycle cosine-squared pulse with zero CEP has a carrier frequency of **36** eV and an ellipticity of $\boldsymbol{1/\sqrt{2}}$. The intensity of each pulse in (a) and (b) is **100** TW/cm^2.

For these two pulse configurations, the features of interference patterns depend on the detection geometry, time delay between pulses, their relative electric field amplitude and carrier-envelope phase, and ellipticities. Our predictions, illustrated by the numerical PT and TDSE results for the ionization of H and He atoms by two orthogonal pulses, are quite general and expected to be valid for ionization of any randomly oriented atomic or molecular target.

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References

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