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Intra- and Intercycle Interferences Govern Phase Delays in Ω-2ω Strong Field Ionization

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Intra- and intercycle interferences govern phase delays in ω-2ω strong field ionization

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Abstract

Phase delays for a typical ω-2ω configuration for hydrogen ionization are characterized. A splitting of the maximum of the forward ionization as a function of the relative phase exhibits the preclusion of the perturbative regime.

Strong-field ionization by laser fields with commensurate frequencies and well-defined relative phase permits the tune and control of the emission process [1,2]. Multiphoton ionization by laser pulses using the fundamental component and one of its harmonics were investigated and applied for controlled ionization, dichroism, orientation of molecules, and control of interference fringes in the electron momentum distribution [1,2]. The temporal shape of the two-color field is determined by the intensities of the two components and their relative phase. Coherent phase control refers to the manipulations of some physical processes through the relative phase. The concepts of phase shifts and time delays in RABBIT have been extended by Zipp *et al.* [3] for two-color (ω-2ω) lasers with controlled relative phase. Very recently, we have theoretically explored the extraction of ω-2ω phase delays by means of the *ab initio* solution of the TDSE and through the development of a perturbation theory for atomic argon [4].

In this work, we develop a strong-field non-perturbation theory of the electronic photoemission process in atomic hydrogen due to a two-color for visible frequency and its first harmonic ω-2ω [Ti:Sapphire laser (800 nm) together with the first harmonic (400 nm)] linearly polarized short laser pulse in the multiphoton regime. We introduce a general theory based on the saddle point approximation (SPA) to study phase delays of photoelectrons. We focus on the extraction of the phase shifts using directional emission in the forward direction. We calculate the ionization time of each interfering electron trajectory, analyzing ω-2ω photoionization. We study the dependence of the electron emission as a function of the relative phase between the ω-2ω fields within the strong field approximation. Different interference structures of the doubly differential momentum distribution arise (see Fig. 1). Atomic units are used unless stated otherwise.

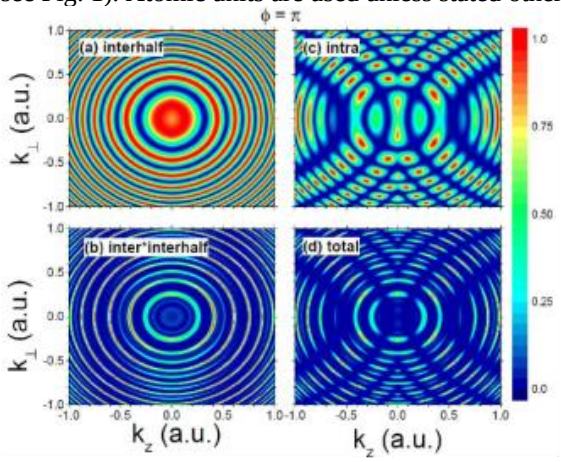

Figure 1: Doubly differential momentum distribution as a function of the longitudinal momentum and perpendicular momentum within the SPA with relative phase ϕ=π. (a) Interhalfcycle factor. (b) Multiplication of the inter- and the interhalfcycle factors. (c) Intracycle factor. (d) Total distribution. All distributions are normalized.

We consider a vector potential of the form $A(t) = -\left[F_{2\omega} / (2\omega) \sin(2\omega t) + F_{\omega} / \omega \sin(\omega t + \phi) \right]$. Within the SPA, electron yield stem from the coherent superposition of semiclassical trajectories. In Fig. 1a the interference between the electron trajectories released from the two half cycles of the vector potential is shown as concentric rings. When multiplied by the intercycle factor coming from the different optical cycles, some or the rings are enhanced (ATIs) and some lessen (sidebands). Electron trajectories within a half cycle also interfere as shown in Fig. 1c. We show the total momentum distribution in Fig. 1d. We find excellent agreement between our SPA results and the corresponding SFA, whose perturbative limit coincide with previous theories.

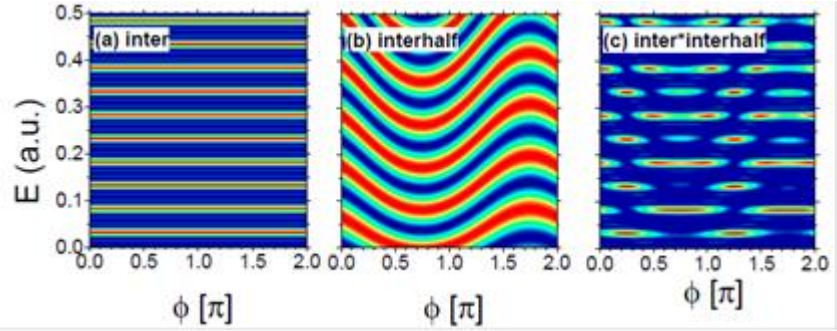

Figure 2: Energy distribution in the forward direction as a function of ϕ for the ω–2ω ionization within the SPA. (a) Intercycle factor, (b) interhalfcycle factor, (c) multiplication of (a) and (b). All distributions are normalized.

The energy spectrum in the forward direction as a function of the relative phase ϕ between the two colors within the SPA is depicted. All multiphoton peaks (ATIs and sidebands) are present in the intercycle factor in Fig. 2a with separation of one ω photon energy, which is independent ϕ, as expected. The interhalfcycle factor can be observed as a 2π-periodic function in Fig. 2b. The separation between interhalfcycle maxima corresponds to a 2ω photon energy and the amplitude of the oscillation increases with energy. The interplay between the inter- and interhalfcycle interferences is plotted in Fig. 2c where both ATI peaks and sidebands are present. We see that the first multiphoton peak just above the threshold (E_n=0.035 a.u.) is an ATI peak with $\phi_0=\pi/4$ and $5\pi/4$. In turn, the first sideband at E_{13}=0.085 maximizes at $\phi_0=3\pi/4$ and $7\pi/4$.
We focus on the extraction of the phase delays accounting the electron forward emission along the direction of the polarized electric fields. Phase delays calculated within our SPA agree not only with our SFA calculations but also with previous perturbation theories [2,3] if the probe field amplitude is much weaker than the pump pulse, or photoelectron energies are close to the threshold (perfurbative regime). The extension of perturbative theories to the strong-field approximation gives rise to novel effects for intermediate and high electron energies like the departure of the sinusoidal behavior of the intensity of ATIs and sidebands as a function of the relative phase ϕ. This results in the splitting of the maxima of ATIs and sidebands as a function of ϕ, as observed in Fig. 2c, which force us to revise the extraction method of phase delays for strong field ionization [5].

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References

[1] D. G. Arbó, et al. S. Nagele, X-M. Tong, X. Xie, M. Kitzler, and J. Burgdörfer, "Interference of electron wave packets in atomic ionization by subcycle sculpted laser pulses", Phys. Rev. A **89**, 043414 (2014).
[2] X. Xie *et al.,* "Attosecond probe of valence-electron wave packets by subcycle sculpted laser fields". Phys. Rev. Lett. **108**, 193004 (2012).
[3] L. J. Zipp, A. Natan, and P. H. Bucksbaum. "Probing electron delays in above threshold ionization". Optica 1, 361 (2014).
[4] S. D. López et al., "Phase delays in ω–2ω above-threshold ionization". Phys. Rev. A 104, 043113 (2021).
[5] D. G. Arbó *et al*, "Semiclassical strong-field theory of phase delays in ω − 2ω above-threshold ionization", Phys. Rev. A (2022, in press).