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Multiphoton Ionization of Hydrogen Atom by Multiple Laser Beams

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This work presents a detailed study of multiphoton ionization in hydrogen-like atoms when interacting with multiple laser beams. We analyze the angular distribution of ejected photoelectrons and how various parameters—such as polarization, phase, and intensity—affect the differential ionization cross-section. Using high-order perturbation theory and the Dalgarno-Lewis method, we solve the time-dependent Schrödinger equation (TDSE) in a semi-classical, non-relativistic framework under the dipole approximation. The study specifically focuses on ionization caused by laser beams of the same frequency but different polarizations and phase differences.

We derive analytical expressions for the multiphoton ionization rates, separating the radial and angular parts of the transition amplitudes. These expressions show how the angular distribution is influenced by parameters like incident beam polarization, phase shift, photon frequency, and beam intensity. Numerical results demonstrate that increasing the number of beams changes the amplitude of the cross-section. This leads to more complex patterns of symmetry and asymmetry in the angular distribution of ejected electrons.

Symmetry dominates in simpler scenarios. For example, in the case of a single beam, the distribution remains symmetric with respect to both polarization axes. As we introduce more beams, asymmetry emerges due to the interference of multiple transition amplitudes. By adjusting the polarization and phase differences between the beams, we control the degree and nature of the asymmetry. This is seen clearly in cases with two, three, and more beams, where the angular distributions deviate significantly from spherical symmetry. In these cases, the effects of asymmetry become more pronounced, especially when different polarization states and phase shifts are applied to the beams.

Polarization plays a particularly significant role in defining the angular distribution. For instance, when using right circularly polarized beams, the symmetry of the distribution is apparent, but by introducing phase differences between the beams, asymmetries quickly become evident. Figures in our results clearly depict these shifts from symmetric to asymmetric distributions as the number of interacting beams and their respective polarizations and phases are varied.

In summary, this work provides a comprehensive theoretical framework for understanding and predicting the behavior of hydrogen-like atoms under multiphoton ionization, with a focus on how laser beam parameters affect the symmetry and asymmetry of angular distributions[1]. The analytical and numerical results presented here open new possibilities for exploring multiphoton processes and offer insights into the experimental observations of electron ejection patterns in multiphoton ionization events. Our formalism also offers a means to further study advanced ionization phenomena, such as above-threshold ionization (ATI), by extending the analysis into the complex plane.

Reference

[1] N. Shrestha *et.al* J. Phys. B: At. Mol. Opt. Phys. 47, 105002 (2014)

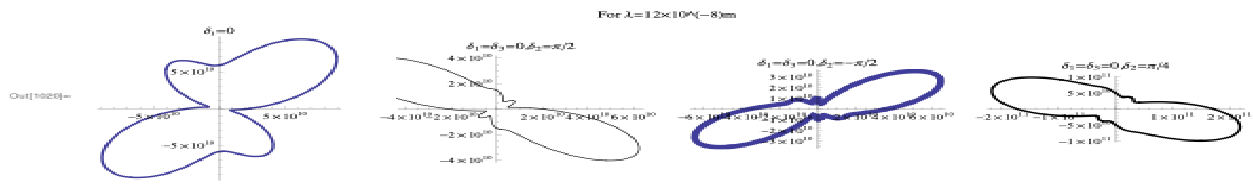

Figure 1. Polar plots of differential cross-section of two-photon ionization with two beams changing polarization, for $\delta_1=\pi/2$, $\delta_2= 0$, and $\zeta_2= 0$, but varying $\zeta_1= 0$, to $\pi/6$, the coordinates in bracket are ($\theta=\pi/2$, ζ_2, ζ_1)

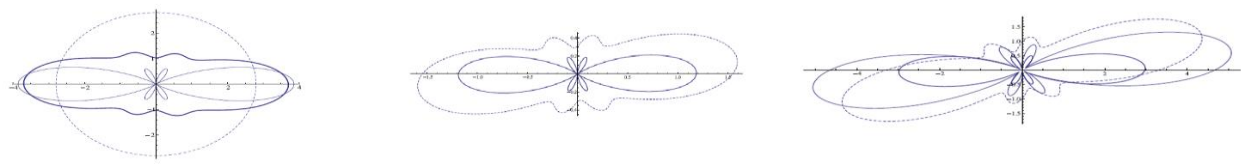

Figure 2. Polar plot of the differential cross -section of the three-photon ionization with single beam, Thin line $\zeta_1=0$,Thick line $\zeta_2=\pi/4$ and Dashed line $\zeta_3=\pi/2$ (left), With three beams, ζ_1, $=\pi/3$, $\zeta_2=0$ and $\zeta_3=\pi/4$Thick and thin lines corresponds $\delta = \pm\,\pi/4$, (middle) and With five beams, Thin line ζ_1, $= 0$, Thick line $\zeta_3= -\pi/2$ and dashed line ζ_1, $= \pi/2$, $\zeta_2 = \zeta_4=\pi/2$, and $\zeta_5=0$, phase of the beams, $\delta_1= \delta_4 = \delta_5 =0$ and $\delta_2= \delta_3 =\pi/2$, (Right), Cross-section is normalized by factor 10^{-45}.