Frustrated Tunneling Dynamics in Ultrashort Laser Pulses

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In addition to the process of tunneling ionization, one also finds a nonzero Rydberg state population, when an atom is subjected to an intense, low-frequency laser pulse. This process is known as frustrated tunneling ionization, and has been explained with a classical model where the electron tunnels close to the peaks of the electric field, and is later captured by the atomic potential [1]. We have studied frustrated tunnelling in Hydrogen with ultrashort pulses using a theory based on the strong-field approximation (SFA) [2], and compared it to results obtained by solving the time-dependent Schrödinger equation (TDSE). We used pulses of 800 nm wavelength, a 2 fs pulse duration and intensities on the order of 10^{14} W/cm^2.

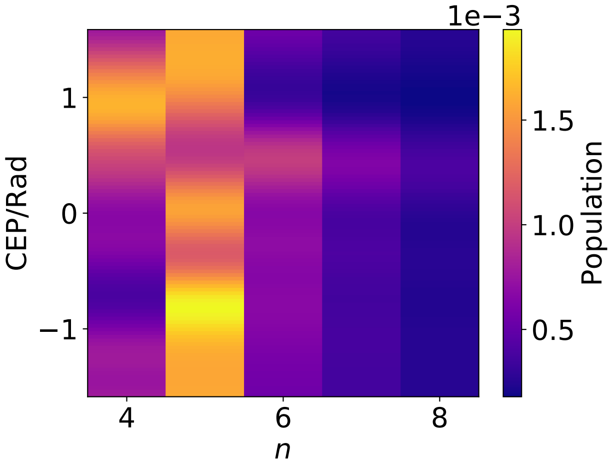

Figure 1: CEP dependence of the Rydberg population with principal quantum number n, calculated with the TDSE

The SFA model that was used relies on a saddle point approximation that is supplemented with additional constraints to ensure that the trajectory associated with a solution of the saddle point equation will have energy and angular momentum that corresponds to a particular Rydberg state. Since we are dealing with short laser pulses, the carrier-envelope phase (CEP) becomes important. The solutions to the modified SFA equations show an intricate dependence on CEP and angular momentum l. As the CEP is varied in our TDSE simulations, we see a modulation in the total population of states with different principal quantum numbers n, see Fig. 1, that the SFA theory can qualitatively reproduce for $n \geq 4$. However, for $n = 2, 3$ we do not see agreement between the TDSE and SFA results. Additionally, when we resolve the CEP variations in l, we do not find an agreement between TDSE and SFA for any n.

In conclusion, we have shown that population transfer to Rydberg states in ultrashort, intense pulses can be interpreted by frustrated tunneling. To support this conclusion, we have also performed TDSE simulations where the continuum states are either removed entirely from the state space, or damped during propagation, and find that the continuum states must be included in order to get the correct Rydberg state population.

References

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