UNIVERSITY OF WARSAW

Abstract

Faculty of Physics

Doctoral Dissertation

Radiative Recombination in Strong Laser Pulses

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In this dissertation, we investigate laser-assisted radiative recombination (LARR) in strong laser pulses, an important phenomenon in strong-field physics. This process is crucial as it serves as a fundamental step of high-order harmonic generation, which ultimately led to the development of attosecond science.

In our study, we provide a comprehensive treatment of the LARR process, starting with an analysis of laser-assisted electron-atom radiative recombination. We consider an electron recombining with a hydrogen-like atom under the influence of a short-range atomic potential in the presence of a laser pulse, that results in the emission of high-energy photons. Additionally, we treat the laser pulse within the dipole approximation. Unlike previous formalisms, our comprehensive treatment of LARR eliminates the nonphysical oscillations in the energy spectrum of emitted photons. Moreover, we identify the laser-field-free recombination, which manifests as a peak in the energy spectrum of LARR. Together with parameters like the electron energy, the carrier-envelope phase of the pulse, and its shape, we also investigate the impact of a train of identical laser pulses on the LARR energy distribution. Our findings show that the energy distribution coherently enhances, varying in proportion to the square of the number of pulses in the train. Furthermore, we conduct a time-frequency analysis of the energy distribution of LARR, which allows for a laser-pulse diagnostics.

Under certain conditions, the dipole approximation may not be applicable. Therefore, the studies mentioned above serve as a foundation for exploring LARR beyond the dipole approximation. Additionally, we aim to investigate the impact of the Coulomb potential on the energy spectrum of LARR. Hence, we study the recombination of an electron to a hydrogen-like positive ion in the presence of the Coulomb potential and the laser field; the latter varying in space and time. To account for the nondipole corrections in the leading order in $1/c$, we perform a relativistic reduction of the Klein-Gordon equation for the scattering state of the electron. Our studies reveal that nondipole corrections that are arising are of three different origins: gauge transformation correction, retardation, and recoil correction. We observe nondipole effects manifesting as an extension of the plateau and an asymmetry in the energy-angle distribution of LARR, primarily attributed to the recoil effect. In addition, we demonstrate a method to enhance the intensity of specific harmonics on the edges of the LARR plateau by chirping the assisting laser pulse. We conclude our investigation by demonstrating the nodal and vortex structures in the LARR probability amplitude.