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Compound-state model for non-sequential double ionization

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Non-sequential double ionization (NSDI) is a strong-field atomic process in which two electrons simultaneously leave atom irradiated by an intense laser pulse.[1] This process has been described successfully by the three-step (TS) model. The first step of this model is the process of tunneling an atomic electron through the barrier which is formed by combining the atomic potential with the electric component of laser field in the maximum phase. The second step is the acceleration of the tunneled electron in the field during the next half of the optical cycle. In the third step the electron reverse direction, as the electric field changes, and returns with increased energy back towards the parent ion. A possible result of this process is the electron-ion recombination and the formation of a highly excited atomic state, which can be further deexcited to the ground state by emitting radiation, the so-called high harmonic generation, or decomposed by NSDI. In numerical simulations of the NSDI the tunneling dynamics (the first step) is treated quantum mechanically or semiclassically, but the electron's motion in the second and the third step is treated fully classically. In order to collect a sufficient amount of data for quantitative analysis, simulations of this kind of collision processes are usually performed using the classical trajectory Monte Carlo (CTMC) method.

For the field intensities close to the threshold for NSDI the so-called compound-state (CS) model [2] might be a valid alternative to the TS model. Both models assume that the NSDI goes via formation of a doubly excited intermediate state in the recollision process. However, the CS model assumes that, due to strong electron-electron interactions during recollision, the excited state has lost almost the complete memory of its formation dynamics [3,4] such that a compound state is prepared. This state determines initial conditions for the rest of the NSDI process. In numerical simulations we start with a compound state of a given energy $E_{\rm CS}$ formed at the moment of recollision $t_{\rm rec}$ and consider its decay in the laser field. The possibility for double ionization strongly depends on the phase of the field at $t_{\rm rec}$. Fixing the carrier envelope phase (CEP) of the laser pulse the parameters $E_{\rm CS}$ and $t_{\rm rec}$ become well-defined functions of the time t_0 when the recolliding electron leaves the barrier after tunneling. Using the CTMC method the NSDI can be simulated by varying randomly the time t_0 and the compound state parameters (except the energy $E_{\rm CS}$ which is a function of t_0). In this way one reduces the full-collision calculations, used in the TS model, to half-collision ones. The later significantly simplifies and speeds up the simulation of NSDI and might be extended easily to non-sequential multiple ionization (NSMI) processes.

References

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