Non-Dipole Recollision-Gated Double Ionization and Observable Effects

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Using a three-dimensional semiclassical model, we study double ionization for strongly-driven He fully accounting for magnetic field effects. For linearly and slightly elliptically polarized laser fields, we show that recollisions and the magnetic field combined act as a gate. This gate selects a subset of the initial tunneling-electron momenta along the propagation direction of the laser field. Only this subset leads to double ionization. This gating is particularly pronounced at intensities smaller than the intensities satisfying the criterion for the onset of magnetic field effects $\beta_0 \approx 1$ a.u. The propagation direction of the laser field is the same as the direction of the Lorentz force $\vec{F}_B$ force (to first order) and is along the $+y$-axis. When non-dipole effects are fully accounted for, we show that the y-component of the initial momentum of the tunneling-electron is mostly negative for events leading to double ionization. The term non-dipole recollision-gated ionization is adopted to describe ionization resulting from an asymmetric distribution of the transverse tunneling-electron initial momentum due to the combined effect of the recollision and the magnetic field.

Non-dipole recollision-gated ionization is a general phenomenon in double electron escape in atoms driven by linearly and slightly elliptically polarized laser fields [1].

Moreover, we show that non-dipole recollision-gated ionization results in an asymmetry in a double ionization observable. Let $\phi \in [0^\circ, 180^\circ]$ denote the angle of the final ($t \to \infty$) momentum of each escaping electron with respect to the propagation axis of the laser field. The observable in question is $P_{\text{asym}}^{\text{DI}}(\phi) = P^{\text{DI}}(\phi) - P^{\text{DI}}(180^\circ - \phi)$, where $P^{\text{DI}}(\phi)$ is the probability of either one of the two electrons to escape with an angle $\phi$. $P^{\text{DI}}(\phi)$ and $P_{\text{asym}}^{\text{DI}}(\phi)$ are accessible by kinematically complete experiments. In the dipole approximation, $P_{\text{asym}}^{\text{DI}}(\phi) = 0$. When non-dipole effects are accounted for, it is shown that $P_{\text{asym}}^{\text{DI}}(\phi) > 0$, for $\phi \in [0^\circ, 90^\circ]$. We also find that $P_{\text{asym}}^{\text{DI}}(\phi)$ has considerable values over a wide interval of $\phi$ at lower intensities. This latter feature is an unexpected one.

We finally show that non-dipole recollision-gated ionization is the mechanism underlying the surprisingly large average sum of the momenta of the two escaping electrons along the propagation direction of the laser field. This large average sum of the electron momenta is roughly an order of magnitude larger than twice the average of the respective electron momentum in single ionization, see figure 1. We recently reported this in [2] for intensities around $10^{15}$ Wcm$^{-2}$ for He at 800 nm (near-infrared) and around $10^{14}$ Wcm$^{-2}$ for Xe at 3100 nm (mid-infrared). If magnetic-field effects are not accounted for the average momentum along the propagation direction of the laser field is zero.

Figure 1: a) The average sum of the two electron momenta $<p_y + p_y^{\text{DI}}>$ in double ionization (black dot-dashed line with open circles), twice the average electron momentum $<p_y>$ in single ionization (black solid line with circles) and the ratio $<p_y + p_y^{\text{DI}}>/<p_y>$ (red dotted line with triangles) as a function of the intensity of the laser field. (b) The average momentum of the tunneling electron $<p_y>$ in double ionization (grey dot-dashed line with open circles) and the bound electron $<p_y^{\text{DI}}>$ in double ionization and the ratio $<p_y>/<p_y^{\text{DI}}>$ (red dotted line with squares) as a function of the intensity of the laser field.
References
