Collective Tunnel Effect in Atoms Driven by Strong Laser Fields

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Sequential tunneling of electrons is known to be the basic ionization mechanism for atomic systems subject to intense low-frequency laser fields. Electron-electron interaction can strongly affect the ionization dynamics, giving rise to various nonsequential channels, whose contribution can highly dominate that of the sequential ionization pathway. The celebrated deviation from the sequential scenario of double and multiple ionization is triggered by rescattering of an electron on its parent ion – the phenomenon known as recollision [1,2]. Its dominant contribution to the rate of double ionization of atoms in linearly polarized fields of intensity $10^{14} - 10^{16}\mathrm{W/cm}^2$ is by now firmly established in experiments and thoroughly described by the theory [3]. Another possible channel of the nonsequential double ionization is collective tunneling, *i.e.*, a simultaneous sub-barrier escape of two electrons from the atom. This mechanism has been discussed within simple models [4,5], but has so far not been evidenced in experiments or exact numerical solutions.

In this contribution, by solving numerically the time-dependent Schrödinger equation for model two-electron two-dimensional (2D) atomic systems (the negative bromine ion and neutral xenon), we demonstrate collective tunneling and describe our numerical findings within an analytic theory based on the semi-classical technique of complex trajectories. We examine the double ionization dynamics in the field of a unipolar electromagnetic pulse, which supports no recollision and therefore allows looking in detail at tiny deviations from the sequential ionization channel.

By analyzing the 2D two-electron probability density, we demonstrate a clear signature of the collective under-barrier motion of the two electrons and show that this motion is consistent with the features of the potential surface of the corresponding reduced three-body (an immobile ion + two electrons) problem. Our results show that the 2D geometry gives rise to a barrier that allows the electrons to tunnel through by having the same longitudinal and opposite transverse coordinates with respect to the field direction. Using the trajectory formalism, we derive the leading exponential term in the collective ionization rate and show that this rate can appear comparable to that of sequential tunneling. Our analysis predicts the presence of two additional symmetric peaks in the lateral momentum distributions of the photoelectron pairs. This three-hump structure of the lateral momentum distribution is absent both for the sequential and rescattering double ionization channels. This feature, specific to collective tunneling, provides a route to an experimental search of this ionization channel.

Also, we demonstrate that the relative contribution of the collective ionization channel is highly sensitive to the pulse duration. In short pulses of duration $\tau = 2 - 4$ fs the collective channel makes a noticeable contribution, while for pulses with $\tau > 10$ fs, ionization proceeds predominantly through the sequential mechanism.

Some results presented in this contribution have been recently published in [6].

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