Experimental evidence for Wigner's tunneling time

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Synopsis The first hundred attoseconds of the electron dynamics during strong field tunneling ionization are investigated

Tunneling of a particle through a barrier is one of the counter-intuitive properties of quantum mechanical motion. Thanks to advances in laser technology and generation of electric fields comparable to those electrons experience in atoms, new opportunities to dynamically investigate this process have been developed. For example, in the so-called attoclock measurements [1] the properties of the electron after tunneling are mapped on its emission direction after its interaction with the laser pulse. These properties are central for the field of attosecond spectroscopy where common techniques such as high-harmonic generation or laser-induced electron diffraction rely on tunnel ionization. In this work we quantify theoretically how the electron's classical trajectories in the continuum emerge from the tunneling process and test the results with those achieved in parallel from attoclock measurements.

We accomplished two key technological enhancements to the attoclock principle in order to achieve a high sensitivity on the tunneling barrier. Firstly we use the near-IR wavelength of 1300 nm to place firmly the ionization process in the tunneling regime and limit non-adiabatic effects. Secondly, we compare the momentum distributions of two atomic species of slightly deviating atomic potentials (argon and krypton) being ionized under absolutely identical conditions (Fig. 1).

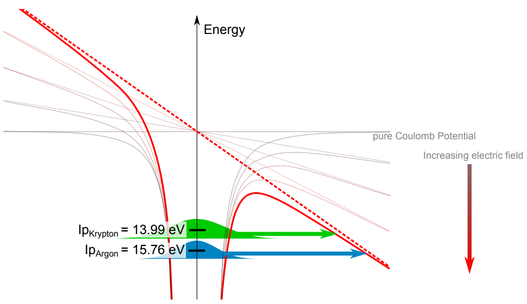

Figure 1. Tunneling ionization for argon and krypton atoms

Experimentally, using a reaction microscope, we apply coincident electron-ion detection in combination with a gas-target that contains a mixture of the two species and succeed in measuring the 3D electron-momentum distributions for both targets simultaneously. Theoretically, the time resolved description of tunneling in strong-field ionization is studied using the leading quantum mechanical Wigner treatment.

A detailed analysis of the most probable photoelectron emission for Ar and Kr (Fig. 2) allows a detailed test of theoretical models and a sensitive check of the initial conditions for the electron at the tunnel exit.

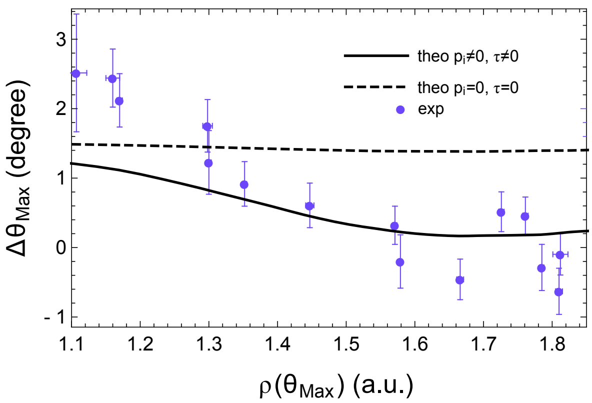

Figure 2. The difference between the most probable photo-electron emission angle for argon and krypton: experiment and theories (with and without initial momentum and tunneling delay time)

The agreement between experiment and theory provides a clear evidence for a non-zero tunneling time delay and a non-vanishing longitudinal momentum of the electron at the tunnel exit [2].

References

[1] P. Eckle *et al.* 2008 *Science* **322** 1525

[2] N. Camus *et al.* 2016 *Arxiv* **1611.03701**

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