MULTIPHOTON DOUBLE IONIZATION OF HELIUM

Manuel Ederer, Stefan Donsa, Fabian Lackner, Iva Březinová, Joachim Burgdörfer

E136 Institute of Theoretical Physics

INTRODUCTION

Double ionization of helium by bright, ultra-short laser pulses is a prototypical test case to study strong electron correlations. Since both electrons leave the nucleus within a fraction of a femtosecond (10^{-15} s) they can share the energy of the absorbed photons via Coulomb interaction. We study the imprint of this interaction for different photon energies on the fully differential two-electron wave function.

THEORETICAL BACKGROUND

The dynamics of the helium atom in a laser field is governed by the time-dependent Schrödinger equation

$$i\partial_t \Psi(\mathbf{r}_1,\mathbf{r}_2,t) = \left[\frac{\mathbf{p}_1^2}{2} + \frac{\mathbf{p}_2^2}{2} - \frac{2}{\mathrm{r}_1} - \frac{2}{\mathrm{r}_2} + \frac{1}{|\mathbf{r}_1 - \mathbf{r}_2|} + (\mathbf{r}_1 + \mathbf{r}_2)E(t)\right]\Psi(\mathbf{r}_1,\mathbf{r}_2,t), \qquad (1)$$

where $E(t)$ is the electric field and $\mathbf{r}_i$ and $\mathbf{p}_i$ are the relative coordinates and momenta of the electrons. We solve Eq. 1 employing the time-dependent close coupling method [1]. After the conclusion of the laser pulse we project the final wave function $\Psi(\mathbf{r}_1,\mathbf{r}_2,t_f)$ onto the symmetrized product of Coulomb waves to obtain the fully differential double ionization probability $P^{DI}(\mathbf{k}_1,\mathbf{k}_2)$ which is experimentally accessible [2].

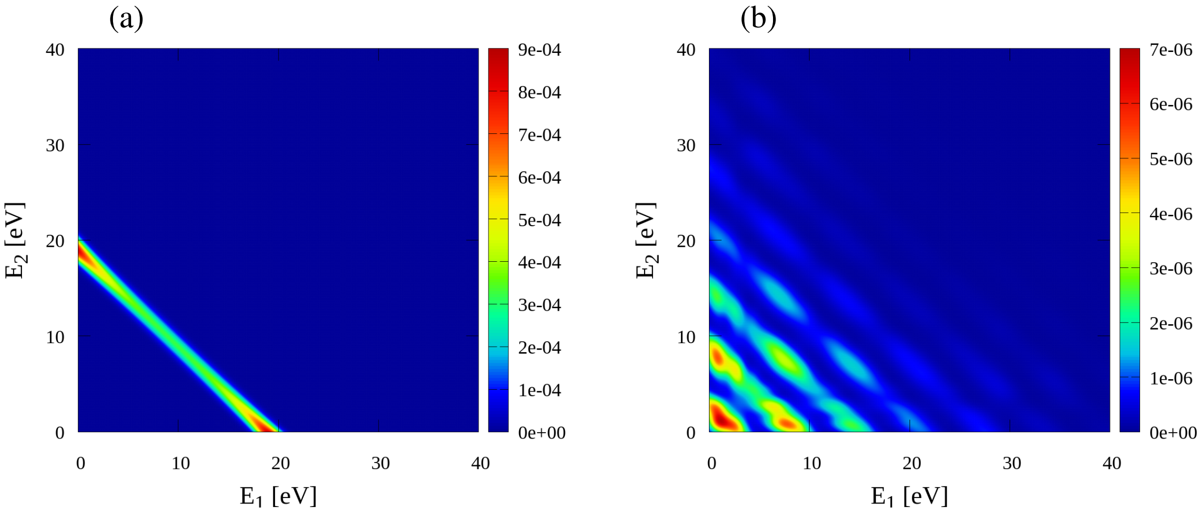

Figure 1: Double-ionization spectra $P(E_1,E_2)$ as a function of the electron energies E_1 and E_2 for a laser pulse with (a) wavelength $\lambda = 25.1$ nm ($\cong$ 49.4 eV), intensity of $I = 10^{14}$ W/cm^2 and total duration of 4 fs and a pulse with (b) $\lambda = 197$ nm ($\cong$ 6.3 eV), $I = 10^{15}$ W/cm^2 and total duration of 8 fs.

RESULTS AND DISCUSSION

The angle integrated doubly-differential double ionization spectrum depends strongly on the energy of the absorbed photons. For an energy of 49.4 eV double ionization can only occur if two photons are absorbed and the electrons share the energy because the energy of one photon is smaller than the second ionization potential of helium. This is referred to as two-photon non-sequential double ionization, see [3]. The resulting energy distribution shows a characteristic band along the total energy $E_1 + E_2 = 2\omega$ with maxima where one of the electrons ends up with close to the total energy, see Fig. 1(a). For photon energy of 6.3 eV where at least 13 photons have to be absorbed to overcome the double ionization potential of ~ 79 eV the energy distribution shows considerable differences compared to the two-photon case. We observe multiple bands where each band along constant total energy corresponds to absorption of an additional photon. Angular resolved quantities like the joint-angular distribution $P(\theta_1 = \phi_1 = \phi_2 = 0°, \theta_2)$ at equal energy sharing ($E_1 = E_2$) provide even more insight, see Fig. 2. For photon energies of 49 eV the joint-angular distribution shows a pronounced minimum for emission of both electrons into the same direction independent for both two or three photon absorptions, due to the electron-electron repulsion. However, for two-photon absorption we observe a distinct maximum for back-to-back emission ($\theta_2 = 180°$) while three photon absorption shows a node at $\theta_2 = 180°$ as this process would violate parity conservation.

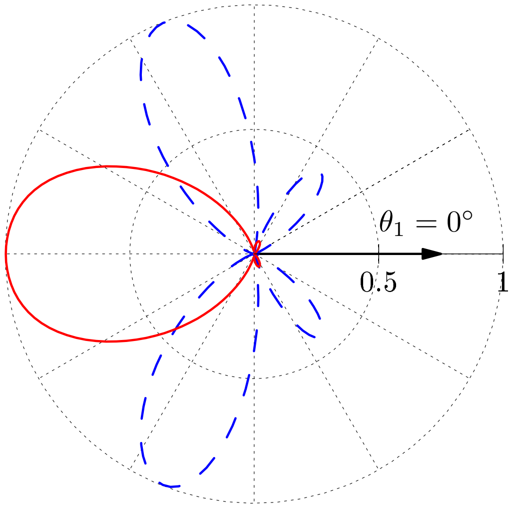

Figure 2: Joint angular distribution $P(\theta_1 = \phi_i = 0°, \theta_2)$ with equal energy sharing ($E_1 = E_2$). Solid line: absorption of two photons with photon energy $\omega = 49$ eV. Dashed line: absorption of three photons with photon energy $\omega = 29$ eV. The direction of the first electron is indicated by the arrow.

CONCLUSION

We investigate double ionization of atomic helium by short, intensive laser pulses with photon energies from 100 eV down to a few eV. The fully-differential energy spectra allow insights into the properties of electronic correlations. In the future we will use fields approaching the infra-red limit (800 nm) and explore the influence of elliptical polarization on multi-photon double ionization.

REFERENCES

[1] M. S. Pindzola and F. Robicheaux. *Time-dependent close-coupling calculations of correlated photoionization processes in helium.* Phys. Rev. A **57**, 318 (1998).

[2] R. Dörner, V. Mergel, O. Jagutzki, L. Spielberger, J. Ullrich, R. Moshammer, and H. Schmidt-Böcking. *Cold Target Recoil Ion Momentum Spectroscopy: a 'momentum microscope' to view atomic collision dynamics.* Physics Reports **330**, 95 (2000).

[3] J. Feist, S. Nagele, R. Pazourek, E. Persson, B. Schneider, L. A. Collins, and J. Burgdörfer. *Nonsequential two-photon double ionization of helium.* Physical Review A **77** (2008).