# Evidence of decrease of potential energy in nonsequential double ionization above threshold for electron impact excitation

XXVIII International Conference on Photonic, Electronic and Atomic Collisions (ICPEAC 2013) IOP Publishing
Journal of Physics: Conference Series **488** (2014) 032042 doi:10.1088/1742-6596/488/3/032042

# Evidence of decrease of potential energy in nonsequential double ionization above threshold for electron impact excitation

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**Synopsis** We study the CEP (carrier envelope phase) dependent correlated electron momentum distributions for nonsequential double ionization of Ar in near-single-cycle short pulses at the intensity of $3.0\times10^{14}$ W/cm$^2$ with a central wavelength of 750 nm measured by Bergues *et al* [Nat. Comm. **3**, 813 (2012)]. A kinematical analysis on the constraints for the correlated electron momenta reveals that the excitation potentials of the parent ion $Ar^+$ are reduced at the instant of scattering.

Recently, the measurements of the correlated electron momentum distributions (CEMD) for nonsequential double ionization (NSDI) of Ar with near-single-cycle, 4 fs laser pulses at the peak intensity of $3.0\times10^{14}$ W/cm$^2$ with a central wavelength of 750 nm have been carried out by Bergues *et al* [1] using the CEP tagging method. While the CEP-resolved spectra enables one to trace the correlated emission of the two electrons on sub-femtosecond timescales in the NSDI processes, the cross-shaped structure observed in the CEP averaged CEMD (see Fig. 1) provides a clear evidence of changes of the threshold of the single charged ion $Ar^+$ at the time when the electron impact excitation takes place.

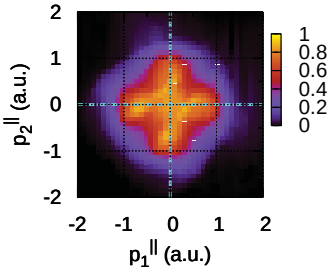


**Figure 1**. Experimental correlated electron momentum distributions along the polarization direction for NSDI of Ar with near-single-cycle, 4 fs laser pulses at the intensity of $3.0\times10^{14}$ W/cm$^2$ [1].

The cross-shaped structure shown in Fig. 1 is mainly attributed to recollision excitation of $Ar^+$ with subsequent tunneling. According to the kinematical analysis on the constraints for the correlated electron momenta [2], it is the ponderomotive energy $U_p = A_0^2/4$, where $A_0$ is the maximum value of the vector potential, rather than the pulse duration of the laser field that plays crucial role in producing the cross-shaped structure in the CEP-averaged CEMD. Besides, the constraints for the correlated electron momenta are also determined by the excitation potential $I_p$.

For electron impact excitation of $Ar^+$, the excitation from $3s^23p^5$ to $3s^23p^43d$ dominates [3]. In Fig. 2, we show the kinematically allowed region for the correlated electron momenta for recollision excitation of $Ar^+$ from $3s^23p^5$ to $3s^23p^43d$ with subsequent tunneling in NSDI of Ar for the laser parameters used in Ref. [1]. It can be seen that the region with small momenta is not covered leading to a small hole in the center. This clearly indicates that to reproduce the cross-shaped structure, the excitation potential has to be reduced [4].

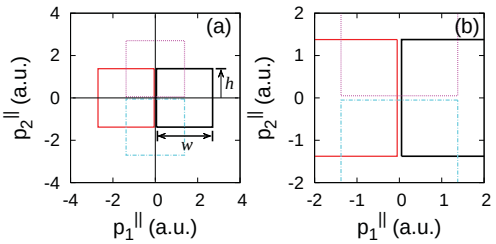


**Figure 2**. Kinematically allowed region for the correlated electron momenta for recollision excitation in NSDI of Ar with $w=2\sqrt{2(3.17U_p - I_p)}$ and $h=A_0$. (a) The whole region; (b) The zoomed-in region of the central part.

## References

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