Decoherence on photoelectron density matrices

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We report the experimental measurement of the full quantum state of an attosecond electron wavepacket using laser-dressed photoionization.

Laser-dressed photoionization spectroscopy has been the cornerstone of attosecond metrology since 2001. In the photoionization of a gas jet by an XUV attosecond pulse combined with a femtosecond infrared pulse, the spectrogram (photoelectron kinetic energy distribution as a function of the laser-XUV delay) gives access to intimate information on the ionization process.

We have recently shown that this historical approach strictly corresponds to a quantum state tomography of the released photoelectron (PE) [1]. Accessing this full quantum state makes it possible to decipher the quantum phenomena that unavoidably affect the PE, such as state superpositions and decoherence. In practice, being based on the sole observation of the kinetic energy of the PE, the technique builds a reduced electron density matrix (EDM), where all the unresolved degrees of freedom have been traced over. The latter can arise due to classical ensemble averaging (e.g. shot-to-shot XUV pulse fluctuations) or due to fundamental quantum mechanical reasons. Indeed although rapidly separated in space, the ion and the PE still form a single quantum system, a pure wavepacket described by a total wavefunction that encompasses all the degrees of freedom of both subsystems. If the kinetic energy of the PE turns out to be entangled with an unresolved degree of freedom, then the reconstructed EDM will exhibit decoherence.

We have implemented this approach experimentally on several attosecond beamlines at CEA-Saclay. The density matrices were reconstructed in various experimental conditions, which allowed us to identify the physical origin of technical decoherence and to mitigate it. This will allow us to study testcases exhibiting fundamental decoherence, for instance due to ion-electron entanglement following photoionization [2, 3].

References

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