Measuring the quantum state of a photoelectron

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The discovery of the photoelectric effect during the late 19^{th} century has been crucial for the development of quantum mechanics and the field of photoelectron spectroscopy. The advent of attosecond science has further improved the field of photoelectron spectroscopy, through measurements of both the amplitudes and phase variations of the momentum distributions of the photoelectrons. In the case of pure states, it is possible to obtain direct information of the ultrafast photoelectron dynamics on the attosecond and femtosecond time scales. In contrast, for mixed quantum states, retrieval of the underlying electronic dynamics is not trivial.

Recently, new protocols have been utilized in order to characterize mixed quantum states and entanglement [1, 2]. Here, we utilize the KRAKEN protocol [3], where the density matrix of pure and mixed photoelectron states are measured by the use of a bichromatic laser field. By scanning over the pump-probe delay for different wavelength separations, $\delta\omega$ (Fig. 1 (a)), the energy-resolved oscillation amplitudes are extracted (Fig. 1 (b)). From which the sparse density matrix is retrieved (Fig. 1 (c)). Using a Bayesian optimization algorithm, the full continuous-variable density matrix of pure and mixed photoelectron states is reconstructed.

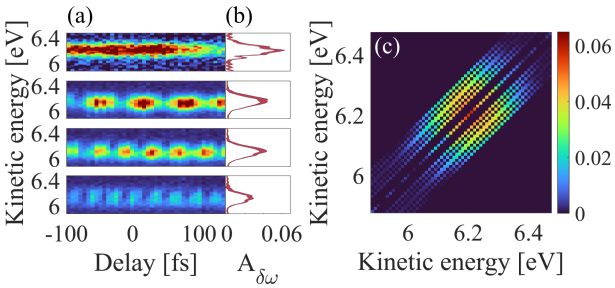

Figure 1: Continuous-variable quantum state tomography of photoelectrons. (a) Photoelectron spectrograms acquired for different values of $\delta\omega$. (b) The extracted energy-resolved oscillation amplitudes, $A_{\delta\omega}$. (c) Sparse density matrix obtained by inserting the oscillation amplitudes for each $\delta\omega$.

The results are benchmarked against ab initio calculations, showing good agreement between experiment and theory. The measured (theoretical) purities of He and Ar are 0.94 ± 0.06 (1.00) and 0.64 ± 0.02 (0.61), respectively. The clear difference between the noble gases is the result of ion-photoelectron entanglement induced by spin-orbit interaction.

References

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