Strong-field ionization inducing multi-electron-hole coherence probed by attosecond pulses

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Synopsis We propose a new scenario to apply IR-pump-XUV-probe schemes to resolving strong field ionization induced and attosecond pulse driven electron-hole dynamics and coherence in real time. The coherent driving of both pulses correlates the dynamics of the core-hole and the valence-hole by coupling multiple continua, which leads to the otherwise forbidden absorption and emission of high harmonics. The emission spectra from the core-valence transition and the core-hole recombination are found modulating strongly as functions of the time delay between the two pulses, suggesting the coherent electron wave packets in multiple continua can be utilized to temporally resolve the core-valence transition in attoseconds.

Recent advances in attosecond spectroscopy has enabled resolving electron-hole dynamics in real time [1]. The correlated electron-hole dynamics and the resulted coherence are directly related to how fast the ionization is completed. Under strong infrared (IR) laser, ionization ignites from the outermost electron because of its long wavelength. The released valence electron and the created hole are further driven by the intense external fields. How their coherence evolves and whether it can be utilized to probe the core dynamics are among the key questions in attosecond physics or even attosecond chemistry. The combination of the ever-shorter attosecond pulses with the ever-intense infrared lasers helps probing and controlling both inner and outer shell electrons coherently on the equal footing.

In this work, we consider atoms with closed shells subjected to an intense IR laser pulse and a time-delayed attosecond pulse (AP) which has a central frequency in resonant with the transition between the inner and valence shells. In the absence of the IR pulse, the direct transition from the inner shell to the valence shell is forbidden due to the Pauli exclusion principle. However, once the IR field induces ionization from the valence shell, the transition is triggered leaving a hole in the inner shell affecting the subsequent rearrangement dynamics. As shown in Fig. 1, strong field ionization from the filled valence shell by IR field creates the associated continuum. Concurrently, it opens the subshell allowing the followed resonant transition pumped by the AP, which creates a hole in the core and transfers the continuum into its own. The attosecond light absorption and the resulted emission are thus gated by the ionization, in close analogy to the ionization induced absorption saturation where the transition energy is shifted by ionization. Meanwhile, the opened AP absorption creates coherence between the valence-hole and the core-hole. The transfer of coherence from ionization into both holes leads to multiple paths of HHG: harmonics can be radiated through recombination into the valence shell (path (v)) and the core hole (path (h)) respectively, or it can be generated upon the resonant core-valence transition accompanied by the transfer of the continua (path (x)). The coherent electron wave packet in multiple continua thus provides the opportunity to temporally resolve the multi-electron-hole dynamics in attoseconds.

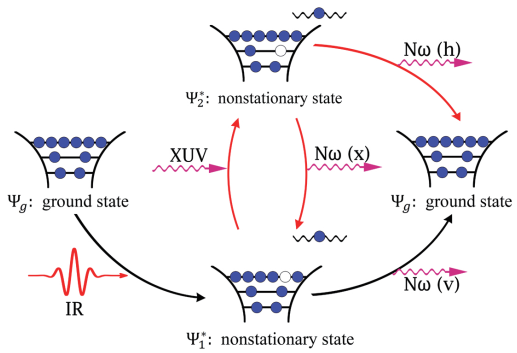

Figure 1. Illustration of the interaction of the atom with the laser and XUV fields and the related high-harmonic generation processes.

References

[1] F. Krausz and M. Ivanov, 2009 *Rev. Mod. Phys* **81** 163

[2] J. Zhao, J. Yuan and Z. Zhao, 2015 *arXiv*: 1510.07947

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