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Multi-photon ionization of atoms in intense short-wavelength radiation fields

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The unprecedented characteristics of XUV and X-ray Free Electron Lasers (FELs) have stimulated numerous investigations focusing on the detailed understanding of fundamental photon-matter interactions in atoms and molecules. In particular, the high intensities (up to $10^{16}\,W/cm^2$) giving rise to non-linear phenomena in the short wavelength regime. The basic phenomenology involves the production of highly charged ions via electron emission to which both sequential and direct multi-photon absorption processes contribute. The detailed investigation of the role and relative weight of these processes under different conditions (wavelength, pulse duration, intensity) is the key element for a comprehensive understanding of the ionization dynamics. Here the results of recent investigations are presented, performed at the FELs in Hamburg (FLASH) and Trieste (FERMI) on atomic systems with electronic structures of increasing complexity (Ar, Ne and Xe). Mainly, electron spectroscopy is used to obtain quantitative information about the relevance of various multi-photon ionization processes. For the case of Ar, a variety of processes including above threshold ionization (ATI) from 3p and 3s valence shells, direct 2p two-photon ionization and resonant 2p-4p two-photon excitations were observed and their role was quantitatively determined comparing the experimental ionization yields to ab-initio calculations of the cross sections for the multi-photon processes. Using Ar as a benchmark to prove the reliability of the combined experimental and theoretical approach, the more complex and intriguing case of Xe was studied. Especially, the analysis of the two-photon ATI from the Xe 4d shell reveals new insight into the character of the 4d giant resonance, which was unresolved in the linear one-photon regime. Finally, the influence of intense XUV radiation to the relaxation dynamics of the Ne 2s-3p resonance was investigated by angle-resolved electron spectroscopy, especially be observing the intensity dependent variation of the angular distribution patterns for the sequential ionization process.