High-order harmonic generation enhanced by intense x rays

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X-ray science is undergoing one of its greatest revolutions to date with the construction of intense x-ray free electron lasers (FELs) in Menlo Park, California, USA (LCLS), Hamburg, Germany (European XFEL), and Harima Science Garden City, Japan (SACLA). These are vast, several-hundred-million dollar machines that provide x-ray pulses that are many million times brighter than current sources. Similarly groundbreaking are the emerging attosecond light sources based on intense, pulsed optical lasers; they are relatively inexpensive laboratory-size instruments. These two emerging radiation sources enable radically new research and have unnumbered potential applications in materials science, chemistry, biology, and physics.

Our work aims at bringing the capabilities of HHG-based attosecond sources to FELs [1,2]. First, we theoretically combine high-order harmonic generation (HHG) with resonant x-ray excitation of a core electron into the transient valence vacancy that is created in the course of the HHG process: the first electron performs a HHG three-step process whereas, the second electron Rabi flops between the core and the transient valence vacancy [Fig. 1]. The modified HHG spectrum due to recombination with the valence and the core is determined and analyzed —for krypton [1] on the $3d \to 4p$ resonance [Fig. 2] and for neon [2] on the $1s \to 2p$—in the respective cations in the light of an optical laser and an FEL. Second, we examine HHG where tunnel ionization (first step) is replaced by direct x-ray ionization of core electron of neon. We use the boosted HHG radiation to predict single attosecond pulses in the kiloelectronvolt regime. For both presented schemes, we find substantial HHG yield for the recombination of the continuum electron with the core hole. Our prediction offers novel prospects for nonlinear x-ray physics, attosecond x rays, and time-resolved chemical dynamics [1,2].

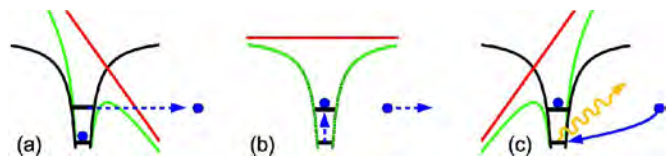

Figure 1 (Color): Schematic of a modified three-step model for the HHG process enhanced by x-ray excitation of a core electron.

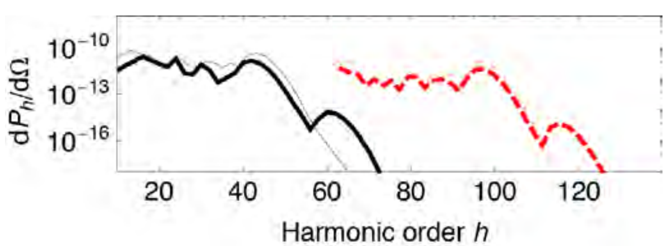

Figure 2 (Color): Photon number spectrum of the h th harmonic for an XUV intensity of 10^{16} W / cm^2 emitted into the solid angle dΩ along the x axis. The optical laser intensity is set to 3×10^{14} W / cm^2 at a wavelength of 800 nm. Both pulses have a duration of three optical cycles. The black, solid curve shows the contribution from recombination with a valence hole; the red, dashed curve correspond to recombination with a core hole. The thin-line spectra are obtained by neglecting ground-state depletion due to direct XUV ionization.

References

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