Attosecond Hard X-Ray Scattering Spectroscopy

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Synopsis We formulate an analytic, semi-relativistic theory of laser-assisted attosecond Compton scattering by a weakly bound electron. We (i) present the evidence of the feasibility of measuring the ground-state electron momentum density in the attosecond regime and (ii) investigate the attosecond Compton streak camera and spectral phase interferometry - proposing two new methods of measuring the duration of a hard x-ray pulse without fundamental restrictions on the measurement accuracy.

Very precise synchronization between the soft x-ray attosecond pulse and an intense laser field is prominent in attosecond science because the infrared field provides the nonlinearity needed for attosecond measurement of attosecond pulses [1].

Recent developments in ultrafast x-ray sources demonstrate that it is technically feasible to generate hard x-ray attosecond pulses in Ångström wavelength range [2] with free-electron lasers. At the very heart of these proposals is the temporal synchronization scheme between the free-electron and an external lasers, the so-called seeded attosecond x-ray radiation.

With the practical attosecond hard x-ray sources becoming available, it is essential to generalize the Compton profile theory to attosecond regime. It is also necessary to extend the ideas of attosecond streak camera (ASC) and spectral phase interferometry (ASPI) to the hard x-ray range. Transferring these techniques to laser-assisted Compton ionization is far from trivial. The photon is scattered, not absorbed, by the weakly bound electron, leading to a quite distinct theoretical description. In spite of the differences we will show that the Compton electron contains complete phase information on the incident pulse provided that we select the momentum of the scattered photon.

Starting with an *ab initio* method, we develop a theoretical approach to describe laser-assisted attosecond Compton ionization. To obtain the appropriate semi-relativistic scattering matrix, we generalize the theory [3] of monochromatic photon scattering by a bound electron and incorporate the separable Coulomb-Volkov continuum [4] into the Furry representation. We analyze the Compton ASC and ASPI and demonstrate the feasibility of measuring Compton profiles in attosecond laser-assisted regime. Compton electron spectra depend on the phase of the laser field relative to the x-ray attosecond pulse. Thus, the relative phase of all frequency components of the attosecond pulse can be determined from the spectrum of Compton electrons.

Once the x-ray pulse is characterized using a well understood atom such as hydrogen, a new frontier of attosecond science will be to utilize the Compton streak camera to measure unknown dynamics in target systems – nuclei, atoms, molecules or solids.

Once attosecond hard x-ray pulses are produced and synchronized to other optical sources, they will become powerful tools for following structure dynamics; each delay produces a single frame in an attosecond movie.

References

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[2] See A. A. Zholents and M. S. Zolotorev, New J. Phys. **10**, 025005 (2008) and references therein.

[3] A. I. Akhiezer and V. B. Berestetskii, *Quantum Electrodynamics*, 3rd ed. (Nauka, Moscow, 1969).

[4] G. L. Yudin *et al.*, J. Phys. B **40**, F93, 2223 (2007); **41**, 045602 (2008).