Attosecond-precision coherent control experiment at FERMI

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Synopsis When an electron is ejected from an atom after a photon is absorbed, an extremely short group delay between photon absorption and electron emission occurs in the photoelectron wave packet. It is of the order of a few attoseconds and is known as the Eisenbud-Wigner-Smith delay. Here we introduce a new approach for measuring the delay with coherently-controlled free-electron laser pulses.

The invention of probing methods on a time scale less than femtoseconds has led to the age of attosecond physics [1], and numerous such ultrafast phenomena currently are being investigated. Photoemission is one of those processes that has received a lot of interest, especially concerning the photoemission delay between photon absorption and photoelectron emission known as the Eisenbud-Wigner-Smith (EWS) delay [2].

We are presenting here a new method for measuring the EWS delay. In this method, we use short wavelength EUV light, consisting of phase-locked fundamental (ω) and second harmonic (2ω) pulses. It requires extremely accurate phase control (few attoseconds). Such fine control is available from the Italian free-electron laser (FEL), FERMI [3]. We report, as a demonstration of the new method, the EWS delay difference between one- and two-photon ionization of atomic Ne.

We carried out the measurement at the LDM beam-line, FERMI. The photon energies were set to 14 eV, 16 eV, and 19 eV for ω, which are below the Ne ionization threshold, while the second harmonics 2ω are above the threshold. Phase-locked bichromatic light beams crossed the atomic gas jets of He-Ne mixtures (We used the He for a calibration). A velocity map imaging spectrometer measured ejected electrons.

The target processes are the photoionization of Ne by one or two photon(s):

$$\mathrm{Ne} + 2\omega \rightarrow \mathrm{Ne}^{+} + e^{-},$$

$$\mathrm{Ne} + \omega + \omega \rightarrow \mathrm{Ne}^{+} + e^{-} \text{ (non-resonant).}$$

Because these electrons emitted by the two different pathways interfere with each other, the electron angular distribution is correlated to the difference of the unique phase shifts. The phase shift difference can be extracted by scanning the optical phase difference between ω and 2ω FEL pulses. The EWS delay τ is defined as the derivative of phase shift η with respect to the photoelectron kinetic energy E: $\tau = \hbar \cdot \partial\eta/\partial E$ [2]. We have measured the phase shift differences at several photon energies and found their slope to estimate the delay difference.

References

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