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Attosecond Control and Spectroscopy of Electrons

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The generation of ever shorter pulses is a key to exploring the dynamic behavior of matter on ever shorter time scales. Over the past decade novel ultrafast optical technologies have pushed the duration of laser pulses close to its natural limit, to the wave cycle, which lasts about one femtosecond (1 fs = 10^{-15} s) in the visible spectral range. Time-resolved measurements with these pulses are able to trace atomic motion in molecules and related chemical processes. However, electronic dynamics *inside* atoms often evolve on an attosecond (1 as = 10^{-18} s) timescale and require sub-femtosecond pulses for capturing them. This talk will review the recent generation, measurement and first applications of sub-femtosecond soft-X-ray pulses (near 100 eV). These X-ray pulses together with the few-cycle laser pulses used for their generation have opened the way to the development of a technique for attosecond sampling of electrons ejected from atoms. This is accomplished by probing electron emission with the oscillating electric field of the few-cycle laser pulse following an excitation of the atom by the synchronized sub-femtosecond X-ray pulse. Sampling the emission of photo electrons in this manner – with an apparatus that may be regarded as an optical-field-driven "streak camera" – allows time-resolved measurement of the X-ray pulse duration as well as of the laser field oscillations. Tracking the evolution of secondary (Auger) electron emission in addition to that of the primary (photo) electrons with the same system provides time-domain access to inner-shell atomic electron dynamics. Measurement of the duration of sub-fs X-ray pulses and their timing with respect to the few-cycle laser waves has opened the way to using this two-colour sampling system for taking "snapshots" of atomic electron dynamics with an exposure time of less than 1 femtosecond. From the recorded snapshots plasma formation by optical-field ionization and the decay of inner-shell atomic excitations has been reconstructed for the first time directly in the time domain. As a result, atomic dynamics can now be watched in slow-motion replay, with time dilated by $\approx 10^{15}$. Microscopy in time (time-resolved spectroscopy) is now being extended into the sub-atomic domain and holds promise for breaking new grounds in the research of the microcosm.