Attosecond science in the liquid phase

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Attosecond time-resolved measurements have so far mainly been performed on gas-phase targets with first extensions to solids. In this lecture, I will present several recent experiments that extend attosecond science into the *liquid phase*. As a first step, attosecond interferometry has been applied to H_2O and N_2O molecules in the gas phase, determining relative photoionization delays between the outer-valence orbitals of these molecules [1]. Comparison with theory [2] revealed that the small delays (< 50 as) measured in the case of H_2O reflect the structureless photoionization continuum of this molecule, whereas the large delays measured in N_2O (up to 160 as) are the signature of shape resonances. Applying attosecond interferometry to a liquid-water microjet [3] we have measured photoemission delays between water in the liquid and gas phases. The challenge of the spectral overlap of multiple photoelectron bands was resolved by developing a new phase retrieval approach that generalizes attosecond interferometry to complex targets [4]. The detailed theoretical analysis of the liquid-gas delays revealed the existence of a new *non-local* mechanism in attosecond interferometry, which makes the technique sensitive, in general, to both mean-free paths and scattering delays [5]. Finally, I will report on the extension of high-harmonic spectroscopy to the liquid phase with the first observation of extreme-ultraviolet high-harmonic generation from the bulk of liquids [6], using the recently invented liquid-flatjet technique [7].

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