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Attosecond soft-X-ray spectroscopy in the gas and liquid phases

HANS JAKOB WRNER, ETH Zurich

Attosecond spectroscopy has the potential to address fundamental questions in molecular sciences. A promising approach is offered by the element- and site-sensitivity of X-ray spectroscopy. We have recently demonstrated the potential of table-top X-ray absorption spectroscopy with a water-window high-harmonic source, observing the temporal evolution of unoccupied molecular orbitals and molecular shape resonances during chemical reactions [1]. Compressing the mid-infrared driving pulses to less than 2 optical cycles, we have demonstrated the extension of this light source to fully cover the oxygen K-edge [2]. Using the same technique, we have also demonstrated the generation of isolated attosecond pulses, which have established a new record of the shortest light pulses ever measured (43 attoseconds) [3]. Since the vast majority of chemical processes takes place in the liquid phase, the extension of attosecond spectroscopy to liquids is desirable. I will discuss the first observation of extreme-ultraviolet high-harmomic generation from liquids, achieved through the application of ultrathin (0.6-2 μm) flat microjets [4]. I will also present the extension of attosecond time-resolved spectroscopy from molecules [5] to liquids [6]. The time delays between photoemission from gaseous and liquid water range from 50-70 attoseconds and are shown to mainly originate from the solvation of water molecules, with liquid-phase electron scattering playing a minor role. These developments set the stage for attosecond time-resolved studies of molecular systems of chemical complexity.
[1] Y. Pertot et al., *Science* **355**, 264 (2017) [2] C. Schmidt et al., *Opt. Exp.* **26**, 11834 (2018) [3] T. Gaumnitz et al., *Opt. Exp* **25**, 27506 (2017) [4] T. T. Luu et al., *Nature Communications* **9,** 3723 (2018) [5] M. Huppert et al., *Phys. Rev. Lett.* **117**, 093001 (2016) [6] I. Jordan et al., *submitted* (2019)