A 2: Attosecond physics I

Time: Monday 11:00–13:15 Location: f107

Invited Talk A 2.1 Mon 11:00 f107

Highly nonlinear ionization of atoms induced by intense HHG pulses — Björn Senfftleben[1], Martin Kretschmar[1], Andreas Hoffmann[1], Mario Sauppe[1,2], Johannes Tümmler[1], Ingo Will[1], Tamás Nagy[1], Marc J. J. Vrakking[1], Daniela Rupp[1,2], and •Bernd Schütte[1] — [1]Max-Born-Institut Berlin — [2]ETH Zürich

High-harmonic generation (HHG) is typically considered to be a weak source of extreme-ultraviolet (XUV) photons. Here we demonstrate a very intense source of few-femtosecond XUV pulses based on HHG, reaching intensities up to 7×10^{14} W/cm^2 [1]. These pulses enable us to ionize Ar atoms up to Ar^{5+}, requiring the absorption of at least 10 XUV photons. This number can be appreciated by considering that it is similar to the number of near-infrared (NIR) photons absorbed in a typical strong-field ionization experiment.

Our results are the consequence of a novel scaling scheme, showing that the optimization of the XUV intensity requires conditions that are distinctly different from the conditions that are required to optimize the HHG pulse energy. An important advantage of our approach is that we use a moderate NIR pulse driving energy ($\approx$ 10 mJ). Therefore, our results make it possible to perform experiments requiring intense XUV pulses in a much larger number of laboratories than is currently the case. This substantially improves the prospects for nonlinear XUV optics experiments, single-shot coherent diffractive imaging of isolated nanotargets as well as attosecond-pump attosecond-probe experiments.

[1] B. Senfftleben *et al.*, arXiv:1911.01375

A 2.2 Mon 11:30 f107

Generation of elliptically polarized high-harmonics: towards chiral isolated attosecond pulses — •Ulrich Bengs and Nickolai Zhavoronkov — Max-Born Institut Berlin

High harmonic generation (HHG) is the fundamental process underlying the generation of attosecond pulses, which allow to study the electronic structure of matter on its natural timescale. However, until recently, HHG was limited to linear polarization. A promising way to overcome this limitation is offered by bicircular HHG [1] which is known to produce circularly polarized pairs of harmonics with opposite helicity. We demonstrate an implementation of bicircular HHG with few-cycle driving fields consisting of a 5 fs, circularly polarized pulse centered around 800 nm and its counter-rotating second harmonic with 8 fs duration. Utilizing the propensity rules that govern the contrast between harmonics of opposite helicity [2, 3] we are able to shape the harmonic spectrum to be dominated by harmonics of only one helicity over a broad spectral range and measure the ellipticity by means of XUV-polarimetry showing, that the harmonics are indeed elliptically polarized. Additionaly, we report the generation of a continuous spectrum spanning 32-55 eV, which lays the foundation for isolated attosecond pulses with elliptical polarization, making the technique a powerful tool in the development of a lightsource for ultrafast chiral-sensitive studies.

[1] D.B. Milosevic et al, Phys. Rev. A 61, 063403 (2000)
[2] A. Jimenez-Galan et al, Phys. Rev. A 97, 023409 (2018)
[3] N. Zhavoronkov and M. Ivanov, Opt. Lett. 42, 4720-4723 (2017)

A 2.3 Mon 11:45 f107

Attosecond XUV Fourier transform spectroscopy — •Laura Maikowski, Lorenz Drescher, Oleg Kornilov, Marc Vrakking, and Tobias Witting — Max-Born-Institut, Max-Born-Strasse 2A, 12489 Berlin

We aim to extend the methods of Fourier transform spectroscopy into the XUV domain. Our goal is to create a phase-locked pair of isolated attosecond XUV pulses, in combination with a strong NIR few-cycle pulse. As pulse splitting in the XUV is difficult, we create a pulse pair in the NIR range and then generate the XUV pulse pair via high harmonic generation [1,2,3]. As we want to create isolated attosecond pulses we have to create a pair of few-cycle pulses. To achieve this we constructed a few-cycle compatible Mach-Zehnder interferometer, which is actively phase-stabilized to a residual delay jitter of 5 as rms. A pair of 4 fs, 800nm few-cycle pulses from this interferometer is used to produce a pair of attosecond XUV pulses in the 15 to 50 eV energy range.

[1] Austin et al. Lateral Shearing Interferometry of High-Harmonic Wavefronts. Opt Lett 36, 1746-48 (2011)
[2] Meng et al. Octave-Spanning Hyperspectral Coherent Diffractive Imaging in the Extreme Ultraviolet Range. Opt. Expr. 23, 28960-69 (2015)
[3] Jansen et al. Spatially Resolved Fourier Transform Spectroscopy in the Extreme Ultraviolet. Optica 3, 1122-25 (2016)

A 2.4 Mon 12:00 f107

Perspectives of high harmonics generation with tailored femtosecond driving pulses — •Lars Englert, Marcel Behrens, Felix Otten, and Matthias Wollenhaupt — Carl von Ossietzky Universität Oldenburg, Institut für Physik, Carl-von-Ossietzky-Str. 9-11, 26129 Oldenburg

In the recent years, we presented work on the coherent control of ultrafast quantum dynamics in tailored femtosecond laser fields, including the generation of polarization-shaped femtosecond laser pulses [1], the tomographic reconstruction of sculpted photoelectron wave packets [2] and the photoelectron circular dichroism (PECD) of chiral molecules [3]. Currently, we combine a commercial table top high harmonics generation (HHG) source, providing XUV radiation up to 100 eV, with polarization shaping of the femtosecond IR driving field to extend our expertise in coherent control from the IR/VIS to the XUV regime. In this talk, we present an overview of the attosecond beamline and discuss perspectives for the oncoming experiments on the control of the HHG process, in terms of gating mechanisms for the generation isolated attosecond pulses and polarization control for the generation of circularly polarized XUV pulses, as well as single-photon PECD and chiral HHG in the XUV regime.

[1] S. Kerbstadt *et al.*: Opt. Express **25**, 12518 (2017)
[2] D. Pengel *et al.*: Phys. Rev. Lett. **118**, 053003 (2017)
[3] C. Lux *et al.*: Chem. Phys. Chem. **16**, 115 (2015)

A 2.5 Mon 12:15 f107

Strong-field coherent control of photoemission from tungsten needle tips with a two-color laser field — •Philip Dienstbier[1], Timo Paschen[1], Lennart Seiffert[2], Thomas Fennel[2], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Institut für Physik, Universität Rostock, 18059 Rostock

Ionization by two-color laser fields with well-defined relative phase allows tuning and controlling electronic dynamics on the sub-femtosecond time scale. In the perturbative photoemission regime we have demonstrated electron emission induced by a fundamental that can be modulated with a contrast of up to 97.5% when superimposing a weak second harmonic field due to interference between two different quantum channels in photoemission from a nanometer sharp metallic needle tip [1,2].

We extend this coherent control scheme to the strong-field photoemission regime by using a two-color field synthesized with few-cycle pulses. In the strong-field regime, not only the ionization but also electron trajectories can be manipulated during the rescattering process by varying the relative phase of the second harmonic field [3]. In this talk we show experimental findings for field-driven dynamics and confirm the results by time-dependent Schrödinger equation and simple-man's model simulations.

[1] M. Förster et al. , Phys. Rev. Lett. **117**, 217601 (2016).
[2] T. Paschen et al., J. Mod. Opt. **64**, 10-11, 1054-1060 (2017).
[3] L. Seiffert et al., J. Phys. B. **51**, 134001 (2018).

A 2.6 Mon 12:30 f107

Two-Color time resolved photoionization experiments with a high-repetition rate laser — •Hemkumar Srinivas, Farshad Shobeiry, Divya Bharti, Anne Harth, Thomas Pfeifer, and Robert Moshammer — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, Heidelberg 69117

Photoionization in atoms and molecules have long been used to study the atomic/ molecular structure. With the advent of ultrashort laser pulses in the femtosecond and attosecond time-scale, it has been possible to observe dynamics at the atomic level in real time.

This is done with the help of a pump-probe scheme wherein the initial laser pulse excites or ionizes the system and this is followed by another pulse with a precise time delay that helps mapping the phase of the emitted electron wavepacket.

In this work, we implement an XUV-IR pump-probe technique called RABBIT[1] to understand and observe electron dynamics in Noble gases and simple molecular systems such as diatomic molecules. Of particular interest is to investigate the effects of the intensity of the probing infrared field on the electron in the continuum and how it affects the angular distribution for the electron emission. The usage of a high-repetition rate laser reduces the acquisition time significantly, thereby making it easier to investigate processes with a relatively low ionization cross-section in a shorter timeframe.

Reference : [1] PM Paul et. al, Science(292) 5522

A 2.7 Mon 12:45 f107

Time operator, real tunneling time in strong field interaction and the attoclock — •Ossama Kullie — Institute of Physics, Department of Mathematics and Natural Science, University of Kassel.

In the present work, we show that our real tunneling time relation derived in earlier works [1] can be derived from an observable or a time operator, which obeys an ordinary commutation relation. Moreover, we show that our real tunneling time has a close relation or actually is equivalent to the Eisenbud-Wigner delay time. Furthermore it can also be constructed from the well-known Aharonov-Bohm time operator. This shows that the specific form of the time operator is not decisive, and dynamical time operators relate identically to the intrinsic time of the system. It contrasts the famous Pauli theorem, and confirms the fact that time is an observable, i.e. the existence of time operator and that the time is not a parameter in quantum mechanics. We discuss the relations with different types of tunneling times such as Eisenbud-Wigner time, dwell time and the statistically or probabilistic defined tunneling time. [1] O. Kullie, Phys. Rev. A. **92**, 052118 (2015), Ann. of Phys. **389**, 333 (2018), Mathematics **6**, 192 (2018)

A 2.8 Mon 13:00 f107

Ionization time in the nonadiabatic attoclock, *Multiphoton process versus tunneling in strong field interaction* — •Ossama Kullie — Institute of Physics, Department of Mathematics and Natural Science, University of Kassel.

The measurement of the tunneling time in attosecond experiments, termed attoclock, triggered a hot debate about the tunneling time and the separation into two regimes of ionization, the multiphoton and the tunneling. In the adiabatic field calibration, we showed in earlier works [1] that our real tunneling time fits well in the experimental data of the attoclock. However, Hofmann et al (J. of Mod. Opt. **66**, 1052, 2019), presented a new experimental data of the attoclock with a nonadiabtic calibration of the field strength. In the present work we show that our model is capable to account for the nonadiabaticity and we find an excellent agreement with the nonadiabatic experimental attoclock result of Hofmann et al. Interestingly, we show that our model offers a clear picture for the multiphoton and tunneling parts, and the well known regime separation is now resolved. In particular the the tunneling part is equalized by the nonadiabaticity, the absorption of $n(F)$ photons (where F is the peak of field strength, and the time delay is ionization time delay with respect to the atomic field strength, where the Barrier suppression ionization sets up. [1] O. Kullie, Phys. Rev. A. 92, 052118 (2015), J. Phys. B **49**, 095601 (2016), J. Phys. Commun. **2**, 065001 (2018)