A 35: Attosecond physics

Time: Thursday 14:30–16:30 Location: f107

Invited Talk A 35.1 Thu 14:30 f107

History and current status of the Keldysh theory — •Sergey Popruzhenko — National Research Nuclear University MEPhI, Kashirskoe shosse 31, 115409, Moscow, Russia

This talk presents an overview of the Keldysh theory of strong field ionization. The historic development and applications of this analytic model of nonlinear ionization of atoms and solids by intense laser radiation proposed by L.V. Keldysh in his seminal work [1] more than 50 years ago are briefly described. The relationship between the Keldysh theory and other analytic approaches to the problem of strong field ionization, including the famous Strong Field Approximation [2,3] is discussed. Special attention is paid to open questions and to those aspects of the theory, which remain actively debated or frequently receive erroneous interpretations. This includes in particular the conditions of applicability, the problem of gauge invariance and the concept of the tunneling time. Finally, prospects for the future development of the theory are outlined.

[1] L.V. Keldysh, Sov. Phys. JETP 20, 1307 (1965).
[2] F.H.M. Faisal, J. Phys. B: At. Mol. Opt. Phys. 6, L89 (1973).
[3] H.R. Reiss, Phys. Rev. A 22, 1786 (1980).

Invited Talk A 35.2 Thu 15:00 f107

Multidimensional control of XUV-initiated high harmonic generation — Doron Azoury[1], •Michael Krüger[1], Henrik R. Larsson[2], Sebastian Bauch[2], David J. Tannor[1], Barry D. Bruner[1], and Nirit Dudovich[1] — [1]Weizmann Institute of Science, Rehovot 76100, Israel — [2]University of Kiel, Kiel D-20489, Germany

In XUV-initiated high harmonic generation (HHG), tunneling ionization is replaced by photoionization with an attosecond XUV pulse [1,2]. Ionization and subsequent IR-mediated propagation get decoupled from each other, allowing for a high degree of control and extending high harmonic spectroscopy to inner shells. Here we demonstrate XUV-initiated HHG from helium and neon atoms by combining an attosecond XUV pulse train and an IR pulse and show that the XUV-IR delay controls the timing of ionization. Moreover, by adding a weak second harmonic field and scanning its phase relative to the IR we retrieve even harmonics that oscillate completely out of phase with the odd harmonics [3]. These observations unambiguously reveal the involvement of electron trajectories and the insignificance of tunneling in the process, showing for the first time that ionization and propagation are decoupled and can be controlled independently. A strong-field model and *ab-initio* calculations corroborate our findings.

[1] K. Schafer et al., PRL 92, 023003 (2004).
[2] G. Gademann et al., NJP 13, 033002 (2011).
[3] O. Pedatzur et al., Nature Physics 11, 815 (2015).

A 35.3 Thu 15:30 f107

Tunneling time in attosecond experiments and time-energy uncertainty relation — •Ossama Kullie — Theoretical physics, institute for physics, university of Kassel, Germany.

In this work [1] we present a theoretical model of the tunneling time and the tunneling process in attosecond and strong field experiments, leading to a relation which performs an excellent estimation for the tunneling time, where we address the important case of the He-atom [2]. Our tunneling time estimation is found by utilizing the time-energy uncertainty relation and represents a quantum clock. The tunneling time is also featured as the time of passage similar to the Einstein's *photon box Gedanken experiment* (EPGE), and our model can be seen as a realization of the EPGE with the electron as a particle in a disturbed Coulomb potential (instead the photon and the gravitational potential in the EPGE). Our work tackles an important case study for the theory of time in quantum mechanics, and is very promising for the search for a (general) time operator in quantum mechanics. [1] O. Kullie, Phys. Rev. A, (2015) accepted. arXiv:1505.03400v2. [2] Eckle et al. Science. 322, 1525 (2008).

A 35.4 Thu 15:45 f107

Tunneling ionization time resolved by backward propagation — •Hongcheng Ni, Ulf Saalmann, and Jan M. Rost — Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany

We assess under which circumstances the attoclock can be used to determine the tunneling ionization time. This is achieved by a novel backward-propagation method, which involves a full quantum treatment of the tunneling process forward in time, followed by a classical backward propagation to identify the tunneling parameters. We find that, if the tunneling concept applies, the corresponding ionization time is around pulse center for single active electrons in helium and hydrogen. The range of validity, quite different for the two atoms, is limited towards low laser intensities by multiphoton ionization and towards high intensities by above-barrier ionization.

A 35.5 Thu 16:00 f107

Mechanisms for subcycle-dependent self-diffraction in transparent solids — •Jan Reislöhner, Aseem P. Pati, Christoph G. Leithold, and Adrian N. Pfeiffer — Institute for Optics and Quantum Electronics, Abbe Center of Photonics, Friedrich Schiller University, Max-Wien-Platz 1, 07743 Jena

A spatial analogue to the carrier-envelope offset phase of few-cycle laser pulses is the phase between the grooves of a grating and its envelope. Here, self-diffraction in a dielectric is studied in a two-pulse geometry where the laser-induced grating comprises only a few grooves. Two mechanisms lead to dependence on the grating-envelope offset phase, which is tuned by subcycle delays between the pulses: Interference, dominant in between the diffraction orders, and a mechanism that affects diffraction orders separately when the laser-induced grating acts as a micro-lens array.

A 35.6 Thu 16:15 f107

Carrier-envelope phase evolution in focused few-cycle laser pulses — •Dominik Hoff[1], Michael Krüger[2,3], Lothar Maisenbacher[3], A. Max Sayler[1], Gerhard G. Paulus[1], and Peter Hommelhoff[2,3] — [1]Helmholtz Institute Jena and Institute for Optics and Quantum Electronics, Jena — [2]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen — [3]Max Planck Institute of Quantum Optics, Garching

Variation of the carrier-envelope phase (CEP) of few-cycle laser pulses has proven to be an effective way to control processes such as attosecond electron dynamics, chemical reactions, and high-harmonic generation. Thus, precise knowledge of the spatial dependence of the CEP is vital to understand and control these processes. Here we combine the recently developed techniques of high precision CEP measurement [1] and photoelectron re-scattering at metal nano-tips [2] to, respectively, provide the attosecond temporal and nanometer spatial resolution necessary to directly map the spatial dependence of the CEP. By scanning the focus with the nano-tip and recording the phase-tagged time-of-flight spectra, we are able to observe a substantial deviation from the monochromatic Gouy-phase. Further, with the help of a theory model we are able to relate our direct measurement of the focus to the chromatic properties of the beam prior to focusing.

[1] T. Wittmann et al., *Nature Physics* **5**, 357 (2009).
[2] M. Krüger, M. Schenk, P. Hommelhoff, *Nature* **475**, 78 (2011).