HL 1: Tutorial: Coherent Control

The term 'Coherent Control of Quantum Systems' comprises a variety of closely related ideas from different branches of physics. They all have the common goal of exploiting coherence properties of laser light or long-wavelength radiation to create quantum mechanical interferences of matter waves that can steer a quantum system into a certain pre-defined target channel. Coherent control techniques are very general and can be applied to virtually any quantum system. This Tutorial provides an introduction to coherent control concepts and discusses recent applications of such ideas in solid state physics and nanooptics as well as chemical physics and chemistry. Theoretical challenges posed by the many-body nature of all real systems are highlighted as well. (Organized by the Semiconductor Physics Division)

Time: Sunday 16:00–18:30 Location: H2

Tutorial HL 1.1 Sun 16:00 H2

Optimal Control Theory — •E.K.U. Gross — Max Planck Institute of Microstructure Physics, Halle (Saale), Germany

An overview of quantum optimal control theory will be given. Usually in quantum mechanics we prescribe an external field, say a laser or a magnetic field, and then solve the time-dependent Schroedinger equation to calculate from the wave function the observables of interest. Optimal control deals with an inverse problem: One first defines a goal that the laser pulse should achieve, the so-called "control target", and then one calculates, with certain algorithms, an optimally shaped laser field that achieves the prescribed goal. Examples of control targets are (i) to switch the chirality of the current in a quantum ring [1], (ii) to keep electrons localized in a given region of space [2], (iii) to minimize or maximize ionization of a molecule with the total fluence of the laser kept fixed [3], or (iv) to drag a wave packet along a given path through a nanostructure. We shall describe in detail how a given goal can be formulated in terms of a target functional which is to be maximized by the optimized pulse. Together with the underlying equation of motion, i.e. the time-dependent Schroedinger equation or the time-dependent Kohn-Sham equation [4], this maximization leads to a set of variational equations whose numerical solution yields the desired optimal pulses. [1] E. Rasanen, A. Castro, J. Werschnik, A. Rubio, E.K.U. Gross, PRL 98, 157404 (2007). [2] E. Rasanen, A. Castro, J. Werschnik, A. Rubio, E.K.U. Gross, PRB 77, 085324 (2008). [3] A. Castro, E. Rasanen, A. Rubio, E.K.U. Gross, EPL 87, 53001 (2009). [4] A. Castro, J. Werschnik, E.K.U. Gross, PRL 109, 153603 (2012).

Tutorial HL 1.2 Sun 16:35 H2

Coherent control in ultrafast nano-optics — •Tobias Brixner[1], Martin Aeschlimann[2], and Walter Pfeiffer[3] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [2]Fachbereich Physik and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern — [3]Fakultät für Physik, Universität Bielefeld, Universitätsstr. 25, 33615 Bielefeld

Coherent control in general exploits the phase properties of light fields to manipulate coherent processes. While these concepts have initially been developed for molecular systems, it has recently become possible also to control nano-optical phenomena, i.e., the properties of electromagnetic fields below the diffraction limit of light. In this talk it will be shown how shaped femtosecond laser pulses can be used to achieve spatial and spatiotemporal control, and fundamental mechanisms will be illustrated [1]. Apart from closed-loop implementations using iterative learning algorithms, analytic schemes have been developed and realized experimentally. Applications of ultrafast nano-control also make possible novel nonlinear spectroscopy techniques.

[1] W. Pfeiffer, M. Aeschlimann, and T. Brixner, "Coherent control of nano-optical excitations," in "Optical Antennas," M. Agio and A. Alù, eds. (Cambridge University Press, 2013), Chapter 9.

Coffee break

Tutorial HL 1.3 Sun 17:20 H2

Coherent control of ultrafast electron dynamics — •Matthias Wollenhaupt — Universität Kassel

Exploiting the coherence properties of laser light along with quantum mechanical interferences of matter waves in order to steer a quantum system into a pre-defined target channel is at the heart of coherent control [1]. The increasing availability of laser sources operating on the time scale of molecular dynamics, i.e. the femtosecond regime, and the increasing capabilities of shaping light in terms of amplitude, phase and polarization (down to zeptosecond precision [2]) brought the temporal aspect of this field to the fore. In this tutorial on coherent control we will shortly review some of the physical principles of coherent control, present some pertinent examples and perspectives of current experimental efforts in controlling electronic excitations with tailored light fields such as the creation of designer electron wave packets [3,4] and charge oscillation driven chemistry [5,6]. [1] M. Wollenhaupt and T. Baumert, Faraday Discuss 153, 9 (2011). [2] J. Köhler et al., Opt Express 19, 11638 (2011). [3] M. Wollenhaupt et al., Appl Phys B 95, 245 (2009). [4] M. Wollenhaupt, M. Krug, and T. Baumert, Phys Journ 11, 37 (2012). [5] M. Wollenhaupt et al., Chem Phys Lett 419, 184 (2006). [6] T. Bayer, M. Wollenhaupt, and T. Baumert, J Phys B 41, 074007-13 (2008).

Tutorial HL 1.4 Sun 17:55 H2

Ultrafast coherent control of electrical currents in semiconductors and nanostructures — •Markus Betz — Experimentelle Physik 2, TU Dortmund

Current flow through semiconductor devices is usually achieved by applying potential differences to contacts. Over the last 15 years, however, also purely optical approaches to induce currents on the femtosecond timescale have been developed. Ultrabroadband light pulses - synthesized from a fundamental and its second harmonic - have proven particularly useful for such coherent control techniques. Current injection thereby relies on a quantum interference of one- and two-photon absorption pathways. The vectorial direction of the lateral current is dictated by the phase structure of the light field and its polarization. In my talk I will review the concept of coherent control of electrical currents in semiconductors. Starting from current injection in the prototypical direct semiconductor GaAs, we have extended the technique to the indirect bandgap materials silicon and germanium. Currents are also induced in single semiconductor nanostructures. In particular, we analyze optically induced currents in electrically contacted GaAs nanowires as well as hybrid structures functionalized with optical antennas. More recent experiments show up spectroscopic applications which conveniently combine the time resolution of ultrafast optics with amplitude- and phase-resolution of interferometric techniques.