Ultrafast dynamics of electrons, excitons and phonons in momentum space

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The dynamics of quasi-particles in non-equilibrium states of matter reveal the underlying microscopic coupling between electronic, spin and vibrational degrees of freedom. We aim for a quantum-state-resolved picture of coupling on the level of quasi-particle self-energies, which goes beyond established ensemble-average descriptions, and which requires ultrafast momentum-resolving techniques. The dynamics of electrons and excitons is measured with four-dimensional time- and angle-resolved photoelectron spectroscopy (trARPES), featuring a high-repetition-rate XUV laser source [1] and momentum microscope detector [2]. I will exemplify this experimental approach by discussing electron and exciton dynamics in the semiconducting transition metal dichalcogenide WSe_2 [3,4]. Our approach provides access to the transient distribution of hot carriers in the entire Brillouin zone of photo-excited semiconductors and allows the quantification of energy relaxation dynamics. I will sketch the capability of multidimensional photoemission spectroscopy of providing orbital information [5], of visualizing the change of the electronic structure during phase transitions [6,7], and of revealing interfacial energy transfer processes in nanoscale heterostructures.

The complementary view of ultrafast phonon dynamics is obtained through femtosecond electron diffraction. The elastic and inelastic scattering signal reveals the temporal evolution of vibrational excitation of the lattice and momentum-resolved information of transient phonon populations [8]. We applied this approach to nickel and retrieved the ultrafast energy flow between electrons, spins, and phonons in this 3d ferromagnet [9].

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