Polaron physics in ultracold atoms and solid-state materials

Dr. Richard Schmidt (Max-Planck-Institute of Quantum Optics, Garching, Germany)

When an impurity is immersed into an environment, it changes its properties due to its interactions with the surrounding medium. Indeed, the impurity becomes dressed by excitations in the environment and may form a quasiparticle called polaron. Polarons feature altered properties such as an effective mass and a modified response to external perturbations.

In this lecture, I will introduce the concept of polaron formation and present recent experimental and theoretical progress on studying a variety of polaronic phenomena. After giving an overview over various types of polaronic states found in solid state systems, physical chemistry, and ultracold atomic gases, I will explain how polarons can be theoretically described by means of simple variational wave functions. To this end, I will focus on the problem of a mobile quantum impurity interacting with a Fermi gas which forms a so-called Fermi polaron. After discussing the observation of Fermi polarons in experiments with cold atomic systems, we will turn to two-dimensional materials where polaron physics has recently become a focal point of research. First, we will briefly introduce two-dimensional semiconductors where the interaction between excitons and electrons leads to polaron formation. After reviewing excitons, we will then apply Fermi polaron theory to demonstrate how the optical properties of atomically thin semiconductor heterostructures can be manipulated by exploiting polaronic effects.

In the last part of this lecture we will turn to the famous Anderson orthogonality catastrophe which deals with the breakdown of the polaron description. The Anderson orthogonality catastrophe takes place in systems where the mass of the impurity approaches infinity, and the generation of an infinite number of low-energy excitations may destroy the quasiparticle. We will briefly discuss how this situation can be described theoretically, and we then relate our findings to current frontiers in research where the formation and destruction of polarons is currently explored.

Prerequisites for attending the lecture: Quantum Mechanics