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Topological phases and polaron physics in ultracold quantum gases

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The description of quantum many-body systems poses a formidable theoretical challenge. A seemingly simple problem is the coupling of a single impurity atom to non-interacting Bogoliubov phonons in a surrounding Bose-Einstein condensate. The system can be described by a polaron model at intermediate couplings – an 80 year problem. The situation has been realized experimentally, but when the impurity mass is small compared to the Boson mass, neither mean-field nor strong-coupling expansions are valid anymore. Now the impurity acts as an exchange particle, mediating phonon-phonon interactions. In this talk I present a semi-analytical solution to the polaron problem. I will show that the approach can be generalized to solve far-from equilibrium polaron problems, too, and elaborate on connections with recent experiments involving ultracold atoms and photons. A completely different class of many-body problems are systems with topological order. In recent years we have seen an uprise of cold-atomic or photonic implementations of artificial gauge fields, providing a corner stone for the realization of topological phases of matter. In the second part of my talk, I will address the challenging problem how non-local topological orders can be detected. It will be demonstrated that many-body topological invariants can be measured, making use of mobile impurities as coherent probes of the highly entangled groundstates. I will discuss Laughlin states and comment on possible realizations using ultracold atoms.