Project A12

Controlled Immersion of Single Neutral Atomic Impurities into a Quantum Gas of another Species

Prof. Dr. Artur Widera
Kaiserslautern University – Physics Department

Summary

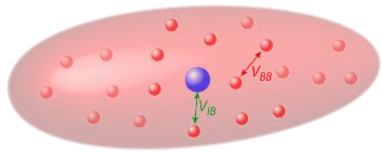
This project aims on investigating single and few impurities immersed in a bosonic quantum gas. The focus lies on emerging quasi-particles called polarons, known from condensed matter systems. Using exceptionally strong and independent control over quantum bath and impurities as well as their interaction strength, polarons shall be studied in strongly interacting or strongly correlated (e.g. 1D) regimes which are hard to access in other physical systems.

The independent control over single atoms is obtained by specifically designed optical potentials experienced by one atomic species, only. We employ the multi-level structure of alkali atoms to cancel the optical dipole potential contributions from two D-line transitions for one species, leading to a light field which exerts a dispersive force only onto the respective other species.

Polarons in a quantum gas

In solids, charge carriers slightly distort the ion crystal lattice. The corresponding dynamics can be understood in terms of so-called polarons, which are quasi-particles formed by the charge carrier dressed by phonons, i.e. lattice vibrations. For small coupling between the charge carrier and the ion crystal, the phonon has essentially the properties of a free charge carrier, while for strong coupling interesting effects can arise: The effective mass of the polaron increases significantly, the binding energy becomes large, and the distortion of the lattice potential leads to self-trapping, i.e. the charge carrier produces its own trapping potential. In real solids, examples of this strong-coupling polaron regime are elusive.

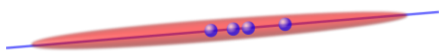
For cold atoms, the Hamiltonian of a single neutral impurity in a bosonic quantum gas can be directly mapped onto the polaron problem [1]. In addition, the transition between weak and strong coupling can be adjusted by magnetic Feshbach resonances controlling the interaction strength between impurity and quantum gas.



The project will create single and few polarons formed by individual Caesium (Cs) atoms immersed in a Rubidium (Rb) Bose-Einstein condensate and study the characterizing properties such as effective mass and binding energy upon approaching and entering the strong coupling regime.

Polarons in a quasi-1D quantum gas

Cold gases allow for engineering of optical trapping potentials in a wide range of parameters. We will use this fact to form the polarons in a quasi-1D geometry, where the motion of atoms is restricted to one dimension, only. Here, it has been shown [2] that for a 1D system the polaronic character should be enhanced, and the strong coupling regime should dominate already at smaller interaction strengths. We will investigate the formation of few polarons in 1D in the weak and strong couling regime, and we will study their spatial distribution. This will reveal the onset of polaron clustering, where polarons tend to attract each other.



Experimental realization

The project involves design and construction of a new experimental apparatus. The system constructed so far has produced Rb Bose-Einstein condensates of a few 10^5 atoms within a few seconds in a crossed dipole trap, imaged by standard absorption. Furthermore, single or few Cs atoms have been trapped in a magneto-optical trap, and a high-resolution and high-sensitivity imaging system has been established.

References

[1] J. Tempere et al., *Phys. Rev. B* **80**, 184504 (2009).
[2] W. Casteels, J. Tempere and J. T. Devreese, *Phys. Rev. A* **86**, 043614 (2012).