Atomic Lattice Excitons

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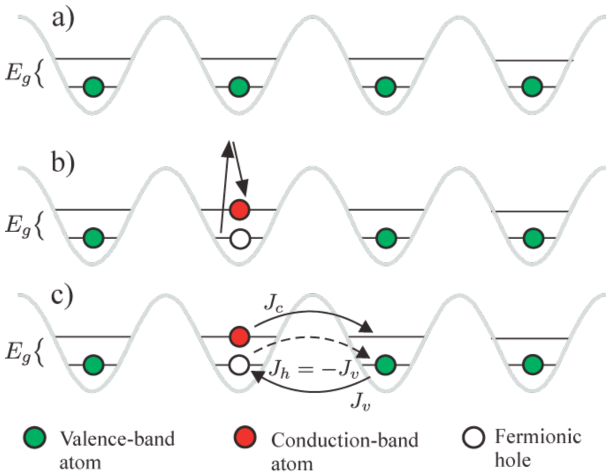
Systems of ultracold atoms in optical lattices offer a highly controllable realisation of many-body lattice models, in which we have a good understanding of the underlying microscopic physics. These systems also are free from uncontrolled disorder, and from strong dissipative processes (e.g., coupling to lattice phonons) that are typically present in solid state systems. As a result, these systems are ideal candidates to study the coherent dynamics of metastable many-body states on relatively long timescales. This was recently evidenced by the study of repulsively bound atom pairs in an optical lattice [1].

In precisely this way, optical lattice systems also offer the opportunity to study certain properties of excitons in an idealised environment. By considering a spin-polarised Fermi gas in an optical lattice in which some atoms are excited to a higher Bloch band, and in which repulsive interactions are engineered between atoms in different bands, it is possible to produce Atomic Lattice Excitons (ALEs) [2]. These bound particle-hole pairs can be described using Hubbard models, and would allow for the study of many properties predicted for semi-conductor excitons, but in a situation where the composite objects are long-lived. In particular, we showed that a condensate of ALEs could be prepared via an adiabatic state preparation process, and could be characterised using readily available experimental techniques, including rf-spectroscopy and noise correlation measurements.



At the same time, ALEs exhibit other interesting properties, in particular the possibility to form a crystalline phase. This arises because atoms in an excited band have a much larger tunnelling rate than those in the lowest band, making it possible for fast-moving excited atoms to mediate effective finite-range interactions between ALEs, for which the centre of mass is located near the slow-moving hole. We investigated these effective interactions and the resulting crystalline phase, both in a Born-Oppenheimer approximation and using numerical calculations based on time-dependent DMRG methods [3-5].

These ideas can be extended to the study of other metastable composite objects in optical lattices that also exhibit interesting quantum phases. One such possibility is the realisation of η-pairing states, which are exact excited eigenstates of the Hubbard model for two fermionic species [6]. These states exhibit off-diagonal long-range order in all dimensions, and if prepared in an experiment should be stationary in time. However, these states would be sensitive to perturbations in the Hamiltonian and imperfections in the state preparation, making them a potentially useful tool to characterise the fidelity of quantum simulation with cold atoms in optical lattices.

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