Quantum dynamics of a coupled atomic-molecular gas in an optical lattice

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Ultracold quantum gases of bosonic and fermionic atoms in optical lattices are highly versatile systems for fundamental studies of quantum many-body physics. They are robust to experimental manipulation and can be described by well-defined theoretical models. Such experiments offer the possibility of forming novel states of ultracold matter, and have the potential for new insights into quantum many-body phenomena. Recent experiments have extended the studies of quantum gases in optical lattices to molecules, using either Raman photoassociation or Feshbach resonance techniques [1].

Motivated by these new experiments and their possible future extensions at the SUT Node of ACQAO, we have commenced a theoretical study of the quantum dynamics of a coupled atomic-molecular system in a Mott state of an optical lattice [2]. As a first step we consider simple cases corresponding to small numbers of atoms and molecules at a single lattice site, without tunnelling, and study the association and dissociation dynamics of the coupled atomic-molecular gas. We treat both the cases of molecular dimers made of bosonic and fermionic atoms, and find a rich variety of periodic and aperiodic solutions (some analytic) that correspond to Rabi-like oscillations between the atomic and molecular states. The solutions can be used as a diagnostic tool for probing the underlying inter-particle interactions, for determination of the distribution of lattice site occupancies, and for precision spectroscopy of the new ro-vibrational structure of the molecules formed under lattice confinement.

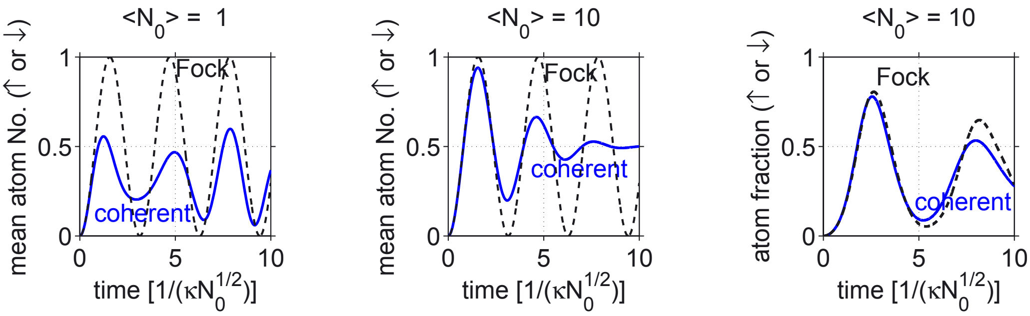

Figure 1: Average number of each type (spin up or down) of fermionic atoms in the lattice mode as a function of a scaled time, dissociated from an average of one (left graph) and ten (middle graph) molecules per lattice site. The two lines are for initial coherent or Fock molecular states. The graph on the right shows the fraction of atoms, relative to the total initial number of molecules, in the case of dissociation into bosonic atoms.

When the quantum gases are in the Mott insulator regime we may treat each lattice site independently, so that the whole of the lattice dynamics can be obtained from analysis of one site. Each site is treated as a Bernoulli trial with a time dependent probability of the occupation numbers. When the insulator is melted and the atoms cross into the superfluid regime, the theoretical treatment is more complicated and we are developing methods to investigate this transition. So far we have investigated up to three interacting sites and are quantifying the effects of the hopping parameters, collisional interactions and molecular association strengths on the crossover regime.

References

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[2] M. K. Olsen, S. J. Thwaite, M. J. Davis, and K. V. Kheruntsyan, in preparation.