Frenkel exciton physics with ultracold molecules

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Ultracold molecules trapped on an optical lattice in a Mott insulator phase form a crystal-like structure. Rotational energy excitation of molecules in such a system gives rise to Frenkel excitons with unique properties. The main question I will discuss is - what can we do with molecules on an optical lattice that cannot be done with solid-state crystals? In particular, I will show that Frenkel excitons in an optical lattice with molecules may exhibit strong non-linear interactions leading to the formation of exciton - exciton bound pairs and tunable exciton - phonon interactions. The latter can be used for quantum simulation of the Holstein model and the study of excitonic energy transport in the presence of a tunable non-Markovian bath. Finally, I will show that a mixture of ultracold molecules on an optical lattice can be used to realize a crystal with tunable impurities, which can be exploited to study exciton localization/delocalization in the presence of dynamically tunable disorder.

Figure 1. Probability density $|\Psi(x)|^2$ describing a Frenkel exciton near the top of the energy spectrum for a 1D array of 1000 LiCs molecules with 10% of homogeneously and randomly distributed LiRb impurities. Different panels correspond to different values of an external electric field.

Figure 2. Excitation energy transfer in an array of five LiCs molecules in a dc electric field perpendicular to the array. Upper panel: evolution of the excitation probability for molecule 1, when no phonons are present; Lower panel: the same, but with phonons in an optical lattice with trapping frequency $\nu_0 = \omega_0/2\pi$ varying in time as indicated in the inset.

References: