INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: Quantum Phases of a Spin-1 Bose Gas in an Optical Lattice: A Focus on Mean Field and Perturbative Approaches

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SHORT ABSTRACT

The thesis investigates the ground state properties of a spin-1 ultracold Bose gas in an optical lattice. We have employed a spin-1 Bose Hubbard model (SBHM) which includes an additional spin dependent interaction potential due to the presence of the hyperfine degrees of freedom. The primary motivation is to explore various quantum phases, such as, Mott insulator (MI), superfluid (SF) and the density ordered phases in the SBHM for either sign (positive or negative) of the spin dependent interaction potential. The phase diagrams are obtained using a site decoupling mean field approximation (MFA) by considering the SBHM in presence of different types of the interaction potential. The formation of the singlet and nematic MI phases and their transition to the SF phase have been carefully scrutinized by analyzing the behaviour of the order parameter and the spin eigenvalues. All the numerical mean field phase diagrams are then compared with the analytical phase diagrams obtained by using a strong coupling perturbative expansion (PMFA) technique. The effects of an on-site random disorder in the SBHM results in a glassy phase, known as the Bose glass (BG) phase in addition to the MI and SF phases. The site inhomogeneities in the MFA is taken care of by defining an indicator which is the fraction of lattice sites having finite SF order parameter and non-integer occupation densities. The transition between these three phases shows a percolation phenomena similar to the statistical mechanics and the phase diagrams are obtained based on the appearance of the SF percolating cluster computed using Hoshen–Kopelman (HK) algorithm. Further, the inclusion of a synthetic and an external magnetic fields is found to be competing against each other on the formation of the spin singlet MI phase. The synthetic magnetic field tries to stabilize the insulating phase while the external magnetic field destabilizes the even MI lobes by suppressing the spin singlet pair formation. As a next, the inclusion of a long range density density extended interaction in the SBHM gives charge density wave (CDW) phase which appears in between the MI and the SF phases. A signature of the formation of the spin singlet and nematic CDW phases are observed at larger values of the extended interaction strength similar to the spin singlet and nematic MI phases. Apart from studying the SBHM in presence of two body interactions, we have extended our calculations up tomulti-body, namely, three body interaction potential. The formation of the spin singlet-nematic and hence the odd-even asymmetry in the MI lobes is found to remain unaffected in presence of both the two and three body repulsive interaction strengths. Although such asymmetry in the MI lobes is absent and the higher order MI lobes except the first one stabilizes in case of a purely repulsive three body interaction strengths. An attractive three body interaction potential helps in stabilizing the third MI lobe and destroys the odd-even asymmetry in the neighbouring even MI lobes. The first and third MI lobes show different orders of phase transition from the MI to the SF phase for higher values of the attractive three body strength.