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Statement of research interests

My research involves theoretical study of low-dimensional and/or strongly correlated condensed matter systems. The specific topics that I plan to work on include

1. Pseudogap phase of Cuprates
2. Ultracold atoms in optical lattices.
3. Open quantum systems.
4. Quantum phase transitions in itinerant magnets.

Below, I briefly sketch some of my ideas regarding future research in the above-mentioned fields.

1. Pseudogap phase of cuprates - One of the central challenges in the field of high temperature cuprate superconductors is to obtain a theoretical understanding of the pseudogap phase. STM studies on these systems (1) have revealed rather clear signatures of charge ordering, which has prompted a number of theories attempting to characterize the pseudogap phase in terms of translational symmetry broken orders such as stripes, d-density wave and so on. In all these works, the role of Mott insulator-superconductor transitions has been overlooked. In Ref. 2, we have introduced a theory which describes this transition in terms of a single dual order parameter and shows that the proper quantum mechanical treatment of the Mott insulator-superconductor transition can naturally give rise to such translational symmetry broken states. The implications of the theory for vortices in cuprate superconductors have also been pointed out.

The work of Ref. 2 is built on the well known quantum dimer model where the electrons in adjacent sites are paired in a spin singlet state. Its chief aim is to study the behavior of these singlet dimers as the system is doped with holes introduced by removing dimers. Whereas this is adequate for describing the charge properties of the system, it can not describe the spin dynamics. A proper description of the spin dynamics would require incorporating the triplet spin excitations of the dimers (dubbed as triplons in earlier literature) and fermionic spin 1/2 excitations that can be formed by breaking the dimers. A general study of the doped dimer model including these excitations is expected to lead to definite predictions for the spin excitations in the pseudogap phase, which can be verified experimentally. It is also expected to shed some light on the role of fermions in the Mott insulator-superconductor transition. This will be one of my areas of research in the future.

2. Ultracold atoms in an optical lattice: The field of ultracold atoms in optical lattice has seen tremendous theoretical and experimental activities in recent years. The most interesting feature of these systems is that they offer unprecedented control over system parameters which can not be achieved in any condensed matter systems. This opens up remarkable opportunities for studying a wide range of interesting phenomenon including superfluid-insulator transitions, the BCS-BEC cross-over, and non-equilibrium dynamics of strongly correlated quantum liquids. My work in this field has largely been focused on understanding the physics of the Mott phases and the Mott insulator-superfluid quantum phase transitions. My future research interests in this field includes

A. Condensates with multiple species of atoms: Recent experiments (3) have shown that it is possible to have condensates with two species of bosonic atoms. The optical lattice depth for these two species as well as the interaction between them can be controlled experimentally. Bosons in such a two species system can be characterized by isospin or their species index. It is well known that they exhibit interesting isospin ordered Mott states (4). The study of the effect of such isospin ordering on the superfluid-Mott insulator transition can lead to a wide range of interesting phases and will therefore be an interesting topic to work on. Also, it is experimentally feasible to dynamically tune the interaction between these two species of atoms. This can lead to interesting non-equilibrium phenomena, which shall be another area of study.

B. Bosonic atoms with dipolar interaction: Recently, condensates of Cr atoms which have magnetic dipolar interactions have been realized (5). The Mott phases of such a system for incommensurate fillings are significantly more interesting, and are expected to exhibit density wave order beyond a critical interaction strength. The duality formalism developed in Ref. 2 in the context of dimer models can prove very useful in analyzing the Mott phases and the superfluid-insulator transitions in these systems. Another area of research will be to study these systems near a Feshbach resonance, where the atoms in the system can form resonant molecular states. This may provide an interesting generalization of our previous work on Mott states and superfluid-insulator transitions of bosons (without dipolar interaction) near a Feshbach resonance (6).

3. Open quantum systems: My research in this area in the past focused mainly on understanding the response of a Cooper pair box to external drive pulse and noise. A Cooper pair box consists of a small superconducting island connected to a Josephson tunnel junction and a gate capacitor. It has been demonstrated that such a circuit can act as a quantum bit (qubit) (7). My past work in this area involved studying the effect of connecting a transmission line to such a qubit. Such connections are an essential part of reading information from the qubit. Experimentally, such a readout scheme is being developed at present (8). We have developed a theoretical description of this readout scheme in the semiclassical limit where the quantum fluctuations of the system can be treated perturbatively. My future research plans in this field are:

A. Quantum effects in a readout process: This will be the first natural extension of our work which shall aim to describe the system away from the semiclassical regime. The readout scheme in Ref. 8 uses a nonlinear Hopf bifurcation transition to distinguish between the qubit states. It is well known that such nonlinear phenomena are inherently classical, and are expected to be washed out by quantum fluctuations. One of the aims of this study shall be to chart out the regime of validity of the semiclassical approximation. The precise nature of the quantum-classical crossover in these systems is also of interest.

B. Multiple qubits: Another interesting project would be to generalize these theories, both classical and quantum, to the case of multiple qubits and/or multiple transmission lines. Such a generalization would provide an understanding of the effect of noise and correlation on the readout process in a multiple bit Cooper-pair box quantum computer and would enable us to study how reading out information from one qubit affects other qubits when the system (qubits and the transmission lines) is in a correlated state.

4. Quantum phase transitions in itinerant ferromagnets: My research in this area is mainly focused on understanding the behavior of the ferromagnetic (FM) transitions in low dimensions. There has been quite a bit of recent activity in this area following the numerical demonstration of a ferromagnetic phase in a class of one dimensional (1D) models. The quantum critical point governing the Luttinger liquid to ferromagnetic phase transition have been studied for Ising ferromagnets using bosonization (9). We have recently obtained an effective theory for Luttinger liquid to FM transitions for Heisenberg ferromagnets in 1D (10) and have shown that this transition has the same dynamical critical exponent as its Ising counterpart. An interesting follow up our work will be to study the effect of disorder, which is likely to be very important due to reduced dimensionality, on the 1D ferromagnetic quantum critical points.

References:

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