TIFR Annual Report 2003-04
THEORETICAL PHYSICS

Condensed Matter and Statistical Physics

Research in this field was conducted in the general areas of non-equilibrium statistical physics, disoredered systems, high temperature-superconductivity and strongly correlated systems.

A variational formulation of the d-wave superconducting ground state and low-lying excitations in doped Mott insulators was developed building on early resonating valence bond ideas of P. W, Anderson. Analytical approximation schemes were developed to gain further insights into our recent variational Monte Carlo results. The effect of disorder on a two-dimensional Mott insulator was studied and found to produce a new metallic phase. The novel metal was shown to be spatially inhomogeneous and coexisting with long range antiferromagnetic order.

The clustering shown by passive, non-interacting particles sliding on a fluctuating surface was studied. The exact distribution of residence times of grains was determined in some sandpile models. The effects of disorder in interacting Bosonic systems with a harmonic trap were studied. The slow decays of orientational correlations in space and time were studied in a system of hard rods on a substrate, undergoing random deposition and evaporation.

Some of the problems studied are described below.

High-Temperature Superconductivity

Various aspects of the strongly correlated superconducting state of the high Tc cuprates and its low-lying excitations were studied using both numerical techniques and analytical approximation schemes.

The coherent spectral weight, effective mass and high energy dispersion of nodal quasiparticles were studied using spectral function moments which can be calculated as equal-time correlation functions in the ground state. This led to important insights into the singular frequency and momentum dependences of the electronic self energy. Detailed predictions were made and compared with the analysis of momentum distribution curves obtained from photoemission experiments on the cuprates. [M. Randeria and N. Trivedi in collaboration with A. Paramekanti (KITP, UCSB)].

The Gutzwiller approximation scheme, previously investigated by Zhang et al for the tJ model, was generalized to the large U Hubbard model and various experimentally relevant correlation functions were studied. These results gave detailed analytical insights into our

earlier numerical results obtained using variational Monte Carlo techniques. [R. Sen Sarma, M. Randeria and N. Trivedi].

The question of tunneling asymmetries in strongly correlated d-wave superconductors was investigated using exact sum rules for projected fermions and spectral functions calculated within the Gutzwiller approximation. [M. Randeria and N. Trivedi in collaboration with P. W. Anderson (Princeton) and F. C. Zhang (Hong Kong)].

Cooper Pairs to Bose-Einstein Condensate Crossover

The problem of the crossover from collective Cooper pairing to the Bose Einstein condensation (BEC) of composite bosons has become experimentally relevant in atomic Fermi gases. In order to understand the validity of previous variational results on this problem, a systematic investigation of quantum fluctuations beyond conventional mean field theory was initiated using the techniques of dynamical mean field theory using the iterated perturbation theory scheme. These fluctuations lead to large quantitative effects in the intermediate coupling regime leading to a significant reduction in the superconducting order parameter and energy gap, and lead to incoherent spectral weight in the one-particle spectral function. [A. Garg and M. Randeria, in collaboration with H. R. Krishnamurthy (IISc, Bangalore)].

Inhomogeneous metallic phase in a disordered Mott insulator in 2D

It was shown that, with increasing randomness, the spectral gap in a 2D Mott-Hubbard insulator is destroyed first at a disorder V_{c1}, while antiferromagnetism persisted up to a higher V_{c2}. Most unexpectedly, between V_{c1} and V_{c2} the system was found to be metallic and was sandwiched between the Mott insulator below V_{c1} and the Anderson insulator above V_{c2}. The formation of the metal started with the spectral gap getting destroyed locally in regions where the disorder potential was high enough to overcome the inter-electron repulsion thereby generating puddles where charge fluctuations were enhanced. With increasing disorder, these puddles percolated and concomitantly the states at the Fermi energy got extended resulting in a spatially inhomogeneous metallic phase that coexisted with antiferromagnetic order. [Nandini Trivedi and Dariush Heidarian]

Linear and Branched Polymers

Numerical simulation techniques are very important tool for studying polymers as the exact results are hard to come by and are available only for simplest models. The efficiency of the incomplete enumeration algorithm for linear and branched polymers was studied. It was found that there is a qualitative difference in the efficiency of the algorithm for linear and branched polymers. The time to generate an independent sample of n sites varies as $n2$ for

linear polymers, but as $\exp(cn^{\alpha})$ for branched polymers, where $0 < \alpha < 1$. For branched polymers on Bethe lattice, our numerical simulations, and non rigorous analytical arguments show that $\alpha = 1/3$. [Sumedha and Deepak Dhar]

Fluctuations of Growing Surfaces

The persistence of height fluctuations was studied in radially growing clusters, models of growth in physical systems e.g. a bacterial colony. The time-dependence of autocorrelations of height fluctuations in such clusters was studied. The surface of the cluster in this geometry is qualitatively different from that in the cylindrical geometry in that the surface width does not saturate.

For the Edwards-Wilkinson surface, the auto-correlation function was calculated analytically and it was shown that it remains non-zero for large times, implying a longtime memory. Using approximate phenomenological arguments, it was argued that this feature persists even in the nonlinear case, as in the Kardar-Parisi- Zhang equation. This is in good agreement with our simulations of growing Eden clusters in two dimensions. [Subhendu B Singha and Deepak Dhar]

Passive Sliders on a Fluctuating Surface

Work on the problem of non-interacting, passive particles sliding under gravity on a fluctuating surface was continued. This problem can be mapped to that of a passive scalar (for instance air bubbles) in a fluid moving under the influence of the flow lines and temperature. Previously, the two-point density correlation function was studied and it was shown that the particles have a strong tendency to cluster, resulting in anomalies in the two point density-density correlation function. The state of the particles has now been further characterised by numerically determining the probability distribution of mass; this is found to have a simple scaling form. Insight into this was gained by considering the different but related equilibrium problem of random walkers on a random landscape. Surprisingly, the results of this problem fit very well our data for the nonequilibrium problem. The change in behaviour of the nonequilibrium system when particles slide faster or slower was studied. Faster sliding was found to result in a local peak in the distribution function at large masses. [Apoorva Nagar and Mustansir Barma]

Self-Organized Criticality

Experiments on piles of long-grain rice, slowly driven by adding grains at one end, which are allowed to leave the pile at the other end, have provided a very good experimental realization of self-organized criticality. These experiments also studied the probability distribution of

residence times of grains. This distribution was studied theoretically in some sandpile models of self-organized criticality.

It was shown that the problem of determining DRT can be reduced to that of finding the probability distribution of hitting time of a single diffusing particle to the boundary, diffusing in a medium with site-dependent jump rates. In the scaling limit of large system sizes, DRT becomes a function of a single scaling variable t/L^b, where t is the residence time, L is the linear size of the system, and b is some exponent. This function is non-universal, and is a complicated function of the spatial distribution of added grains used to drive the pile to its steady state. This function aws determined explicitly for a one-dimensional sandpile when grains are added randomly only at the ends. When grains are added with equal probability everywhere, it was proved that the exact scaling function of the DRT is a simple exponential. This result is independent of dimension, and of the shape of the pile. [Punyabrata Pradhan and Deepak Dhar]

Orientational Correlations in an Assembly of Hard Rods in a Plane

A system of hard rods shows an interesting entropy-driven transition from a low-density orientationally disordered (isotropic) phase to a high-density ordered (nematic) phase in three dimensions. In two dimensions, this spontaneous symmetry breaking is not possible. A model of infinitely thin rods was studied using Monte Carlo simulations allowing deposition and evaporation on a two-dimensional substrate. The ratio of deposition and evaporation rates controls the equilibrium density of rods. For densities above a critical value, the system is in a nematic-like phase characterised by algebraically decaying orientational correlations. Orientational correlation functions for both spatial and temporal behaviour were studied. Although the ordering field in the case of rods is a quadrupole moment rather than a spin vector, the simulation data suggest that the transition is of Kosterlitz-Thouless type. This was confirmed by comparing the decay of correlation functions involving different multipolarity. A simple phenomenological analytical treatment for a slowly varying orientational field of hard rods reproduces quite well the behaviour observed in simulation data. [Mahendra Khandkar and Mustansir Barma]

Phase Transitions in Periodically Driven Systems

Phase transitions in nonequilibrium systems is an active area of current research. The long-time behavior of a class of periodically driven open macroscopic systems was studied. It was found that in certain range of the parameters of either the system or the driving fields, the time-averaged asymptotic behaviour effectively mimics that of certain other equilibrium systems that are then explicitly specified. This was illustrated with various examples how one could understand these driven systems and phase transitions in them with the help of the knowledge of the corresponding effective equilibrium systems. [Sreedhar B. Dutta.]