TIFR Annual Report 1999-00
THEORETICAL PHYSICS

Condensed Matter and Statistical Physics

Research in this subject lies in the general areas of non-equilibrium statistical mechanics, disordered systems, superconductivity, and strongly correlated systems. Some of this work is described below.

Fluctuation Dominated Phase Ordering

Ordering processes in nonequilibrium statistical systems have features which are not shared by their equilibrium counterparts. One such example arises in a system of hard-core particles sliding under gravity on an independently fluctuating surface. It was found that the fluctuations of the surface lead to clustering of initially randomly-arranged particles, over a length scale which grows indefinitely with time. The steady state of the system has macroscopic clustering of particles, but the fluctuation of the underlying surface makes it qualitatively different from usual phase ordered states: (a) The particle clusters are distributed according to a power law. (b) The order parameter has a distribution which remains broad even in the thermodynamic limit. (c) The scaled two-point spatial correlation function has a cusp at small values of the argument. Useful insight into the nature of this new kind of ordering phenomenon comes from the analytical study of a simplified model related to the fluctuations of the surface. (D. Das and M. Barma)

Models of Aggregation and Break-up

A lattice model was studied where particles carrying different masses diffuse and coalesce upon contact, and also unit masses adsorb to a site with rate q or desorb with rate p. This is a generalization of the Takayasu Model which allows desorption. It was shown that the model has a nontrivial nonequilibrium phase transition in all dimensions. The critical and off-critical properties of this model were studied analytically within a mean field theory and numerically in one dimension. (S.N. Majumdar and M. Barma with S. Krishnamurthy of University of Oxford, UK)

A simple one dimensional model of mass transport was studied analytically. A parameter p interpolating between continuous time dynamics ($p \to 0$) and discrete parallel update dynamics ($p = 1$) was introduced. It was shown that the steady state mass distribution has an algebraic tail for small m, $P(m) \sim m^{-\beta}$ where the exponent β depends continuously on the parameter p. An analytical formula for $\beta(p)$ was derived assuming that a product measure holds in the stationary state. (R. Rajesh and S.N. Majumdar)

Spatio-temporal correlations in a class of models with aggregation and injection were calculated exactly. The two-point mass-mass correlations in arbitrary spatial dimensions were obtained for a family of models which includes as special cases the Takayasu model and the q-model of force fluctuations in bead packs. The exact calculation of the variance of mass proves explicitly that the upper critical dimension of the Takayasu model is 2. Explicit expressions were obtained for the correlation functions in the q-model which can be used to test the applicability of the q-model in experiments (R. Rajesh and S.N. Majumdar)

Persistence

New analytical results for random walk persistence were obtained. The problem of no zero crossing or persistence of a non-Markovian Gaussian stochastic process was studied. A new resummed perturbation theory was derived by making a connection between the problem of persistence and the calculation of the energy eigenfunctions of a quantum mechanical problem. (S.N. Majumdar with C. Sire (Toulouse, France) and A. Rudinger (Stuttgart, Germany))

The zero temperature coarsening dynamics in an Ising chain, in presence of a dynamically induced field that favors locally one phase to the other, was studied analytically and numerically. This model can be alternately viewed as a simple Ising model of granular compaction. At late times, the system decays into a fully compact state (where all spins point in the same direction) in a slow logarithmic manner $\sim 1/\log t$, a fact that has been observed in recent experiments on granular systems. (S.N. Majumdar with D.S. Dean of Toulouse, France and P. Grassberger of Wuppertal, Germany)

Other Problems in Statistical Physics

The different universality classes of sandpile models with stochastic toppling rules were investigated. (D. Dhar and S. Sabhapandit)

Large-scale numerical studies were undertaken to determine the distribution of sizes of erased loops in the loop-erased random walk problem in 2 and 3 dimensions. (H. Agrawal and D. Dhar)

Lattice gas cellular automata were studied and some directions for further developments were identified. (H. Agrawal)

Several strategies for better utilization of cache or fast access memory in computers were analyzed analytically. A performance factor α was introduced, which measures the fraction of the cache area utilized when the main memory is accessed at random. α was calculated exactly for different competing strategies, including the hash-rehash and the skewed-associative strategies, which were earlier analyzed only via simulations. (S.N. Majumdar and J. Radhakrishnan)

Melting and Pinning of Vortex Lattices

The first simulations of a three dimensional (3D) system of 1000 magnetic flux lines (vortices) in a type II superconductor were performed using quantum Monte Carlo techniques for an equivalent system of interacting boson world lines in (2+1)D. The pure vortex system was found to show a sharp first order melting transition from an ordered triangular lattice to a liquid of entangled flux lines with increasing temperature. In the presence of a small number of strong columnar pins, the crystal is transformed into a Bose glass phase which melts into a defected entangled liquid through a continuous transition. (P. Sen and N. Trivedi with D. Ceperley of University of Illinois, Urbana-Champaign, USA)

Disordered D-Wave Superconductors

Short coherence length d-wave superconductors with a finite density of unitary-limit scatterers were studied using the Bogoliubov-deGennes technique, and found to have physical properties (density of states, superfluid stiffness, etc.) very different from those obtained by the standard diagrammatic approach. This difference was shown to be due to the spatially inhomogeneous response to disorder ignored within the conventional framework. (A. Ghosal, M. Randeria and N.Trivedi)

Phase Fluctuations in D-Wave Superconductors

A detailed study of phase fluctuations in layered d-wave superconductors was undertaken, taking into account the long range Coulomb interaction in a layered structure. A quantum XY model was derived and analyzed within a variational treatment to understand the effects of thermal and quantum effects of longitudinal phase fluctuations on low temperature properties. (A. Paramekanti and M. Randeria, with T. V. Ramakrishnan of I.I.Sc., Bangalore)

Photoemission Spectroscopy of High Tc Superconductors

The ongoing collaboration with the experimental angle-resolved photoemission (ARPES) group at the University of Illinois at Chicago and Argonne National Laboratory led to several new results on Bi2212 superconductors. First, improved methodologies were developed for the determination of the Fermi surface from ARPES data. Second, the existence of sharp quasiparticles excitations over the entire Fermi surface at low temperatures in the superconducting state was demonstrated. This is important because sharp quasiparticles do not exist above Tc, and further they dominate low temperature transport properties. Finally, a theoretical study was made of sum rules which connect the ARPES spectral function with the thermodynamic condensation energy. (M. Randeria with J.C. Campuzano, M.R. Norman, A. Kaminsky and J. Mesot of University of Illinois at Chicago and Argonne National Laboratory, USA)

Impurities in Antiferromagnetic Insulators

The effects of magnetic impurities on a 2D Hubbard antiferromagnet were studied by a numerical, self-consistent method. Unlike previous perturbative calculations, it was found that even when the impurity spin is equal to the host spin, the correction to the long wavelength magnon energies is momentum-dependent. For impurity spin different from the host spin, a logarithmically diverging correction was found, as in earlier calculations. (P. Sen)