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THEORETICAL PHYSICS

Condensed Matter and Statistical Physics

Research in this field is in the general areas of nonequilibrium statistical mechanics, disordered systems, superconductivity, and strongly correlated systems. Some of the work done in the last year is described below.

Self-Organized Criticality

A important open question in this field has been the question of classification of different universality classes of sandpile models. Since the avalanche activity in sandpile models can grow, diffuse and die, they fall the general class of reaction diffusion systems. It is expected to fall in the universality class of active-inactive transition with many absorbing states. It was shown that the coupling of the activity with a conserved field changes the critical behavior, and the generic behavior of sandpile models, both directed and undirected, is in the directed percolation universality class. The results are based on some analytical arguments for the simplest cases, supported by numerical simulations. [P. K. Mohanty and D. Dhar]

Pico-Canonical Ensembles

The main problem in having a proper ensemble description of glassy states has been the difficulty in making precise the notion of 'sum over nearby configurations only'. This is made precise in the notion of 'pico-canonical ensembles' where averaging is done only over a exponentially small fraction of the energy surface. These were explicitly calculated for the simplest case of one-dimensional lattice gas with nearest neighbor couplings.

The dynamics is Markovian, which satisfies detailed balance, but at low temperatures, some transitions are not allowed, and the dynamics becomes strongly non-ergodic. The phase space breaks up into a large number of sectors, the number growing as volume of system. In pico canonical ensemble, we sum over states in only one of the sectors. The free energy can be explicitly determined in each of these sectors, and also the probability that the system would fall into that sector at low temperatures. [D. Dhar]

Approach to the Steady State in Disordered Zero-range Processes

The zero-range process describes a system of particles with intra-site interactions which are modelled by occupation-dependent hopping rates. Random disorder in the rates arises in various physical contexts like polymerization in a random medium with imperfect traps and traffic flow in a system of cars with different preferred speeds. For a wide class of disorder distributions, there is a phase transition from a homogeneous phase to one in which macroscopic number of particles reside at the site with the lowest hopping rate, as the density is increased. The question arises: how does the system locate the globally slowest site to reach steady state? It was found that there is a two-step approach to equilibrium: the first step involves the formation of local 'condensates' on sites with relatively low hopping rates; the second stage involves mass transfer between such condensate sites and ultimate transfer to the slowest site. This process is described by a dynamic exponent z whose value depends on the power n which characterises the disorder distribution near its lower cutoff. Arguments based on local equilibrium were used to find an expression for z which was checked against extensive Monte Carlo simulations for consistency. The main result of this study is that for $n > 1$, the bulk of the system shows normal diffusion but anomalous diffusion for $n < 1$, leading to different expressions of z in the two regimes. [M. Barma and K. Jain]

Distributions for Periodically-driven Brownian Particles

What is the steady state of a system driven by periodic forces and subjected to noise? This question was addressed in the context of Brownian particles in a confining potential and further driven by a force which is periodic in time and whose amplitude is space-dependent. The large time distributions averaged over a period were derived in two frequency regimes: slow and fast, compared to the frequency set by the confining potential. In the low-frequency limit, this involves averaging over a probability distribution of the Boltzmann form determined by the instantaneous potential. In the high-frequency limit, the Fokker-Planck equation is transformed with a shift of variables by an amount which itself is determined by an autonomous dynamical equation. In either case, the distribution has the equilibrium Boltzmann form with a modified potential which depends on mass, viscosity and frequency. In several cases, the distribution leads to the conclusion that the Brownian particles would get segregated into distinct patches in the steady state. [Sreedhar Dutta and M. Barma]

Variational Studies of Superconductivity in Doped Mott Insulators

A variational formulation of the strongly correlated superconducting state, which builds on earlier RVB (resonating valence bonds) ideas, was shown to give remarkable quantitative and qualitative insights into the doping dependences of various experimental results on high Tc cuprates. Two new directions were explored: trial excited states to study the superconducting gap, and the use of variational wavefunctions to study spin-charge separation in RVB Mott insulators. [A. Paramekanti, M. Randeria and N. Trivedi]

Photoemission Spectroscopy

The collaboration with the UIC-Argonne group on the theoretical analyses of angle-resolved photoemission spectroscopy (ARPES) experiments focused on lineshape analysis and Fermi surface determination in strongly correlated systems. In addition, the coherent-incoherent crossover on the overdoped side of the cuprate phase diagram was studied using the temperature- and doping-dependence of the bilayer splitting probed via ARPES and correlating this with transport measurements. [M. Randeria, with J. C. Campuzano, M. R. Norman, A. Kaminsky and S. Rosenkrantz (University of Illinois at Chicago and Argonne National Laboratory, USA)]

Metal-Insulator Transition in 2D

Motivated by recent experiments showing the unexpected existence of a metal in a disordered 2D system, the properties of the Anderson-Hubbard model that includes the combined effects of correlations between electrons and disorder were explored. The temperature-dependent conductivity and thermodynamic properties of the 2D disordered Hubbard model was calculated using determinantal quantum Monte Carlo techniques and found to show strong dependence on particle-hole symmetry at half filling. [P.J.H. Denteneer (Univ. Leiden), R. T. Scalettar (UC Davis), and N. Trivedi].

Distribution of Transverse Distances in Directed Animals in Bulk and Near a Wall

The average number of sites at a given transverse distance in the directed animals with s sites in d-dimensions was calculated by relating it to the two-point correlation function of a lattice gas with nearest neighbour exclusion in $(d-1)$ dimensions. For 2-dimensional square lattice this function for large s has a scaling form of $\sqrt{s}f(x/\sqrt{s})$, where $f(\xi) = \mathrm{erfc}(\sqrt{3}\xi/2)$. We also found that $\phi(0,s)$ can be determined in terms of the animals number generating function of the directed animal.

The density profile for a directed animal confined to half space interacting with one of the walls of the wedge was also determined exactly. We also determined exactly phase transition between an adsorbed phase and a desorbed phase as a function of wall activity was studied. [Sumedha and D.Dhar]

Hysteresis in Random-field Ising Model

Hysteresis in the random-field Ising model with an asymmetric distribution of quenched fields was studied in the limit of low disorder in two and three dimensions. The spin flip process was related to bootstrap percolation, and it was shown that the characteristic length for self-averaging $L^\star$ increases as $\exp(\exp(J/\Delta))$ in 2d, and as $\exp(\exp(\exp(J/\Delta)))$ in 3d, for disorder strength Δ much less than the exchange coupling J. For system size $1 \ll L < L^\star$, the coercive field h_{coer} varies as $2J - \Delta \ln\ln L$ for the square lattice, and as $2J - \Delta \ln\ln\ln L$ on the cubic lattice. Its limiting value is 0 for $L \to \infty$ both for square and cubic lattices. For lattices with coordination number 3, the limiting magnetization shows no jump, and h_{coer}

tends to J. [Sanjib Sabhapandit, D. Dhar and P. Shukla (NEHU)]