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THEORETICAL PHYSICS

Condensed Matter and Statistical Physics

Research in this field has been carried out in the general areas of nonequilibrium statistical mechanics, disordered systems, superconductivity, and strongly correlated systems. Some of this work is described below.

Models of Aggregation with and without Quenched Disorder

Exact results were found for a simple lattice model of aggregation in which masses diffuse and coalesce upon contact with rate 1 and every nonzero mass chips off a single unit of mass to a randomly chosen neighbour with rate w. The dynamics conserves the average mass density ρ and in the stationary state the system undergoes a nonequilibrium phase transition in the $(\rho - w)$ plane across a critical line $\rho_c(w)$. The phase diagram was calculated analytically in arbitrary spatial dimensions and shown to be independent of dimension. Direct and indirect numerical evidence strongly suggests that the mean field asymptotic answer for the single site mass distribution function and the associated critical exponents are independent of dimension. [R. Rajesh and S. N. Majumdar]

The effect of quenched disorder on such an aggregation-chipping system was studied within a model where chipping occurs only at certain fixed locations. A simplified model with a single chipping site was studied in arbitrary dimension, both in the absence and presence of external drive. Exact and approximate analytical methods along with numerical simulations were used. An interesting finding is the existence of a phase with strong mass fluctuations in which both the mobile and immobile infinite aggregates can coexist. This phase occurs in all cases except in one dimension in the presence of drive. In the latter case, it was found that the system exhibits a phase transition from a phase with an immobile infinite aggregate to the one without an infinite aggregate as the density is decreased. In the presence of extensive disorder, it was argued that the system should show a phase transition similar to one described above, irrespective of dimension and drive. [K. Jain and M. Barma]

Tagged Particle Correlations in Particle Systems

Analytic expressions were derived for the correlations between the positions of tagged particles in the random average process, an interacting particle system in one dimension. It was shown that in the steady state the mean squared fluctuation of a tracer particle grows subdiffusively in the absence of external bias but the displacement of diffusively in the presence of bias. The prefactors of the subdiffusive and diffusive growths as well as

the universal scaling function describing the crossover between them were computed exactly. The mean squared fluctuation in the position difference of two tagged particles separated by a fixed tag shift was computed in the steady state and it was shown that the external bias has a dramatic effect in the time dependence of shifted tag correlations. For fixed tag, it increases monotonically with time in the absence of bias, but non-monotonically in the presence of bias. [R. Rajesh and S. N. Majumdar]

Weak Dynamic Scaling

A coupled-field lattice model proposed earlier to describe the motion of crystals drifting through a viscous medium was analysed in the phase in which the system supports kinematic waves. The steady state was found exactly along a certain representative locus in the phase diagram. The long-time, large-distance properties of the correlation functions were studied using symmetry arguments, Monte Carlo simulations and self-consistent mode-coupling methods. For certain values of the coupling constants, it was found that there are two distinct dynamic exponents in the same system. Earlier known examples of such weak scaling involved situations in which at least one of the fields evolved autonomously. This work identifies new symmetry-related conditions under which weak dynamic scaling occurs, even in the presence of two-way nonlinear coupling between fields. [D. Das and M. Barma with A. Basu and S. Ramaswamy (IISc, Bangalore)]

Hysteresis in Random Field Ising model

The zero-temperature hysteretic response of the random-field Ising model to slowly varying external field is one of the few problems where nonequilibrium response can be calculated exactly in a model with disorder and short-ranged interactions. In earlier work, it was shown that this model can be solved exactly on a Bethe lattice. This study has been now extended to two dimensional lattices. It was shown that the response is very different on the square and hexagonal lattice, even in the limit of weak disorder. On the hexagonal lattice, the hysteresis loops have no discontinuous jumps, but the area of the loop remains finite. On the square lattice, there is a jump in the magnetization for weak disorder, but the area of the hysteresis loop goes to zero in the limit of large system size increases, and zero disorder. [D. Dhar and S. Sabhapandit with P. Shukla (N. E. H. U. , Shillong)]

Distribution of sizes of loops in loop-erased random walks

In the loop-erased random walk problem, it was shown that the probability that the erased loop has an area A varies as A^{-2} for large A, independent of the space-dimension d, for $2 \leq d \leq 4$. The exponents characterizing the distribution of perimeters and areas of erased loops in $d = 2$ and 3 were determined numerically by large-scale Monte Carlo simulations. This also provides a numerically efficient way to determine the exponent for the distribution of avalanches in the three-dimensional abelian sandpile model. The extremal statistics of

the largest, second and third largest erased loops for a random walk was studied, and it was shown that the average ratios of these are strongly affected by the correlations between loops. [H. Agrawal and D. Dhar]

Other problems in Statistical Physics

The probability that a fluctuating nonequilibrium field does not change sign upto some time t (persistence) decays as a power law $\sim t^{-\theta}$ in many nonequilibrium systems. The exponent θ was computed analytically for interfaces, random walks and various other stochastic processes. A crucial difference between continuous-time persistence and discrete-time persistence was pointed out for stationary processes. [S. N. Majumdar with A. J. Bray and G. C. M. A. Ehrhardt (University of Manchester, U.K.), C. Sire and D. S. Dean (Universite' Paul Sabatier, France)]

A connection was pointed out between the extreme value statistics of correlated random variables and a travelling front. Exploiting this connection, various analytical results were derived for the random binary search tree problem in computer science. [S. N. Majumdar with P.L. Krapivsky (Boston University, U.S.A.) and E. Ben-Naim (Los Alamos National Laboratory, U.S.A.)]

A simple model describing the dynamics of efficiency in a given network was proposed and studied analytically. A nonequilibrium phase transition was found between a phase where the average efficiency increases with time and one where the average efficiency is stagnant. [S. N. Majumdar with P.Ł. Krapivsky (Boston University, U.S.A.)]

Nonequilibrium coarsening dynamics in presence of kinetic disorder was studied analytically and numerically in a one-dimensional spin model. The results were used to explain certain features of the experiments on granular compaction in glass beads. [S. N. Majumdar with D. S. Dean (Universite' Paul Sabatier, France) and P. Grassberger (NIC, Forschungszentrum Julich, Julich, Germany)]

A class of lattice gas cellular automata (LGCA) models was studied, and connections with models which are a hybrid of the conventional LGCA and percolation and sandpile models were explored. Coarse-graining of these models brings out their relation with other problems in percolation theory. [H. Agrawal]

Nonequilibrium interface growth of two-dimensional surfaces is not very well understood theoretically. A 2+1 dimensional growth model was studied and its equivalence to diffusion in an assembly of interacting strings in 2 dimensions established. [P. K. Mohanty and D. Dhar]

Variational Wavefunctions and High T_c Superconductivity

Strongly correlated superconductors were studied using a projected variational wavefunction, with Monte Carlo methods used to impose the no-double-occupancy constraint exactly. Equal-time correlation functions were interpreted as moments of (dynamical) spectral

functions, and used to obtain new results for the ground state and low energy excitations of the 2D Hubbard model. Various experimentally important quantities such as coherence length, momentum distribution, nodal quasiparticle weight and Fermi velocity, optical spectral weight and superfluid density, were calculated, and their doping dependence studied. Quantitative comparisons showed good agreement with existing experiments on the high temperature superconductors. Definite predictions were made for the doping dependence of the coherence length, and quasiparticle self-energy at the gap nodes. [A. Paramekanti, M. Randeria, and N. Trivedi]

Phase Fluctuations and Dissipation in D-Wave Superconductors

The effect of dissipation, possibly due to low energy electronic excitations in a d-wave superconductor, on phase fluctuations at low temperature was studied. The resulting renormalizations of the ab-plane and c-axis superfluid densities, measured by penetration depth experiments, was calculated. It was shown that while quantum effects may be moderately large in the high T_c superconductors, thermal phase fluctuations had a negligible effect at low temperature. [A. Paramekanti and M. Randeria, with L. Benefatto, S. Caprara and C. Castellani (University of Rome, Italy)]

Photoemission Spectroscopy of High T_c Superconductors

The main focus of the ongoing collaboration with the UIC-Argonne angle-resolved photoemission (ARPES) group was on developing the methodology for quantitative analysis of ARPES lineshapes to extract the electronic self-energy. This was used to establish the existence of sharp nodal quasiparticles at temperatures well below T_c in the high T_c superconductors. [M. Randeria with J.C. Campuzano, M.R. Norman, and A. Kaminsky (University of Illinois, Chicago and Argonne National Laboratories, U.S.A.)].

Inhomogeneous Pairing in Disordered Superconductors

In previous work on disordered s-wave superconductors done using the Bogoliubov-deGennes mean field theory, the energy gap was found to persist into the disordered insulating state. In order to gain deeper insight into this unexpected result a generalized formulation of Anderson's pairing of exact eigenstates was developed that included the inhomogeneity in the pairing amplitude. This feature, which has been neglected in all previous theories, was found to be central for understanding the *increase* of the energy gap with increasing disorder in the insulator. [A. Ghosal, M. Randeria, and N. Trivedi]

Metal-Insulator Transition in 2D: Role of Particle-Hole Symmetry

It was demonstrated that particle-hole (ph) symmetry played a crucial role in determining the transport and thermodynamic properties of models describing strongly correlated electrons with disorder. For the half-filled Hubbard model in 2D it was shown that the low-temperature conductivity decreased with increasing disorder when ph-symmetry was preserved (for example with nearest neighbour hopping disorder). However, the opposite behavior showing an increase of the conductivity with increasing disorder was found when ph-symmetry was broken (for example with site disorder or next-nearest-neighbour hopping disorder). Further, the Mott insulating gap in the energy spectrum was found to be insensitive to weak disorder when ph-symmetry was preserved, whereas in the absence of such a symmetry the gap diminished with increasing disorder. [N. Trivedi with P.J.H. Denteneer (Leiden University, Holland) and R.T.Scalettar (University of Caifornia at Davis, U.S.A.)]