TIFR Annual Report (2012-13) - Department of Theoretical Physics

Condensed Matter and Statistical Physics

Stochastic strategies for Minority Games

The *Minority Game* is a model of interacting agents, who try to choose between two options every day, and those who are in the minority are winners. Stochastic strategies for playing a version of this game was studied, and it was found that the optimal strategies can be determined self-consistently using a new solution concept called co-action equilibrium. This is more efficient than the deterministic strategies studied earlier. The average payoffs in the steady state show a non-analytic dependence on the discount parameter, even for a finite number of agents. [V. Saidevan and D. Dhar]

Fully packed plates on a cubic lattice

Random fully-packed configurations of $2 \times 2 \times 1$ boxes in 3 dimensions were studied as a function of concentration of plates in different orientation. A phase transition was found to occur from a sublattice ordered phase to a layered phase, as the difference between the fractions of different orientations of plates is increased. The critical exponents of this transition are being studied by Monte Carlo simulations. [S. Biswas, K. Damle and D. Dhar]

Active-absorbing phase transition in assisted diffusion models

Active-absorbing phase transitions were studied in a class of models of interacting particles in one dimension. In these models, a particle can move only if it has another particle within a distance n. At low density, all particles eventually become immobile, and the phase is called inactive phase. At higher densities $\rho > \rho_c$, a non-zero fraction of the particles is active in the steady state. It was shown that this fraction varies as $\sim (\rho - \rho_c)^n$ for the model with range n. [R. Dandekar and D. Dhar]

Condensation and intermittency in an open-boundary aggregation-fragmentation model

Transport of biomolecules through the Golgi apparatus of cells is believed to occur either via single molecules shuttling between large and stationary aggregates or via the collective movement of the large aggregates themselves or by some combination of the two processes. Motivated by this scenario, a simple one-dimensional model was used to study the interplay of movement and aggregation of large masses and fragmentation of small masses in open systems with influx and outflux of mass at the boundaries. As influx is increased, the system undergoes a phase transition from a normal (fragmentation-dominated) to a condensate (aggregation-dominated) phase with unusual steady state and dynamical properties. In the condensate phase, the total mass shows giant fluctuations due to the formation and exit of macroscopic aggregates. The time series of the total mass also exhibits breakdown of self-similarity and strong intermittency, which is characteristic of turbulent systems. In the normal phase, by contrast, the total mass has Gaussian fluctuations and its time series is non-intermittent. The system was studied using numerical simulations, supplemented by analytical results in the absence of fragmentation. A related phase transition occurs even when the movement of large masses is biased. [H. Sachdeva and M. Barma with M. Rao (RRI, Bangalore)]

Fractional spin textures and their entropic interactions in the frustrated magnet SCGO

Motivated by experiments on the archetypal frustrated magnet $SrCr_{9p}Ga_{12-9p}O_{19}$ (SCGO), the classical Heisenberg model on the pyrochlore slab (Kagomé bilayer) lattice with site-dilution $x = 1 - p$ was studied to address generic aspects of the physics of non-magnetic vacancies in a classical spin liquid. It was explicitly demonstrated that the pure ($x = 0$) system remains a spin-liquid down to the lowest temperatures, with an unusual *non-monotonic* temperature dependence of the susceptibility, which even turns diamagnetic for the apical spins between the two kagome layers. For $x > 0$ but small, the low temperature magnetic response of the system is most naturally described in terms of the properties of spatially extended spin textures that cloak an *orphan* $S = 3/2$ Cr^{3+} spin in direct proximity to a pair of missing sites belonging to the same triangular simplex. In the $T \to 0$ limit, these orphan-texture complexes each carry a net magnetization that is exactly half the magnetic moment of an individual spin of the undiluted system. Furthermore, it was demonstrated that they interact via an entropic *temperature dependent pair-wise exchange interaction* $J_{eff}(T, \vec{r}) \sim T\mathcal{J}(\vec{r}\sqrt{T})$ that has a logarithmic form at short-distances and decays exponentially beyond a thermal correlation length $\xi(T) \sim 1/\sqrt{T}$. The sign of J_{eff} depends on whether the two orphan spins belong to the same Kagome layer or not. A detailed analytical account of these properties was provided using an effective field theory approach specifically tailored for the problem at hand. These results are in quantitative agreement with large-scale Monte Carlo numerics.[K. Damle, A. Sen and R. Moessner (Dresden)]

Néel to valence-bond solid transition on the honeycomb lattice: Evidence for deconfined criticality

A spin-1/2 Heisenberg model on the honeycomb lattice with nearest-neighbour antiferromagnetic exchange J that favours Néel order, and competing 6-spin interactions Q, which favor a valence bond solid (VBS) state in which the bond-energies order at the *columnar* wavevector $K = (2\pi/3; -2\pi/3)$, was studied. Using projector Quantum Monte Carlo techniques, evidence for a direct continuous quantum phase transition between the Néel and VBS states, analogous to the deconfined critical point between these states on the square lattice, was found. This implies that such deconfined critical points can exist on the honeycomb lattice although Berry phase effects allow tripled hedgehog defects of the Néel order parameter to play a role in the critical theory, unlike the square lattice case in which only quadrupled hedgehog defects are allowed. [K. Damle with F. Alet and S. Pujari (Toulouse)]

Elastic response of nanoscale charge density wave resonators

The changes in various physical quantities across a phase transition in microscopic systems can be quite different from the behaviour in bulk crystals. For the case of the charge density wave (CDW) transition, the signatures of the new order parameter are observed in the electronic properties and concomitant changes in the elastic properties have been seen in macroscopic crystals. The screening of charge by electrons strongly affects the lattice stiffness. Nanoelectromechanical systems (NEMS) provide an ideal platform for studying the mechanical response of nanoscale structures at high frequencies in the MHz range. Experiments on suspended nanowire resonators of $NbSe_3$, that undergo an incommensurate CDW transition, showed an abrupt peak in the resonant frequency (corresponding to a large fractional change in the elastic modulus) as a function of temperature. A simple Frenkel-Kontorova model was developed for explaining this anomalous behaviour - the large change in the measured elastic properties (as compared to macroscopic crystals) was related to a pinning-depinning transition between the CDW and ionic lattice. [Vikram Tripathi with S. Sengupta, N. Samudrala, V. Singh, A. Thamizhavel, M. M. Deshmukh and P. B. Littlewood (Argonne National Lab.)]

Colossal nonsaturating linear magnetoresistance in two-dimensional electron systems at a GaAs/(Al,Ga)As heterointerface

Strongly inhomogeneous media composed of two materials with very different Hall angles can exhibit very large, linear magnetoresistance over a wide range of magnetic fields. This behaviour does not have a magnetic origin; rather, it is geometrical in nature. Strongly disordered 2D electron systems in GaAs heterostructures were observed to show colossal nonsaturating linear magnetoresistance. It was argued that this is essentially a geometric magnetoresistance effect arising from electronic phase separation in the disordered 2D system. A simple model of a 2D inhomogeneous system was analytically shown to give a nonsaturating linear magnetoresistance whose magnitude was found to depend on the asymmetry in the Hall conductivities of the two components. [Vikram Tripathi with M. A. Aamir, S. Goswami, A. Ghosh (IISc Bangalore), M. Baenninger, I. Farrer, D. A. Ritchie (Cambridge), and M. Pepper (University College, London)]

Excitonic Condensates in Double-layer Graphene

Excitonic condensates have been predicted to occur in double-layer graphene (two sheets of graphene separated by a dielectric and coupled through Coulomb interactions) for a long time, although current experiments have not been able to observe it. To see whether disorder in the samples leads to destruction of the condensate, the robustness of an excitonic condensate in double-layer graphene to fluctuations in local density in the layers and associated charge inhomogeneities were studied. It was shown that the effect of layer density fluctuations on excitonic condensates is equivalent to effect of random Zeeman field on a superconductor. The stability of the excitonic condensate to these fluctuations was found to be strongly dependent on the size of the excitonic gap. It was also shown that transport measurements (like Coulomb drag experiments) are more promising candidates for observing signatures of exciton condensation in an inhomogeneous sample compared to bulk thermodynamic experiments. [Rajdeep Sensarma with D. S. L. Abergel (Maryland) and Sankar Das Sarma (Maryland)]

Quantum dynamics of disordered bosons in an optical lattice

The equilibrium and non-equilibrium properties of strongly interacting bosons on a lattice were studied in the presence of a random bounded one-body disorder potential using Gutzwiller projected variational techniques and canonical transformations. In equilibrium, the well known phase diagram, where a compressible but non-superfluid Bose glass phase separates the incompressible Mott insulating phase and the superfluid phase, was recovered with this technique. The non-equilibrium response of this system to a periodic drive, where, starting from the superfluid phase, the hopping parameter is ramped down linearly in time and then back to its initial value, was also studied. In absence of disorder, the long time excitation density goes to a constant, while the order parameter and the energy relax as $1/\tau$ and $1/\tau^2$ respectively, where τ is the characteristic time of the ramp. In presence of disorder, it was shown that the excitation density decays exponentially with τ, with the decay rate increasing with increasing disorder, to an asymptotic value, which is independent of the strength of the disorder. [Rajdeep Sensarma with Chieng-Hung Lin (Maryland), Krishnendu Sengupta (IACS Kolkata) and Sankar Das Sarma (Maryland)]