Research Highlights of Statistical Physics and Soft-Condensed Matter Group

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In our group, research is diverse and multi-disciplinary. The problems are mostly based on classical statistical mechanics, modeling and computer simulations. In general, problems are related to Soft-condensed Matter and Computational Statistical Physics. We mostly study Phase transitions and Critical phenomena in equilibrium and out of equilibrium situations. Different analytical techniques such as Mean field, Transfer matrix, Exact series expansion and Renormalization group theory are applied besides different computational techniques such as Monte Carlo, Molecular Dynamics and Exact enumeration.

Recently we have been rigorously involved in exploring a number of different problems such as: Two phase flow in a porous media, Percolation of diffusion limited aggregates, Corrosion of random solids:Inverse fiber bundle and percolation, Fiber bundle on fractal supports, Random Spring Network: Brittle to ductile transition, Variational transfer matrix and disordered Ising magnet, Ising magnet and negative magnetization, Active Matters under external constraints, Active matter in active fluids, Statistical Mechanics of Active Ising model and many others. Study of aerosols: Pollutants and Rainfall, Reaction diffusion systems, Modeling of Mitochondria and study of its Enzyme kinetics, Cancer as a dynamical phase transition,

This time, I have two full positions, one in the regular category and another in the special drive category. I also have two other shared positions, one with Prof. Dilip Pal and the other one with Prof. Pankaj Kumar Mishra. Below we describe the problems we tentatively offer this time.

1. Problems for full regular/special drive positions:

(i) Two phase flow in a two component porous media: Two-phase flow in a two-component porous medium is a complex and significant area of research, particularly relevant to fields such as hydrology, petroleum engineering, and environmental science. Here, two immiscible fluids flow through a porous medium composed of two distinct solid components, each with its own properties. The interplay between fluid-fluid interactions, solid-fluid interactions, and the heterogeneity of the solid matrix leads to complex behaviors that are challenging to predict but crucial for applications in energy, environment, and materials science. Understanding these dynamics through experiments, theory, and simulations is key to optimizing processes in various engineering and environmental contexts. One needs to develop the flow equations analytically, simulate the flow in the porous medium by Monte Carlo technique and understand the physics of two phase flow in porous media.

(ii) Percolation of diffusion limited aggregates: Percolation and diffusion-limited aggregation (DLA) are two fundamental concepts in statistical physics and the study of fractal growth processes. When combined, these concepts help to understand complex systems such as fluid flow in porous media, the formation of natural structures, and the spread of diseases or pollutants. The study of percolation of diffusion-limited aggregates bridges two rich fields in statistical physics, offering insights into complex growth phenomena and transport properties in disordered systems. It involves theoretical development and Monte Carlo simulation.

(iii) Brittle to ductile transition in Random Spring Network: The brittle to ductile transition in random spring networks is a compelling topic in materials science and statistical mechanics. This transition characterizes how a material can change its failure mode from brittle (fracturing suddenly under stress) to ductile (deforming plastically before breaking) as various parameters are altered. A random spring network is a theoretical model used to study the mechanical properties of disordered materials. It consists of nodes (representing atoms or molecules) connected by springs (representing chemical bonds) arranged randomly. The springs can have varying properties such as stiffness and strength, and the network can be embedded in different spatial dimensions. The study of brittle to ductile transition in random spring networks combines theoretical modeling, computational simulations, and experimental research to explore how disordered systems respond to mechanical stress. By manipulating network connectivity, spring properties, and external conditions, one can gain insights into the fundamental mechanisms governing material failure and design materials with optimized mechanical performance.

(iv) Dynamic phase transition in active particles: Dynamic phase transitions in active particles involve changes in the collective behavior of self-propelled particles under varying external fields. Active particles, which can convert energy from their environment into directed motion, exhibit a wide variety of behaviors not seen in equilibrium systems. These behaviors can include clustering, swarming, and phase separation, often driven by non-equilibrium forces and interactions. Dynamic phase transitions in active particles represent a frontier in the study of non-equilibrium systems, revealing a host of new phenomena and potential applications. By combining theoretical models and computational simulations, we aim to uncover the principles governing these transitions.

(v) Antiferromagnetic Ising model with long range multisite interactions: The antiferromagnetic Ising model with long-range multisite interactions is an extension of the classical Ising model, incorporating more complex and realistic interaction patterns. This model is particularly relevant in the study of magnetic materials, where interactions are not limited to nearest neighbors and can involve multiple sites simultaneously. The antiferromagnetic Ising model with long-range multisite interactions provides a rich framework for exploring complex magnetic behaviors and phase transitions. By incorporating these interactions, the model becomes more representative of real-world systems, enabling the study of frustration, exotic phases, and critical phenomena. Analytical methods, numerical simulations, and theoretical frameworks are crucial for uncovering the intricate properties of these systems and understanding their implications in various fields.

2. Problem sharing with Prof. Dilip Pal:

Understanding of Pollution and Rainfall: Understanding of Pollution and Rainfall: The parameters of daily weather, such as temperature, rainfall, wind velocity, etc., are complex processes. Several nonlinear interactions are involved in these processes; thus, characterizing them is a challenging task. Noticeable deviations from the normal distributions have been observed, and the stochastic nature of such processes is very prominent. It has been noticed that the variations of these parameters are not gradual but frequent, along with controlled jumps occurring in it. One needs to investigate these properties by applying the tools of non-equilibrium statistical mechanics such as self-organized criticality, fractal analysis, nonlinear and temporal Fourier analysis, etc.

3. Problem sharing with Prof. Pankaj Kumar Mishra:

Study of dynamics of active particles in active fluid: Active particles in active fluids are a fascinating topic within the field of soft matter physics and non-equilibrium statistical mechanics. The interplay between particle activity and fluid dynamics leads to a wealth of complex behaviors and emergent phenomena that challenge our understanding of non-equilibrium systems. Research into active particles in active fluids involves a combination of theoretical models, computer simulations, and experimental studies. Theoretical models often use statistical mechanics and hydrodynamics tools to describe the macroscopic behaviors resulting from microscopic rules. Simulations provide insights into the complex dynamics that are difficult to capture analytically. In this problem, one needs to develop theoretical models and perform computer simulations.