Unveiling Phases and Phase Transitions in Inhomogeneous Active Systems

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Physics

by

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Abstract

The active matter systems can be recognized as a collection of particles in which the individual components possess nonzero motility by converting the energy from their surroundings and also from the medium. The active particles spontaneously self-organize when present in large numbers reveal fascinating properties like persistent motion, phase separation, clustering, self organisation and so on. Understanding these unusual properties exhibited by active systems on different length scales, has been a focus of research in recent decades. This thesis present the projects related to various phenomena in active matter systems e.g. birth and death, disorder in one dimensional active systems, inhomogeneous substrates and mixture of polar and nematic systems. All the projects are presented in following chapters:

Chapter 1 is the historical context and description of active systems. The definition and fundamental characteristics of active systems are covered in this chapter. We also go through various methods for researching active systems, such as agent-based modelling. The remaining chapters are structured as follows.

In Chapter 2, we study a collection of self-propelled polar particles on a two-dimensional substrate with birth and death. We introduce a minimal lattice model for the system using active Ising spins, where each particle can have two possible orientations. The activity is modeled as a biased movement of the particle along its direction of orientation. The particles also align with their nearest neighbors using Metropolis Monte Carlo algorithm. The system shows a disorder-to-order transition by tuning the temperature of the system.

The chapter 3, explores the effect of quenched disorder on the characteristic of self-propelled particles in one-dimension. Here, particles interact with disorder which serve as directional cues. The study investigates how the density of the disorder influence the emergence of ordering and clustering in the collection of the self propelled particles. We introduce the microscopic model as well as corresponding coarse-grained equations of motion for the local density and the orientation of particle. Disorder affects the macroscopic ordering in the system, the size of the ordered clusters decays algebraically with disorder.

In chapter 4, we discuss how the active Brownian particles (ABPs) can be identified as a successful way of modeling the moving microorganism on the substrate. We studied the dynamics and the steady state of ABP moving on a two-dimensional substrate with space-dependent activity. On the substrate, some regions are marked as high in activity, and other regions are such that particles behave as passive Brownian particles. The final steady state of particle density profile, polarization and flux very much follows the structure of

the inhomogeneous activity, and the density in high activity region is lower, maximum at the interface and nearly constant with mean density in the passive region. The steady state density profile for various shapes and designs on two-dimensional substrates is studied. Hence, the collection of ABPs on an inhomogeneous substrate can mimic the inhomogeneity of the substrate.

Further in 5 we couple the liquid crystal with external species present in it and these external species have polar symmetry unlike the liquid crystal which are apolar in nature. The strings are visible in the order parameter field of both polar and apolar species. For polar species, the magnitude of the order parameter is close to zero along the string which is acting like domain wall seperating two oppositely oriented domains of polar species. We observe the defect pairs connected through strings are not necessarily opposite in nature, it can be same (+1/2,+1/2), (-1/2,-1/2), as well as opposite (+1/2,-1/2).

The thesis is finally concluded in chapter 6 with a synopsis of all the chapters mentioned above with future prospects.

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Certificate

It is certified that the work contained in the thesis titled **Unveiling Phases and Phase Transitions in Inhomogeneous Active Systems** by **Mr. Pawan Kumar Mishra**, Roll Number **19171019**, has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of **Ph. D. Degree** in **Physics**.

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I, **Pawan Kumar Mishra**, certify that the work embodied in this thesis is my own bona-fide work and carried out by me under the supervision of **Dr. Shradha Mishra** from July 2019 to August 2024 at the **Department of Physics**, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers whenever and wherever their works have been cited in my work in this thesis. I further declare that I have not wilfully copied any others' work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

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Certificate by the Supervisor

It is certified that the above statement made by the student is correct to the best of my knowledge.

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Dedicated

to

My grandfather

Late. Shri Shobh Nath Mishra

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