INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

Active matter or self-propelled particles (SPPs) are characterised by their inherent ability to consume energy from the environment and eventually drive themselves out of equilibrium. Bacteria swarms, cell clusters, insects, fish schools, birds, human crowd, and even many artificial self-driven systems are all examples of the active matter which exhibits collective motion. In a seminal work, Vicsek et al. proposed a model for studying the collective motion of SPPs in two dimensions, famously known as the Vicsek model (VM). In this model, a large number of SPPs move together at a constant speed (v_0), and they align their direction of motion with their neighbours through a short-range alignment interaction. However, the average direction is subject to an angular noise (η). For a given density (ρ_0), an orientational order-disorder transition occurs at a critical noise (η_c). Though the order of transition depends on the values of (ρ_0, v_0), the properties exhibited at the transition point are characterised and understood rigorously.

Perturbations or agitations are common in nature. For example, migration of a herd of animals across forests or steps, traffic flow in busy cities, a microbial colony in natural habitats etc. Hindrance or external disturbances along the path of SPPs can cause a perturbation in the system in the form of disruption of their motion or change in orientation. However, the collective dynamics of SPPs with inherent perturbation in the system is rarely studied. In this thesis, we have studied the collective dynamics of SPPs incorporating a trapping perturbation in the VM under which the SPPs get trapped for a while with a position-dependent trapping probability as they pass through the trapping region and pick up a random velocity direction on release. The study of the VM incorporating such a perturbation reveals several novel properties of the system. It sheds light on the order of transition in the VM, identifies the crossover system size, and clarifies the existence of a tricritical point.

One of the main criteria of VM is that all the SPPs should have the same velocity. However, in natural systems, the velocities of particles need not be the same during collective motion. For example, fast-moving (active) and slow-moving (dormant) bacteria in a bacterial population or slow-moving vehicles and speedy vehicles in daily traffic. We have studied the collective behaviour of a binary mixture of SPPs with two different motile properties, such as slow-moving SPPs with velocity v_s and fast-moving SPPs with velocity v_f ($v_f \gg v_s$). Both inter and intra-particle interactions are considered in the alignment interaction. The model exhibits many different self-organised pattern formation and

phase separation under a short-range interaction without external force or repulsion. The mixing of two different SPPs has a strong non-universal effect on the critical behaviour of the system when the system is studied for higher and higher values of v_f keeping v_s fixed. For high v_f, discontinuous transitions occur not only for the fast-moving SPPs but also for the slow-moving SPPs and the whole system as well.

The effect of orientation adapters on the collective behaviour of SPPs is a crucial aspect to study in the context of VM. In this model, adapter SPPs exist besides the usual SPPs in equal proportion. The adapter SPPs do not interact among themselves but adopt the velocity orientation of the usual SPPs through local interactions. However, the usual SPPs do interact with themselves as well as with the adapters. The adapters move with velocity v_a and induce nontrivial behaviour in the system. The transition nature of the usual SPPs with high velocity v_0 remains as that of the VM. In contrast, the adapters without self-interaction and with $v_a \ll v_0$ synchronise with the usual SPPs and obtain different behaviour. However, interestingly, the adapters with $v_a \gg v_0$ make the transition continuous for both the usual SPPs and the adapters.

The thesis represents many novel results obtained from different models of collective motion of SPPs incorporating perturbation, different species and orientation adapters. The novel results obtained in studying such active systems will be helpful to understanding many related fields, such as swarm robotics, molecular biology, biomedical applications, security systems, traffic and crowd management etc.