Individual and collective behavior of active and passive particles in different environment

THESIS SUBMITTED FOR THE AWARD OF

DOCTOR OF PHILOSOPHY

in

PHYSICS (THEORETICAL)

by

VIVEK SEMWAL

Supervisor

DR. SHRADHA MISHRA

DEPARTMENT OF PHYSICS

INDIAN INSTITUTE OF TECHNOLOGY

BANARAS HINDU UNIVERSITY

VARANASI - 221 005

ROLL NUMBER 17171015

YEAR OF SUBMISSION 2022

Chapter 7

Summary and conclusion

7.1 Summary

In this thesis, we studied the three classes of self-propelled particles or active matter (i) active Brownian particles, (ii) run and tumble particles, (iii) active chiral particle and (iv) dynamics of a single particle on Lorentz lattice gas. This approach may allow us to develop a novel nonequilibrium theory that unifies a wide range of intriguing phenomena that occur in systems of self-propelled particles. With the help of these approaches we can also regulate the trajectory of the particles without designing the structure for the particles. More specifically, we study whether such nonequilibrium systems possess an equilibrium-like property. We address here where these different self-propelled particle are equally behave in which regime. In chapter 1, we covered a thorough introduction to nonequilibrium statistical mechanics, along with its historical context. In chapter 2, we have studied the motion of active particles on two dimensional periodic undulated surface in the presence of active friction. We found their is competition between the activity and surface undulation, based on this we draw the phase diagram of the system for different type of trajectory. We also shows the equivalence of diffusivity from Green-Kubo and mean square displacement (MSD). In chapter 3, we introduced a minimal model of run and tumble particle in the presence of passive particles. We characterize the dynamics of the particle for different values of size ratio and tumbling rate. We found dynamics of the active particle always shows the transition from ballistic to diffusion region, for passive particles motion of the particle always shows transition from superdiffusive to subdiffusive. Crossover time is increasing with increasing size ratio of the passive particles. The chapter 4 unveiled a basic model of chiral active particle. Chirality of the particle shows different type of dynamics. Dynamics of the particle shows transition from ballistic to diffusive and subdiffusive depend upon the chirality. The competition between activity and chirality leads to three distinct phases as we slowly tune the chirality. For small chirality, when linear motion dominates, effective dynamics of particles are enhanced in comparison to a single chiral particle with the same chirality. It leads to macroscopic clustering of particles. For intermediate chirality, when linear and circular motion is comparable, the particles show weaker clustering with small cluster formation. The effective dynamics are suppressed. For a strong circle swimmer of large chirality, the particle's motion is mainly confined to its location, and no clustering is observed. Using Langevin dynamic simulation in Chapter 5, we looked at the passive disk-shaped particles on a two-dimensional substrate in the presence of effective external potential due to the active medium. The effective potential is obtained for a binary combination of active and passive particles for a variable size ratio S and fixed activity. We found potential is attractive for small distances for large size ratio. Our results show a good match with similar experimental system of passive particles in bacterial suspension. In Chapter 6, we develop a random lattice with crossing bonds with random bond length and bond angle. We develop a random lattice that is more generic and similar to numerous random lattices seen in social and natural networks. We further studied the dynamics of a single particle moving on such lattice and find its dynamics is a random walk with mean square displacement of particle motion varies linearly with time. We further decorated the lattice with two types of rotators present and introduced two models: Model 2, where the rotators rotate the incoming particle to its extreme right and left available paths and Model 3, where it gets deflected in any possible right or left available path with equal probability. For the case of Model 2, for a given configuration model is deterministic but randomness is introduced through different given configuration of rotators. Model is studied for various ratios of rotators. For each r_e, initial dynamics of particle is subdiffusive with a unique expoenent 2/3 and late time dynamics is traversing. Hence starting from a given distribution of rotators, particle have a finite probability of traversing. We characterise the probability of traversing $P_T(t)$. For Model 3, when left and right rotators rotate the direction of incoming particle randomly to one of the right or left available paths. Hence now model has less deterministic nature as the case (i). Due to this initial dynamics of particle is diffusive and late time (t) shows the ballistic motion. Our current study focus on the dynamics of a single particle. Model will be interesting if it is studied for many particles interacting system.

7.2 Future prospects

In the dynamics of the particle on periodic undulated surface where motion of the particle on fixed amplitude of surface undulation, it is also interesting to study dynamics of the particle on random surface undulation. In the run and tumble model where size ratio of passive particle is always greater than active particles, it is also interesting to know dynamics of the particle in presence of lower size ratio of passive particles and different packing fraction of active and passive particles. Chirality of the particles is also responsible for different phases in the system. Knowing this is also intriguing what happen if the dynamics of the particles in presence of random chirality of the particles. Lorentz lattice model will be interesting if it is studied for many particles interacting system. Finally, it will be intriguing to calculate the active-passive mixture's acquired potential analytically.

****