Abstract

Finite systems of charged particles under spatial confinement are of interest to physicists. Such systems occur in different physical environments like ions confined in Penning or Paul traps, electrons in quantum dots, electrons above the surface of liquid He and ions in optical traps etc. These systems are also relevant in the studies of the white dwarfs and neutron stars because Coulomb crystallization is believed to take place in the interior of white dwarfs and on the surface of neutron stars. These finite clusters can be considered as small counterparts of large Coulomb systems under spatial confinement. In laboratory systems the charged particles are trapped by using electrostatic or electromagnetic fields. Complex (dusty) plasmas provide a unique plateform to study such small systems under spatial confinement. The dust particles can be confined both in 3D and 2D in a dusty plasma. Due to the large spatial and temporal scales of the dust particles, the dynamics can be observed at individual kinetic level. In our work, we consider such systems of a finite number of charged dust particles in both two- and three- dimensions. It has been shown in complex plasma experiments that an isotropic three-dimensional confining harmonic potential can be realized due to the superposition of gravity, ion-drag, thermophoretic and electric field forces on a dust particle. In complex plasmas the interaction among the charged dust particles is normally modeled as repulsive Yukawa potential. Therefore, these clusters are commonly known as "Yukawa clusters". In our work, we investigate the structure, dynamics and phase transitions of finite dust clusters via Molecular dynamics simulation and analytical calculations both in the presence and absence of an external magnetic field. A chapter wise description of the work is given below.

Chapter 1 introduces the concept of complex (dusty) plasma to the readers. It provides a brief overview of the key properties of this unique state of matter. The chapter explores the occurrence of complex plasma in various laboratory,tokamak plasmas, plasma application facility and space plasma environments. It also discusses several self-organization phenomena observed in complex plasmas, the different wave modes present, and the behavior of finite clusters of particles in both the presence and absence of an external magnetic field.

In **Chapter 2**, we explore the structure and dynamics of three-dimensional finite clusters of charged dust particles within complex plasmas, using both Newtonian and Langevin dynamics simulations. The static structure is examined through various diagnostic tools, including the Radial Distribution Function, the Center-Two-Particle Correlation Function, and the Angular Correlation Function. Our analysis reveals that the static structure of the system remains relatively stable regardless of the dynamics employed. The dynamics of individual particles within the cluster are characterized by the Mean Squared Displacement and the Van Hove Self-Autocorrelation Function.

In **Chapter 3**, the dynamics of finite three-dimensional Yukawa clusters of charged dust particles were studied as a function of an external magnetic field applied along the z-direction and Coulomb coupling parameter. It was observed that the cluster exhibits a first-order phase transition from an ordered rotational phase to a disordered rotational phase. At a suffciently high magnetic field strength as well as Coupling parameter, the vibrational motion of the cluster freezes and the system retains only a rotational motion. The chapter contains the manuscript published in Physical Review E [H. Sarma, R. Sarmah, and N. Das, "Phase transition of three-dimensional finite-sized charged dust clusters in a plasma environment," Phys. Rev. E 107, 035206 (2023)].

In **Chapter 4**, the collective and single particle dynamics of two dimensional Yukawa clusters of charged dust grains were studied in the presence of an externally applied transverse magnetic field. The oscillation spectra obtained from simulations are compared with the dispersion relations derived from analytical calculations under the harmonic approximation. In the presence of a strong magnetic field, a longitudinal optic branch appears in a linear chain configuration, while a 2D isotropic cluster shows two distinct branches, with the higher frequency branch approaching the cyclotron frequency. To investigate single-particle dynamics at various levels of magnetization, the mean squared displacement is analyzed for the 2D cluster. At higher coupling parameters, the cluster transitions from normal to superdiffusive behavior as the magnetic field strength changes, due to the interplay between the cyclotron and harmonic time periods. Conversely, at lower coupling parameters, the cluster remains subdiffusive across all magnetic field strengths. This chapter contains the research work published in Physics of Plasmas [H. Sarma and N. Das, "Phonon spectra of finite dust clusters under a transverse external magnetic field," Phys. Plasmas 31, 063704 (2024)].

Chapter 5 contains the concluding remarks on the thesis. This chapter also presents a future outlook of the thesis work.