Chapter 5

Conclusion and future outlook

This thesis explores the structure, dynamics and phase transition of finite dust clusters in complex plasma using Molecular Dynamics simulation. Finite clusters in complex plasma are representative of a wide class of non-linear mesoscopic systems having a finite degrees of freedom that are observed in different physical systems. Previous studies on these clusters have revealed that the behaviour of these systems depends strongly on the exact number of particles present on the system and they exhibit collective oscillations, nested shell structure and magic numbered shell configurations. In this thesis we have done a systematic investigation of the static and dynamic properties of harmonically confined two as well as three dimensional dust clusters in complex plasma. The presence of an external magnetic field in complex plasma experiments have been shown to alter the dynamics of the dust particles significantly in many complex plasma experiments. We investigated the effect of an external magnetic field in finite dust clusters in complex plasma in this thesis besides the studies in the absence of an external magnetic field.

Chapter 1 of this thesis introduces complex plasma to the readers. It discusses the key properties of a complex plasma namely macroscopic neutrality, Debye shielding, characteristic frequencies and Coulomb coupling parameter. The charging of the dust particles in plasma via different mechanisms is introduced and the occurence of dusty or complex plasmas in various astrophysical and laboratory environments is discussed. Strong correlation can be achieved in a complex plasma at room temperature because of the very large charges on the dust grains. Different self organization phenomena in a complex plasma are also discussed in this chapter for explample, formation of Coulomb crystals, voids, vortices and Lanes. Moreover, the finite clusters formed in a complex plasma which is the physical system under consideration in this thesis is also introduced in this chapter besides giving an overview of magnetized dust clusters. Moreover the numerical approach used in the thesis has also been discussed in this chapter in details along with the diagnostic tools used to probe the static structure and collective and single particle dynamics of dust clusters.

In **Chapter 2** of the thesis we analyzed the structure and dynamics of a three dimensional Yukawa cluster via both frictionless Molecular Dynamics and Langevin Dynamics to understand the effect of neutral friction. The static structure was analyzed through Radial Distribution Function, Center-two-particle correlation function and both intra- and inter-shell angular correlation function. The C2P and intra- shell angular correlation remains largely unaffected by the introduction of dust-neutral collision in the dynamics. However, the inter-shell angular correlation function exhibits sharp peaks in case of frictionless Molecular Dynamics which vanishes in the presence of dust-neutral collision. Moreover, the first peak height of RDF remains higher for all the values of coupling strengths in frictionless MD than that in Langevin Dynamics. The particles in the cluster always have an angular motion. The rotational motion of the particles is coherent in the sense that they rotate about a common axis in case of fMD. However, even at a very small value dust-neutral collision frequency the rotation of the particles about a common axis vanishes which can be attributed to the faster decay of temporal correlation of interparticle distance and interparticle angular separation in LD than that in fMD.

Chapter 3 of the thesis deals with the phase transition of a finite 3D dust cluster in the presence of an external magnetic field. The cluster remains in a fluidlike state at a lower value of Coulomb coupling parameter at zero external magnetic field. At a sufficiently small value of the coupling parameter and in the presence of a small magnetic field the particles in the cluster exhibit disordered rotation around the spherical surface. The particles exhibit both rotational and vibrational motion in this state. However, as the magnetic field strength or the Coulomb coupling parameter is increased beyond a certain value the particles in the cluster collectively exhibit ordered rotational motion about a common axis. The phase boundary corresponding to this ordered-to-disorderd rotational phase transition was obtained and found to obey a power law behaviour with an exponent equal to 0.5 at constant dust number density.

In **Chapter 4** the single particle and collective dynamics of two dimensional Yukawa clusters in complex plasma is studied by using Langevin Dynamics simulation in the presence of an externally applied transverse magnetic field. To study the collective dynamics, we obtained the Longitudinal and Transverse current correlation spectra at different strengths of the transverse external magnetic field. The observed spectra were compared with the analytically derived dispersion relation using harmonic approximation. The analytical dispersion relation shows good agreement with the spectra obtained from the simulation. The spectra of a 1D chain was found to consist of two branches with one low frequency acoustic branch and another high frequency optic branch. The acoustic branch was found to be purely longitudinal in nature whereas the optic branch has mixed longitudinal and transverse character. The collective oscillation spectra of an isotropic 2D cluster was also found to consist of two branches with the higher frequency branch approaching cyclotron frequency with the increase in the magnetic field strength. It was shown that there are two different timescale regimes for the phonon spectra of the cluster defined by the two inequalities : $\tau_c < \tau_{int}$ and $\tau_c > \tau_{int}$ where, τ_c is the cyclotron time period of the dust grains and τ_{int} is the dust-dust interaction time scale defined by the dust-plasma frequency ($\tau_{int} = \frac{2\pi}{\omega_{pd}}$). An analysis of the single particle dynamics of the 2D cluster also reveals two timescale regimes in the cluster defined by two inequalities : $\tau_c < \tau_{conf}$ and $\tau_c > \tau_{conf}$, where τ_{conf} is the harmonic time period. It was found that the cluster exhibits superdiffusion in the regime where, $\tau_c < \tau_{conf}$ whereas, for $\tau_c > \tau_{conf}$ the cluster exhibits normal diffusion.

We are planning to achieve the following goals in the future :

- To study the phase transition in the presence of an external magnetic field taking into account both ion dynamics and dust-neutral collision.

- To understand the underlying physical mechanism of the crossover from normal to superdiffusive state as a function of the applied transverse magnetic field strength in a two dimensional cluster.

- To study the structural relaxation of the finite three-dimensional dust cluster.

- To study the phase transition in a 3D Yukawa cluster in the presence of an external magnetic field with varying total number of particles.