Abstract

The study of dusty plasmas holds significant importance in the realm of plasma physics and has far-reaching implications in various scientific disciplines. Dusty plasmas are unique and fascinating due to the presence of charged dust grains, which introduce intricate dynamics and phenomena not observed in conventional plasmas. Dusty plasmas are ubiquitous in nature and found in astrophysical environments like interstellar clouds, planetary rings, and cometary tails. Therefore, insights gained from dusty plasma research contribute to a deeper understanding of natural phenomena, such as the formation of celestial bodies and the dynamics of cosmic dust. Dusty plasmas have practical applications in a wide range of technological fields. They are encountered in industrial processes, semiconductor manufacturing, and even space exploration. A comprehensive understanding of their behavior is essential for optimizing processes, developing new technologies, and ensuring the safety and efficiency of space missions. Furthermore, dusty plasmas serve as a unique laboratory for studying complex physical phenomena, including particle-particle interactions, nonlinear wave propagation, instabilities, and phase transitions. Dusty plasmas provide insights into fundamental principles of collective behavior in plasmas, which have relevance in fields beyond plasma physics, such as condensed matter physics and nonlinear dynamics. In summary, the study of dusty plasmas is not only essential for advancing our understanding of natural phenomena but also for enabling technological advancements and providing valuable insights into fundamental physics. It represents an interdisciplinary research area with far-reaching implications for science and technology.

This thesis explores the profound intricacies of laboratory dusty plasmas

in the strong coupling limit. By conducting a thorough analysis of interaction mechanisms, self-diffusion processes, and rheological behaviors, this thesis provides valuable insights into the understanding of these complex systems. The findings presented within these chapters collectively illustrate the complex behaviors of dusty plasmas and emphasize their relevance in both astrophysical and laboratory contexts.

Chapter 1 of the thesis presents a comprehensive introduction to the captivating field of plasma physics, with a specific focus on dusty plasmas. The chapter commences by defining plasma and subsequently explores the distinctive realm of dusty plasmas, characterized by the presence of solid dust particles that introduce complex dynamics into the system. It proceeds to elucidate the fundamental characteristics of dusty plasmas, emphasizing their astrophysical relevance and their significance in laboratory environments, while also introducing complex plasma as a unique state of matter within the plasma realm. Furthermore, the chapter explores the dynamic behavior of dust particles within plasmas and examines a variety of waves propagating through these intriguing media, including Dust Acoustic waves, Dust Ion Acoustic waves, Electrostatic Dust Cyclotron waves, and Electrostatic Dust Ion Cyclotron waves. Additionally, it introduces the concept of strongly coupled dusty plasmas, highlighting their distinct properties and their occurrence in both natural and laboratory settings. Finally, this chapter provides an introduction to the interaction potential of complex plasma systems, establishing the foundation for subsequent chapters that will delve deeper into these aspects.

In Chapter 2, methodologies adopted in the work to study the interaction mechanism, transport coefficient, and rheological behaviors of complex plasmas have been discussed. It begins with the establishment of Fluid Theory as the foundational framework for comprehending the interaction potential within plasma systems. We have provided a detailed report on the simulation technique, explaining the principles and procedures involved in conducting Molecular Dynamics simulations for dusty plasmas. In the chapter, a discussion was presented regarding the theoretical background of the Green-Kubo formalism, which forms the foundation for calculating transport coefficients in molecular systems. The chapter provided a comprehensive exploration of the underlying principles and concepts that underpin this formalism, including the fundamental basis of the fluctuation-dissipation theorem and its connection to equilibrium fluctuations and transport properties.

In Chapter 3, the wakefield phenomena around a charged dust grain in a streaming complex plasma in the presence of an external magnetic field have been studied. Previous investigations had predominantly focused on the influence of a magnetic field aligned with the ion flow direction, which led to significant wakefield suppression. However, the influence of a transverse magnetic field, perpendicular to the ion flow direction, on the wakefield remained less explored. In this work, a comprehensive study of the wakefield characteristics was presented when exposed to a transverse magnetic field relative to the ion flow direction, with the help of Linear Response Theory. We analyzed the impact of magnetic field strength on the wake potential profile, examined the influence of ion flow velocity, and investigated the effect of ion-neutral collision frequency on wakefield characteristics.

In Chapter 4, our primary focus was on examining the diffusive behavior of a strongly correlated dusty plasma within magnetized flowing conditions. In this chapter, we extend our inquiry to explore the diffusion coefficient of a three-dimensional dust ensemble embedded in a flowing plasma in the presence of a moderate magnetic field using Langevin dynamics simulation. It was found that the asymmetric wake potential created due to streaming ions drives the dusty plasma from a sub-diffusive to a super-diffusive regime. The chapter also elucidates the intricate dependency of the cross-field diffusion coefficient on the magnetic field's strength, revealing three distinct regimes: (a) a scaling behavior of B^{2-3} for ultra-low magnetic fields in a strongly correlated state, (b) a nearly linear scaling of $B^{\simeq 0.1}$ for moderate magnetic fields, and (c) a classical inverse quadratic scaling of B^{-2} for relatively large magnetic fields. Notably, our analysis