Chapter 9
Numerical Approach to Thermal Conductivity of Electrorheological Complex (Dusty) Plasmas

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ABSTRACT

Electrorheological complex (dusty) plasmas (ER-CDPs) are type of plasmas with rheological behavior under external electric field (EEF). In this chapter, the nonequilibrium molecular dynamics simulations method is used to tune thermal conductivity for two-dimensional (2D) complex plasma liquids using EEF in different directions. Anisotropic thermal conductivity is investigated in three different cases, (i) E_x(x-axis), (ii) E_y(y-axis), and (iii) E_{xy}(xy-axis) and with constant external perturbation force ($P_x = 0.02$). The thermal conductivity under the influence of EEF is different in different directions. Obtained results are compared and discussed with previous known theoretical, simulation, and experimental data for 2D systems in constant EEF. The appropriate normalized thermal conductivity with Einstein frequency at constant EEF follows universal temperature scaling law. These comparisons and discussions show that algorithms of EEF of different cases with Yukawa potential have accuracy and consistency. These comparisons validated a new numerical model that can be used for variations of EEF along with different system sizes and plasma parameters.

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1. INTRODUCTION

In this chapter, our focus is to explore the electrorheological complex (dusty) plasmas (ER-CDPs) by investigating thermal conductivity for two-dimensional (2D) systems using molecular dynamics (MD) simulations. First, it describes the basics of plasmas, CDPs, and ER plasma physics. The existence of CDPs in nature, laboratories and industries is explained in detail. Further, reviewed the CDPs concepts in the sense of basics with a historical overview and current stage of knowledge. The importance of ER-CDPs are discussed by their possible applications in industry, laboratory and space. The general theory and mechanism of ER-CDPs, its main parameters and characteristics are discussed. Next is the introduction of computer simulation techniques used in this study, and a historical overview of molecular dynamics (MD) simulations and the model and method are explained in detail. The purpose and motivations of the presented work are to be obtained from simulation data of thermal transport properties at numerous CDPs' parameters, together with previous work that has been done to date. It provides necessary problems, justifying the current work performed with the contribution for this chapter.

1.1. Plasma

Plasma physics, a fascinating and complex branch of physics, explores the behavior and properties of plasma, often called the fourth state of matter. Unlike solids, liquids, or gases, plasmas are ionized gases where electrons and ions coexist in a high-energy state, generating a complex interplay of electromagnetic forces. This field of study explores the behavior of plasmas in different contexts, ranging from the burning temperatures of stars and astrophysical phenomena to the controlled environments of fusion reactors. Understanding plasma physics is essential for advancing fusion energy research, aiming to harness nuclear fusion, the same process that powers the sun, as a clean and virtually limitless energy source. Additionally, plasma physics plays a fundamental role in astrophysics, explaining phenomena like solar systems and the dynamics of interstellar and intergalactic mediums. Moreover, it finds applications in technologies such as plasma TVs, spacecraft propulsion systems, and cutting-edge materials processing techniques. The study of plasma physics continues pushing scientific knowledge's boundaries, offering insights into the fundamental nature of matter and energy while shaping the future of sustainable energy solutions and technological innovations (Fortov & Morfill, 2009; Shahzad, et al., 2018; Shukla, 2001).

1.2. Review Concepts of CDPs

Dust is present everywhere in space and on Earth. The CDPs are a composition of four elements: electrons, ions, neutral atoms and dust particles (grains). In nature, CDPs are ubiquitous in astrophysical situations like comets, interplanetary, interstellar clouds, or the rings of Giant planets, liquids in the white dwarf, interior of supernova cores, neutron stars, etc., (Fortov & Morfill, 2009; Shukla, 2001). The coulomb crystal of dust particles was observed in (Chu & Lin, 1994). After that, research in this direction increased drastically, the dust particles can be grown in a laboratory through a chemical reaction and sputtering.

Nowadays, research on CDPs has become an exciting field in the sciences and technologies. The most thrilling event in the area of CDPs occurred in 1980 for the planet Saturn mission. Mendis (1997) observed the bright comet in a distant ancestor, an excellent cosmic laboratory for investigating the CDPs and their dynamical and physical consequences. The other appearances of CDPs are the zodical lights, the origin nebula, the noctilucent cloud etc., at the laboratory level; CDPs are an available terrestrial laboratory in