Abstract

Nonlinear dynamics and chaotic evolution of plasma instabilities an important phenomenon to investigate due to their significance in both laboratory and astrophysical contexts. Plasma instabilities occur when a plasma deviates from its equilibrium state, leading to inherently nonlinear and complex behaviours. This involves exploring how small perturbations can escalate into large-scale, chaotic motions. In this dissertation, we first provide fundamental information on nonlinear plasma waves, nonlinear dynamics, and chaos theory. Following this, we investigate the propagation of nonlinear coupled drift ion acoustic shock waves in an electron-positron-ion (*epi*) plasma with fully degenerate adiabatically trapped electrons. We formulate a novel complex nonlinear equation featuring a fractional $3/2$ power nonlinear term to describe this phenomenon. Nonlinear drift ion acoustic waves (NDIAWs) are significant in both compact astrophysical objects and laboratory plasmas created under extremely low temperatures. To elucidate the dynamics of the derived equation of motion, we employ the phase plane theory of planar dynamical systems, as the final equation of motion is nonintegrable. Linear stability analysis and phase space analysis reveal that the system exhibits a pair of shock waves, a finding reported for the first time in the literature. Additionally, we investigate the effects of changes in the system's parameter values, including the ratio of positron to electron number density, collisional frequency, magnetic field strength, drift velocity, and angle of propagation.

In the second study, we investigated relativistic quantum degenerate plasmas (RQDPs), characterized by ultra-low temperatures and high densities, which have emerged as an intriguing frontier in space plasma and compact astrophysical objects like the cores of white dwarfs and giant planets. Our investigation employs a complex nonlinear equation with a $3/2$ fractional term. We examine the intricate interplay between adiabatically trapped electrons and the shock front using phase portrait analysis of a planar dynamical system. This exploration allows us to understand the effects of various controlling parameters on shock profile, steepness, and associated dynamics. An external periodic force is introduced in the current mathematical model to investigate the quasiperiodic and chaotic behaviour of the system. Additionally, Fast Fourier Transform (FFT) and bifurcation analyses are performed to reveal the quasiperiodic and chaotic nature of the attractor in the nonlinear dynamical system. It is observed that the commensurable and incommensurable characteristics of the system's natural frequency and the external periodic force (EPF)

frequency play a significant role in its quasiperiodic and chaotic behaviour. This study provides valuable insights into the fundamental characteristics of shock waves under different system parameters and sheds light on the chaotic behaviour of the system due to the commensurability of its frequencies.

In the final part of our study, we extended the work described in the first study by investigating NDIAWs in QDPs with adiabatically trapped electrons. This study focuses on understanding the evolution of NDIAWs through the lens of nonlinear dynamics, encompassing shock waves, solitons, and solitary shock waves, as well as the influence of an EPF in QDPs. Using magnetohydrodynamic (MHD) principles, we derive the nonlinear wave equation with fractional nonlinearity. Various analytical tools such as phase plane theory, Sagdeev potential, FFT, sensitivity analysis, Lyapunov exponent, and bifurcation analysis are employed within the frameworks of Burgers, Korteweg–de Vries (KdV), and KdV-Burgers (KdVB) equations to analyse the nonlinear dynamics of NDIAWs under different plasma parameters, particularly in the context of white dwarfs. Introducing EPF into the derived planar dynamical system facilitates the investigation of quasiperiodic, aperiodic, and chaotic behaviour in NDIAWs. It is observed that the solutions of the Burgers equation exhibit pairs of shock waves, the KdV equation features compressive solitons, and the KdVB equation features solitary shock waves, all within the defined plasma parameters of white dwarfs. Additionally, the sweeping of EPF frequency ω plays a crucial role in exploring the quasiperiodic route to chaos.

Overall, this investigation has provided significant insights into the phase space trajectories of planar dynamical systems with adiabatically trapped electrons in QDPs. QDPs have numerous applications, such as, in astrophysics, they are crucial for understanding dense stellar objects like white dwarfs and neutron stars, aiding in stellar evolution and supernova modeling. In laboratories, QDPs facilitate advanced material science, enabling the study of exotic states of matter and the development of novel quantum materials. Thus, this study will open new frontiers in both fundamental sciences and technologies.