



Ion-acoustic and Buneman instabilities in collisional plasmas with q -nonextensive distribution



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HIGHLIGHTS

- Obtaining generalized dielectric permittivity in presence of moving electrons.
- Collision frequency, q -parameter and drift velocity affect the growth rate.
- Plasma is stable for ion to electron temperature ratio greater than 0.26.

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ABSTRACT

The ion-acoustic and Buneman instabilities are studied in a current carrying plasma by taking into account the collisional effects and q -nonextensive distribution function. Using the kinetic theory and Bhatnagar–Gross–Krook collision model, a generalized dielectric permittivity function in the presence of moving electrons and electron and ion–neutral collision frequency is derived. The longitudinal dispersion relation in the Buneman and ion-acoustic instability limit is obtained. The results of the Buneman instability shows that the collision frequency, the q -parameter and electron drift velocity affect the growth rate of the instability. Finally, the profile of the ion-acoustic growth rate indicates that by increasing the ion to electron temperature ratio the instability growth rate decreases.

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1. Introduction

The study of the current carrying plasmas yields a wide variety of interesting physics and applications such as dusty plasmas [1], inertial confinement fusion [2], electron and ion acceleration [3] and etc. In these plasmas various different instabilities [4–6] can be excited and developed in the wide range of frequencies. For several decades these instabilities have been studied theoretically, experimentally and by simulation model. Buneman and ion-acoustic instabilities are two kinds of these instabilities in which the plasma becomes unstable. The Buneman instability is sharply excited when the relative velocity between electrons and ions far exceeds the electron thermal velocity [7–9]. However, when the relative velocity between electrons and ions is less than the electron thermal velocity, the instability is called the ion-acoustic instability [5,10]. The Buneman instability was first studied by O. Buneman in 1958 [11] and then was discussed in detail much later by many authors. Hirose [12] has shown that the perturbed electric field related to the Buneman instability saturates at a certain value which depends on the initial electron kinetic energy. Using analytical and computer simulation, Ishihara et al. [13,14] have studied the nonlinear saturation of the Buneman instability in field free plasma. They concluded that the instability saturates at the same saturation value as predicted by Hirose [15]. In the high frequency regime, El-Shorbagy [16,17] has investigated the Buneman instability in a relativistic cold and warm plasma waveguide. He demonstrated that the growth

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rate of the instability in relativistic warm plasma is reduced compared to the cold relativistic plasma and non-relativistic (both cold and warm) plasma. Considering the two fluid model for electrons and ions, Shokri et al. [18] have studied the nonlinear evolution of the low frequency Buneman instability in a current carrying plasma. They found that the profile of the electron density has a sharp peak in the steady state which is due to the negative nonlinear diffusion coefficient in diffusion equation. In addition, Niknam et al. [19] have simulated the Buneman instability in a current carrying plasma. They obtained that at a certain time known as the saturation time the amplitude of the growth rate reaches its maximum and then decreases.

On the other hand, the ion-acoustic instability was for the first time predicted by Tonks and Langmuir [20] in 1929 and later observed in the laboratory in 1933 [21]. Since then, the ion-acoustic instability have been extensively studied by fluid and kinetic theory, by simulation model and investigated in different plasma environments. The current-driven dust ion-acoustic instability in a collisional dusty plasma with charge fluctuations has been explored by Tribeche et al. [22]. Sukovatov [23] has studied the linear theory of the ion-acoustic instability in the E-region ionospheric plasma.

Note that in all above mentioned papers it has been assumed that the charged particles have the Maxwellian distribution function. In some years ago, multi-fractals concepts encouraged Renyi [24] and then Tsallis [25] to propose a q -nonextensive distribution for non-equilibrium environments. However, the Tsallis distribution is one of the non-Maxwellian distributions. The non-Maxwellian distributions have been confirmed by some observations which have been done in the Earth's bow shock [26], in the upper ionosphere of Mars [27], in the vicinity of the Moon [28], and in the magnetosphere of Jupiter and Saturn [29,30]. This non-equilibrium distribution can be applied for systems with long-range interactions, such as plasmas and gravitational systems [31]. Assuming the q -nonextensive distribution function, Lima et al. [32] have discussed the dispersion relation for electrostatic plane wave propagation in a collisionless thermal plasma. Using the kinetic theory and nonextensive approach, Liu et al. [33,34] have investigated the ion-acoustic instability in the collisionless unmagnetized current driven plasmas. Considering the Tsallis statistical mechanics, the ion-acoustic solitary waves in a plasma have been studied by Tribeche et al. [35,36]. Taking into account the q -nonextensive distribution, the nonextensivity in a non-isothermal plasma system with the Coulombian long-range interaction is investigated by J. Du [37]. Considering the Sagdeev pseudo-potential approach, Shahmansouri et al. have derived the energy like equation for dust-acoustic solitary waves in a plasma having q -nonextensive ion and electron distributions and cold dusty particles [38]. In addition, the statistical interpretation of the hydrogen atom within the framework of Tsallis Statistical Mechanics in the Canonical Ensemble has been studied by Livadiotis [39]. Saberian et al. [40] have explored the low frequency acoustic like modes in nonextensive pair plasmas by employing a kinetic theory based on the Vlasov and Poisson's equations. Recently assuming the particle in cell method, Niknam et al. [41] have investigated the nonlinear evolution of the Buneman instability in a current carrying plasma with q -nonextensive electron velocity distribution.

Most recent works has been done on the collisionless plasmas. But in some plasmas such as the fast ignition scenario of laser inertial confinement fusion [42], the collisional processes can be very effective. The collisional effects have been studied by some authors. Hao et al. [2] have shown that the collisional effects can attenuate or enhance the current filamentation instability which depends on the drift anisotropy of the beam and the background plasma. By taking into account the electron-neutral collision frequency and using the kinetic theory, the evolution of the filamentation instability in a weakly ionized current carrying plasma with q -nonextensive distribution has been investigated by Khorashadizadeh et al. [43]. They found that in the diffusion frequency region, the collisions can increase the maximum growth rate of the filamentation instability. However, to the best of our knowledge, investigation of the Buneman and ion-acoustic instabilities in a current carrying plasma by taking into account the q -nonextensive electron and ion velocity distribution function and collisional effects has not been extensively studied. Thus in this work the Buneman and ion-acoustic instabilities in a collisional current carrying plasma with q -nonextensive velocity distribution have been discussed. In the Buneman instability it is assumed that the moving electrons have the q -nonextensive distribution and ions are a neutralizing background. Both electrons and ions in the ion-acoustic instability have the q -nonextensive velocity distribution and only electrons are assumed to have an initial velocity and ions have no initial velocity. The reason of this behavior is as follows: as we know, when a sufficiently strong electric field is applied to a plasma, the electrons move with a velocity much greater than the thermal velocity. Electrons respond to the electric field because their mass is so small. In other word, electrons respond to the strong electric field rapidly but ions do not have enough time to answer the field. Thus, ions are assumed to be a neutralizing background. In this case the Buneman instability can be exited. In contrast, in the ion-acoustic instability the strength of the electric field is weak so that the electron drift velocity is less than that of the electron thermal velocity. In addition to electrons, in this case ions also have enough time to respond to the field and thus the condition ion-acoustic instability is achieved.

Considering Bhatnagar–Gross–Krook (BGK) collision model, the q -nonextensive velocity distribution and using the kinetic equation, a generalized q -dielectric permittivity is obtained. Then, the dispersion relation for the Buneman and ion-acoustic instability is achieved and plotted numerically. The Buneman instability results show that by increasing the q -parameter and electron velocity, the instability growth rate increases; while by increasing the collision frequency, the amplitude of the growth rate decreases. In addition, the growth rate diagram of ion-acoustic instability indicates that by increasing the q -parameter and electron velocity, the growth rate increases. Moreover, by increasing the ion to electron temperature ratio the amplitude of the growth rate decreases.

This work is organized in five sections. In Section 2, the basic equations are presented. Using the kinetic theory, BGK collision model and q -nonextensive velocity distribution, a generalized dielectric permittivity and consequently the q -dispersion relation is obtained. This dispersion relation is limited in two cases. One of these cases is the Buneman instability

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