Ion-acoustic double-layers in magnetized nonthermal plasmas

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Introduction

It is well known that laboratory and space plasmas can contain distinct populations of hot and cold electrons. In two-electron plasmas, electron-acoustic waves (EAWs) with wave frequency larger than the ion plasma frequency can be generated [1]. In a classical paper of 1978, Bezzerides *et al.* [2] investigate the nonlinear regime and analyze the existence of rarefaction waves and shocks in a two-electron temperature isothermal plasma. The study of rarefaction waves (and shocks) is important for a variety of problems in plasma physics, including the investigation of the current-free double layers [3].

A double layer (DL) consists of a positive/negative Debye sheath, connecting two quasineutral regions of a plasma. These nonlinear structures can be found in a variety of plasmas, from discharge tubes to space plasmas. A DL may be regarded as a BGK equilibrium, for which certain conditions must be fulfilled. The best known of these structures is the strong Langmuir DL, which is characterized by a large electric current across the DL. The current-free double layer (CFDL) constitutes a different group, for which there is no trapped ion population. In the present work the so-called ion-acoustic double-layers (IADLs) are investigated. It is worth to mention that in general the plasma distributions near a DL are strongly non-Maxwellian [4], with long tails observed in some cases [5].

As mentioned before, here we investigate the IADLs in a magnetized two-electron plasma. It is believed that the IADLs are responsible for the acceleration of electrons in the auroral region [6]. The cold and hot electrons are modeled by the Maxwellian and κ distributions, respectively. The reduced form of the κ distribution is equivalent to the distribution function obtained from the maximization of the Tsallis entropy, the *q* distribution [7], with the parameter κ measuring the deviation from the Maxwellian equilibrium. Here some preliminary results are presented, and the influence of the energetic electrons on the behavior and existence of the DLs is discussed.

Basic equations

We consider a homogeneous magnetized electron-ion plasma with two electron populations: a hot component, and a cold one. The ion-acoustic wave propagates in the *x* direction, making an angle θ to the direction of the magnetic field (assumed to be in the *x-z* plane). Following Ref.[8], the fluid equations are used to describe the dynamics of the cold ions. For the normalized electron density we have

$$n_e = n_c + n_h = (1-\delta)e^{\phi\tau} + \delta[1-\phi/(\kappa-3/2)]^{-(\kappa-1/2)}$$

where $\delta = N_{h0}/N_0$ and $\tau = T_h/T_c$. Transforming the coordinates by a Galilean transformation $\xi = x - Mt$ (M is the velocity of the moving frame) and assuming a quasineutral ($n_e \approx n_i$) condition, we obtain the DL solution

$$\phi(\xi) = \psi/2[1-\tanh(\alpha\xi)]$$

with

$$\alpha = \Omega/|\sin\theta|(B_3/8)^{1/2}\psi .$$

and

$$B_3 = A_3 - (4A_2/3 + A_1^2/2)\cos^2\theta/M^2$$

$$A_3 = (1-\delta)\tau^3/6 + \delta(\kappa-1/2)(\kappa+1/2)(\kappa+3/2)/6(\kappa-3/2)^3$$

$$A_2 = (1-\delta)\tau^2/2 + \delta(\kappa-1/2)(\kappa+1/2)/2(\kappa-3/2)^2$$

$$A_1 = (1-\delta)\tau + \delta(\kappa-1/2)/(\kappa-3/2).$$

To obtain the solution above we considered only small values of the potential ϕ and also some specific boundary conditions. All the equations are normalized and ψ is the maximum amplitude of the DL. The velocity of the DL is given by

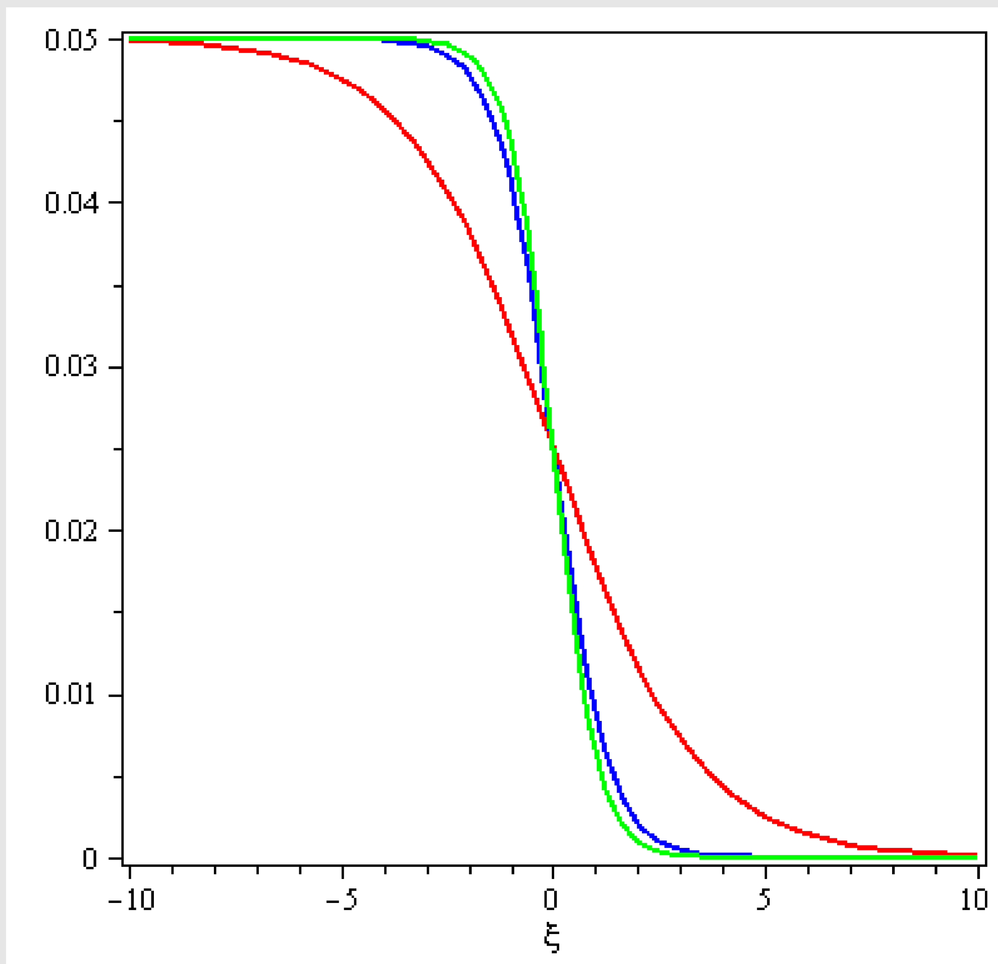
$$M = \cos\theta/A_1^{1/2}(1+1/6A_1|3A_1^2/2-A_2|\psi).$$

Since the DL exists only for $B_3 > 0$, we must have

$$M^2/\cos^2\theta > (4A_2/3 + A_1^2/2)/A_3.$$

Preliminary results

It is easy to observe that the magnetic field Ω only affects the amplitude and the thickness of the DL. The same can be said about the angle θ (this model is valid only for 0 < θ < π/2). It is also observed that the DLs described by our model only exist for large values of δ and τ. For δ=0.9 and τ=12 the DLs are observed only for the Maxwellian case (κ=500). As τ increases the DLs are observed for smaller values of κ. Therefore, we can say that, for a set of parameters (Ω, θ, δ, τ), electron nonthermality seems to destroy the double-layers. The figure below shows the form of the DL for Ω=1, θ=0.1, δ=0.9, τ=18, ψ=0.05 and different values of κ (κ=3 - red, κ=5 – blue, κ=500 – green). Further analysis and comparison with previous works are still to be done.



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