Effects of friction on modes in collisional multicomponent plasmas

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Plasmas both in the laboratory and in space are frequently in the state of partial thermodynamic equilibrium (i.e., with an initial temperature disparity of the plasma constituents). Collisions in such plasmas will after some time eventually result in equal temperatures of the species, implying an evolving plasma. There exists a long standing controversy in the literature, which deals with the effects of this temperature disparity on the perturbations in such an evolving plasma, more precisely on the ion acoustic (IA) waves. In Ref. 1 it is claimed that the corresponding energy transfer may result in the instability of the acoustic mode at large wavelengths (within the quasi-neutrality limit), and that this growth may be described within the fluid theory. The necessary condition for the instability obtained in Ref. 1 for an electron-ion plasma is, in fact, very easily satisfied because it requires only a very small temperature difference between the two species (electrons and ions), viz. $T_e > 4 T_i/3$. This instability condition is obtained by using the energy equations including the source/sink terms originating from the collisional transfer, together with the corresponding friction force terms in the momentum equations. The sufficient instability condition is stronger because of additional dissipative effects, like viscosity and thermal conductivity.

However, the current-less instability described in Ref. 1 is based on a model which disregards the same temperature disparity in the description of the spatially homogeneous background, which, due to the same reasons, must be time evolving. In other words, the effects of collisions in the background plasma have been explicitly neglected. Note that because of the time evolution, the term background is used instead of the equilibrium. These effects of collisions have been discussed in Ref. 2, published one year after Ref. 1, and for the same quasi-neutrality case. There, it is claimed that there is no instability for any temperature ratio of the two plasma components, and moreover, that this holds even in a current-carrying plasma, as long as the difference between the electron and ion equilibrium velocity remains below the sound speed. All that was needed to come to that conclusion was to let the background plasma evolve freely in the presence of the given temperature difference.

However, we observe that Ref. 2 has apparently remained almost unnoticed by researchers, in contrast to the widely cited Ref. 1.

In the present work, this controversy is revisited for any two-component plasma. Essential for the problem is the energy equation describing the temperature variation. In the simplified form that we shall use, it contains only the collisional energy transfer source/sink term on the right-hand side. This simplified form is used for clarity only because, according to Ref. 1, in the absence of currents, that term alone is supposed to yield an instability. The results obtained here can be summarized as follows. i) The friction does not affect the IA mode in the limit of quasi-neutral perturbations. ii) Even using the non-evolving model equivalent to Ref. 1, there is no instability of the IA mode, contrary to claims from Ref. 1. iii) When the background plasma is properly described as evolving in time, and as long as the quasi-neutrality is used, collisions do not produce a growth of the ion acoustic mode. iv) When the Poisson equation is used instead of quasi-neutrality, in principle there is a possibility for a positive growth-rate of the IA mode. It appears as a combined effect of the breakdown of the charge neutrality from one side (introduced by the Poisson equation), and the heat transfer (the compressibility and advection in energy equation) from the other side, all within the background of a time-evolving plasma. However, as the equilibrium plasma evolves in time, with the relaxation time τ, the obtained growth time must be (much) shorter than the relaxation time. Yet, this shows to be impossible and we conclude that there is no instability in the electron-ion plasma with an initial temperature disparity if the plasma evolves freely and if there is no a source acting in such a way as to maintain the temperature difference.

[1] T. D. Rognlien and S. A. Self, Phys. Rev. Lett. 27, 792 (1971).
[2] G. Bateman, Phys. Rev. Lett. 29, 1499 (1972).