Electron-Acoustic Mode in a Plasma of Two-Temperature Electrons

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It is shown that if electrons of a plasma have two different temperatures, there exists an electron acoustic mode. When the number of high-temperature electrons is smaller than that of low-temperature ones, this mode strongly Landau-damps, while in the opposite case, a solitary wave can propagate.

In this letter, we wish to report that if electrons of a plasma have two temperatures $T_h \gg T_c$, an electronic acoustic mode, that is, the electron-acoustic wave exists. Using the three-fluid model for the hot and cold electron-fluids and the ion fluid, we get the dispersion relation,

$$\frac{k^2}{\omega_{p0}^2}+\frac{m}{M}\frac{n_{i0}}{n_0}\frac{1}{(-\lambda^2+c_i^2)} +\frac{n_{c0}}{n_0}\frac{1}{(-\lambda^2+c_c^2)}+\frac{n_{h0}}{n_0}\frac{1}{(-\lambda^2+c_h^2)}=0. \quad (1)$$

Here $n_0=n_{c0}+n_{h0}=n_{i0}$ is the unperturbed density, the subscripts i, c and h specify the ions, the hot and cold electrons, respectively, λ is the phase velocity ω/k, c the iso-thermal sound velocity and $\omega_{p0}^2=4\pi n_0 e^2/m$. For small wave number, $k \ll \sqrt{\omega_{p0}^2/(c_h^2-c_c^2)}$ $(\equiv L_D^{-1})$, it is easy to derive from (1) the roots

$$\lambda^2=(n_{h0}c_c^2+n_{c0}c_h^2)/n_0. \quad (2)$$

If the number of the hot electrons is much smaller than that of the cold electrons, i.e. $n_{h0} \ll n_{c0}$, λ^2 is approximated as $c_h^2-\varepsilon_n(c_h^2-c_c^2)$, where $\varepsilon_n=n_{h0}/n_{c0}$. Introducing this expression into the equations of motion, we can find the following aspects of this mode: for the hot electrons, the pressure gradient is balanced with the inertia and the effect of the electric field is not significant, but for the cold electrons, the inertia is balanced with the electric field and role of the pressure is not important and for the density perturbation δn, $\delta n_h=-\delta n_c$ holds, so that the ion-motion may be neglected; physically, the hot electrons move as if it were neutral, because the electric field is shielded by the cold electrons. However, the approximate expression of λ^2 implies that this mode Landau-damps appreciably. To show this, we solved numerically the corresponding dispersion relation of the Vlasov equation. The result is illustrated in Fig. 1 for the density ratio (ε_n) and the temperature ratio (ε_T) both equal to 0.1, from which we can conclude that for the long wave length both of the real and imaginary parts are proportional to k, namely for $k \ll L_D^{-1}$, $\omega_r \approx kc_h$ and $\omega_i \approx \alpha k c_h$, where $\alpha \approx 0.5$. We also confirmed that as far as k is small the linear k-dependence of ω_r and ω_i is valid even when ε_n and ε_T are varied. Further α does not appreciably depend on ε_n and ε_T; for example, for $\varepsilon_n=1/100$ and $\varepsilon_T=1/10$, $\alpha \approx 0.5$, and for $\varepsilon_n=1/10$ and $\varepsilon_T=1/20$, $\alpha \approx 0.6$. Since this mode strongly Landau-damps, the

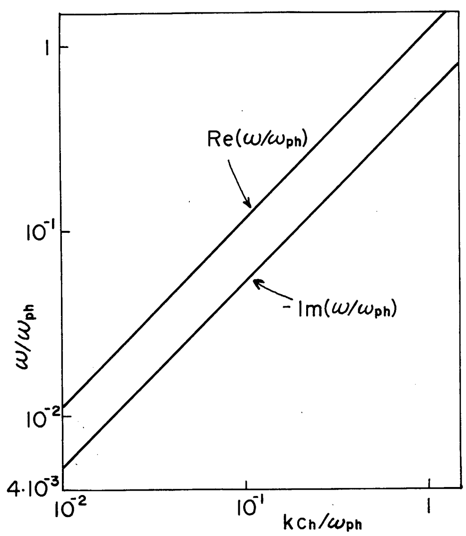

Fig. 1. Real and imaginary parts of the frequency are displayed as functions of wave number. The frequency and wave number are normalized by ω_{ph} and $(c_h/\omega_{ph})^{-1}$, respectively, where $\omega_{ph}=\omega_{p0}\sqrt{n_{h0}/n_0}$.

velocity-distribution evolves by the ballistic mode. Therefore we would deduce that the heat of the hot electrons is carried with thermal velocity. Conversely, if this mode is continuously excited by external force, the electric field energy could be converted to the hot electrons by the inverse Landau-damping. For large amplitude, however, it does not Landau-damps. Instead, an amplitude oscillation will occur, for which putting the bounce-frequency $\omega_B \cong k(e\phi/m)^{1/2}$ equal to ω_i we find $\phi \sim \kappa T_h/e$, which means a very strong electric field. This case might be related to the possibility of the ion-acceleration considered by Valeo and Bernstein[1] in the laser-produced plasma. We wish to note that there are many problems concerning high temperature electrons, in which the electron acoustic wave will play an important role.

If the number of the hot electrons is much larger than that of the cold ones, i.e. $n_{h0} \gg n_{c0}$, it becomes possible that the roots of eq. (1) satisfy the condition $c_h \gg \lambda \gg c_c$. (This condition requires large temperature ratio, such as $T_h \gtrsim 100 T_c$.) Then the electron acoustic waves do not strongly Landau-damp and the fluid-approximation could be used. In this case equations of motion imply that for the hot electrons the inertia term is negligible so that the Boltzmann-distribution may be assumed, while for the cold electrons the inertia is balanced with the electric force. For large amplitudes, the solitary wave can propagate and propagation of weakly nonlinear waves is approximated by the K-dV equation. Since much more hot electrons exist than the cold ones, this case is rather unusual, but could be realized under special circumstance such as in plasma boundary.

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Reference

1) E. J. Valeo and Ira B. Bernstein: Phys. of Fluids **19** (1976) 1348.