On behavior peculiarity of electron plasma

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Abstract. The analysis of the analytical solution of the problem of the behavior of electron plasma in the AC electric field is fulfilled. Debye mode describes shielding of the external electric field in the plasma. The analysis of the region of existence of Debye mode, depending on the plasma parameters has been realized. A non-trivial dependence of the region of existence of Debye mode on the degree of degeneracy of the electron gas are revealed. For the case of nearly degenerate electron gas Debye mode has several areas of existence, depending on the frequency of the electric field.

1. Introduction

The plasma behavior near boundary are now intensely investigated [1,2]. On the shielding of the electric field close to the border Debye mode has a decisive influence. Debye mode is the solution of the kinetic Vlasov-Boltzmann and Maxwell equations. We will consider the kinetic equation in BGK approximation [3]. We will consider the case of small electric fields. This allows for the linearization of the kinetic equation. For the collisionless case, the solution on the behavior of plasma in one-dimensional case was first obtained by Landau. In this work it was firstly introduced the concept of collisionless damping (Landau damping) [4]. For collisional plasma the problem has been solved for degenerate case in [5]. The non degenerate case has been considered in [6].

2. The model and the solution

We will consider the one-dimensional case. So the electric field depends only on one coordinate. Designate this coordinate by \(x\). According the assumptions, any solution can be represented as a decomposition of the field strength on their own decisions. In dimensionless form it looks like this [6]

\[ e(x) = e_{as} + e_d(x) + e_c(x). \]

Terms \(e_{as}\), \(e_d(x)\), \(e_c(x)\) are Drude, Debye, and van Kampen modes respectively. Note that the Drude mode does not depend on the \(x\) coordinate. However, the Debye mode is not always present in the decomposition for its solutions. It is only present when the dispersion function has a root at these parameters (frequency of the external electric field and the collision frequency in the plasma). Our goal was to determine the existence regions of Debye mode in the space of these parameters. To determine the existence of a root, the authors used the principle of the argument. This principle in the application to the conditions of this problem leads to next result. The complex plane was divided into regions, where exists and not exists root. The boundary of this region is determined by the parametric curve

\[ L(\alpha): \quad \Omega = \sqrt{L_1(\mu, \alpha)}, \quad \varepsilon = \sqrt{L_2(\mu, \alpha)}, \quad 0 \leq \mu \leq +\infty, \]
$$L_1(\mu, \alpha) = \frac{s_0(\alpha)}{s_2(\alpha)} \frac{\mu^2 \left[ \lambda_0(\mu, \alpha) \left( 1 + \lambda_0(\mu, \alpha) \right) + s_2^2(\mu, \alpha) \right]^2}{\left( -\lambda_0(\mu, \alpha) \right)^2 \left( 1 + \lambda_0(\mu, \alpha) \right)^2 + s_2^2(\mu, \alpha)};$$

$$L_2(\mu, \alpha) = \frac{s_0(\alpha)}{s_2(\alpha)} \frac{\mu^2 s_2^2(\mu, \alpha)}{\left( -\lambda_0(\mu, \alpha) \right)^2 \left( 1 + \lambda_0(\mu, \alpha) \right)^2 + s_2^2(\mu, \alpha)}.$$

Here $\Omega$ is the dimensionless frequency of the external field, $\varepsilon$ is the dimensionless collision frequency in the plasma, $\alpha$ is the dimensionless degeneration coefficient of the plasma. Numerical analysis of the presented expressions has been fulfilled.

Figure 1 presents parametric curves for several variants of partially degenerate plasma. The ratio of the degeneration of plasma $\alpha$ changes from -5 to 5. In the figure the following notation is used: $D^+$ – region of existence of the root and $D^-$ is the area where there is no root. It is seen that graphs with $\alpha=-3$ and $\alpha=-5$ are practically identical. Also the graph for Maxwell plasma, where $\alpha=-\infty$, too, was close to 1 and 2.

Figure 1. The dependence of the location of the curve $L$ from the value of the coefficient $\alpha$.

Further study of the behavior of the curve during the growth of $\alpha$ showed an interesting feature. The right branch of the curve, more curves and appear region in which the root (and therefore Debye mode) appears and then disappears. Figure 2 shows the curve $L$ corresponding to the ratio of the degeneration of plasma $\alpha=30$. It is seen that for $\varepsilon=1.5$ with increasing frequency of the external field we get the following picture: Debye mode first there is, then she disappears, then appears again, then vanishes again.
At about $\varepsilon=1.8$ radical expression for the curve L always vanishes, i.e. the graph will always touch the axis $\varepsilon$. When $\alpha=+\infty$ (fully degenerate plasma) the width of the loops on the graph will tend to zero. But it is a subject for further research.

3. Conclusion

Thus, it was shown that the Debye mode in the case of nearly degenerate electronic plasma shows a non-trivial dependence on parameters. These parameters include the frequency of collisions of electrons and frequency of the external electric field. This leads to some new features of screening of the external electric field by the plasma.

Region, where there is unusual behavior Debye mode, is very narrow. The width of this region decreases with the growth of the degree of degeneracy of electron plasma. For Maxwell plasma, this behavior is not observed.

These effects can manifest themselves in the interaction of electromagnetic waves with the surface of conductive medium or a conductive layer [7-10].

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