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ON SOME PROPERTIES OF ANISOTROPIC PLASMAS

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I. ELECTROSTATIC SHIELDING

The problem of electrostatic shielding potential in a plasma with anisotropic kinetic temperatures is discussed in the first part of this paper. We suppose that the applied magnetic field is along the Z axis of Cartesian coordinates. The electron distribution function may be taken as

\[ f(r) = n e^{-\frac{m}{2} (e \cdot A) \cdot (e \cdot \vec{v})} \]  

(1)

where

\[ \vec{A} = \frac{m}{kT_e} \begin{pmatrix} (kT_e)^{-1/2} & 0 & 0 \\ 0 & (kT_e)^{-1/2} & 0 \\ 0 & 0 & (kT_e)^{-1/2} \end{pmatrix} \]  

(2)

\( T_e \) is the temperature along the main axis (Z axis) of tensor \( \vec{A} \) and \( k \) is the Boltzmann constant, \( m \) and \( \vec{v} \) are the electron mass and velocity respectively.

By using the integral transformation

\[ F(\omega) = \int d\vec{v} f(r) \delta(\vec{v} - \vec{v}_{\text{rel}}) \]  

(3)

we obtain the one dimensional distribution function

\[ F(\omega) = \left( \frac{m}{kT_e} \right)^{3/2} \exp\left( -\frac{m\omega^2}{2kT_e} \right) \]  

(4)

where \( \omega = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2} \) is the effective temperature along the \( \hat{z} \) direction, \( \hat{\omega}_x \) and \( \hat{\omega}_y \) are the components of \( \omega \) along and perpendicular to the Z axis respectively.

On the problem of positive charged test particle (coordinate \( \vec{r} = 0 \) and velocity \( \vec{v} = 0 \)) shielded by electron clouds, the Coulomb forces between particles are the chief interactions. The correction of shielding effect caused by magnetic force is neglected. In other words, it is assumed that the effect of applied magnetic field is only to maintain the anisotropic of electron velocity distribution function.

In this case, we obtain that the electric potential function is given by

\[ V_\omega(\vec{r}) = \frac{Q}{4\pi} \int \frac{(\hat{\omega}_x \hat{\omega}_y \hat{\omega}_z)}{\omega_x^2 + \omega_y^2 + \omega_z^2} \exp(\vec{\omega} \cdot d\vec{r}) \]  

(5)

where \( Q \) is the electric charge of test particle, and \( \omega \) is the electron plasma frequency.

When \( T_\omega \neq T_e \), let \( \xi = \frac{\omega}{kT_e} \)

(6)

As \( |\xi| < 1 \), integrating (6), we get

\[ V_\omega(\vec{r}) = \frac{Q}{4\pi} \int \frac{\hat{\omega}_x \hat{\omega}_y \hat{\omega}_z}{\omega_x^2 + \omega_y^2 + \omega_z^2} \exp(\vec{\omega} \cdot d\vec{r}) \]  

(7)

where \( k \) is the electron density along the \( \hat{z} \) direction.

\[ \frac{\partial}{\partial \omega} \left[ \int \frac{\hat{\omega}_x \hat{\omega}_y \hat{\omega}_z}{\omega_x^2 + \omega_y^2 + \omega_z^2} \exp(\vec{\omega} \cdot d\vec{r}) \right] \]  

(8)

where \( \omega = (\omega_x, \omega_y, \omega_z) \) and \( n \) and \( \alpha \) are the electron density and charge respectively, \( \beta(\omega, x) \) is the Legendre Polynomial of second order.

It can be seen that, besides the exponential decay terms, there is also a slow decay term proportional to \( R^2 \) in (3).

When \( n = 0 \), (8) may be reduced to

\[ V_\omega(\vec{r}) = \frac{Q}{4\pi} \int \frac{\hat{\omega}_x \hat{\omega}_y \hat{\omega}_z}{\omega_x^2 + \omega_y^2 + \omega_z^2} \exp(\vec{\omega} \cdot d\vec{r}) \]  

(9)

Therefore,

\[ \frac{\partial}{\partial \omega} \left[ \int \frac{\hat{\omega}_x \hat{\omega}_y \hat{\omega}_z}{\omega_x^2 + \omega_y^2 + \omega_z^2} \exp(\vec{\omega} \cdot d\vec{r}) \right] \]  

(10)

where \( \omega = (\omega_x, \omega_y, \omega_z) \) and \( n \) and \( \alpha \) are the electron density and charge respectively, \( \beta(\omega, x) \) is the Legendre Polynomial of second order.

Finally, according to the Poisson-lation, the shielding electron density \( \rho_s \) given by the electron distribution function (4) is

\[ \rho_s = \frac{Q}{4\pi} \int \frac{\hat{\omega}_x \hat{\omega}_y \hat{\omega}_z}{\omega_x^2 + \omega_y^2 + \omega_z^2} \exp(\vec{\omega} \cdot d\vec{r}) \]  

(11)

The total shielding charge quantity is then

\[ \int \rho_s d\vec{r} = -Q \int \frac{\omega_x \omega_y \omega_z}{\omega_x^2 + \omega_y^2 + \omega_z^2} \exp(\vec{\omega} \cdot d\vec{r}) \]  

(12)

It proves that the shielding effect is complete, therefore (1) is a rational distribution.

II. STRICT CRITERIONS OF KINETIC INSTABILITY CAUSED BY INJECTED NEUTRAL PARTICLE BEAMS

A number of strict and general instability criterions may be obtained by analyzing the geometric properties of the dispersion relations of special plasma waves.

In the second part of this paper, Nyquist diagrams of cyclotron instabilities caused by plasma streams are analysed. At first, the calculation method on instability criterions of \( n_s \) (the plasma stream density), \( n_s \) (the static plasma density), \( B \) (the applied magnetic field strength), \( \hat{\omega} \) (the wave number), \( \nu \) (the velocity) and \( T \) (the temperature) are obtained. The numerical results of Hydrogen plasma are obtained.

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Secondly, the cyclotron and electrostatic instabilities caused by two neutral plasma streams are also analysed. The numerical results of Hydrogen plasma are also given. Finally, a necessary condition of electromagnetic instabilities caused by plasma streams is derived.

REFERENCES