ABSORPTION OF LOWER HYBRID WAVES AND TEMPERATURE RELAXATION IN PARAMETRICALLY UNSTABLE INHOMOGENEOUS PLASMA

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The absorption mechanisms for high frequency waves in plasmas have received much attention in recent years, as such waves can be used for heating of fusion plasma. Thus the lower hybrid frequency region has been extensively studied.

The temperature relaxation processes between the electrons and ions in isotopic plasma have been investigated in [1]. The problem of temperature relaxation in magnetised plasma is studied in [2]. It is found that the relaxation rate between the electron and ion temperature contains, in addition to the usual Spitzer rate, an anomalous term which diverges logarithmically. The influence of the external electromagnetic radiation on the temperature relaxation process in isotropic plasma is considered in [3]. It is shown that the presence of radio-frequency electric field leads to the relaxation time increase.

In the present report, on the basis of kinetic fluctuations theory, the absorption of lower hybrid waves and the relaxation process between the electron and ion temperatures in a magnetised inhomogeneous plasma with density gradient is considered. The case when the external pump wave excites the lower-hybrid and the electron drift waves is investigated. The inverse relaxation time is calculated and its dependence on pump wave intensity and density gradient is obtained. It is shown that the presence of parametric instability leads to the relaxation time decrease.

Note that the case of uniform plasma has been investigated in [4].

Consider an inhomogeneous magnetoactive plasma (the constant magnetic field is directed along Z-axis) imbedded in the external electric field $\vec{E}_0(t) = E_0 \vec{y} \cos\omega_0 t$ which we use in the dipole approximation. We choose inhomogeneity to be in the y-direction. Then a Maxwellian distribution function corresponding to an exponential density gradient may be written as

$$f_{0\alpha}(p, y) = \frac{n_0}{(2\pi m_\alpha T_\alpha)^{3/2}} \exp\left(-\alpha'\left(\frac{p_x}{m_\alpha \Omega_\alpha} - y\right)\right) \exp\left(-\frac{p^2}{2m_\alpha T_\alpha}\right) \qquad (1)$$

In formula (1) $p^2 = p_x^2 + p_y^2 + p_z^2$ and $\alpha' = \frac{1}{n_0}\frac{dn_0}{dy}$ is the plasma inhomogeneity parameter. Here we assumed Ω_α to be homogeneous and will neglect temperature gradient.

It is well known that the density of the electromagnetic field energy absorbed by the plasma ion component is defined by the formula:

$$W_i = \frac{3}{2} n_e \dot{T}_e \quad (2)$$

where n_α and T_α are the density and the temperature of the particle of kind α. From another hand

$$\dot{T}_e = \frac{T_e - T_i}{\tau_{ei}} \approx -\frac{T_e}{\tau_{ei}} \quad (3)$$

Comparing the expressions (2) and (3) we find

$$\frac{1}{\tau_{ei}} = -\frac{W_i}{\frac{3}{2} n_e T_e}, \quad (4)$$

when the density of the electric field energy is connected with the collision integral by the expression [5]:

$$W_i = n_i \int \frac{p^2}{2m_i} J_i \cdot d\vec{p} \quad (5)$$

Let us consider the parametric decay of the pump wave into lower hybrid and electron drift waves

$$\omega_0 = \omega_{ek} + \omega_{De} \quad (6)$$

where $\omega_{De} = -\frac{k_\perp \alpha T_e}{m_e \Omega_e}$ is the electron drift frequency and ω_{ek} lies in the lower hybrid frequency region $\omega_{ek} = \omega_{LH} \left(1 + m_i \cos^2\theta / m_e\right)^{1/2}, \omega_{LH} \approx \omega_{pi}$

In the region above the instability threshold the integral electric field fluctuations are developed and the plasma becomes turbulent. Under these conditions superthermal fluctuations field intensity is substantially higher than the level of thermal noise. Therefore the diffusion coefficient $D \propto \left\langle \delta\vec{E}\,\delta\vec{E} \right\rangle_{\omega,\vec{k}}$ gives the main contribution to the collision integral and the density of electromagnetic field energy absorbed by the plasma ion component may be presented in the form

$$W_i = \int \frac{d\vec{k}}{(2\pi)^3} \int \frac{d\omega}{2\pi} \cdot \frac{\left\langle \delta\vec{E}\,\delta\vec{E} \right\rangle_{\omega,\vec{k}}}{4\pi} \cdot \omega \cdot Jm\chi_i^o \quad (7)$$

It is shown in [4] that the electric field fluctuations spectral density $\left\langle \delta\vec{E}\,\delta\vec{E} \right\rangle_{\omega,\vec{k}}$ is expressed through the correlators of noninteracting particles and the plasma dispersion functions depending on the intensity and frequency of pump wave. For the saturation of parametric instability we take into account the additional wave damping due to the scattering of charged particles by suprathermal electric field fluctuations. Solving the nonlinear equation (7) we obtain the expression:

$$W_i \approx \frac{1}{16} \frac{e^2 n \omega_{ek} \omega_{De}}{m_e \omega_o^4 \gamma_{ek}} \frac{E_o^4}{B_o^2} \frac{(k_{\perp 0} c)^2}{(k_0 r_{De})^2} \quad (8)$$

where k_0 is the wave number determined from the decay condition (6).

Substituting (8) in (4) as a result we have

$$\frac{1}{\tau_{ei}} \approx \frac{1}{24}\frac{e^2\omega_{ek}\omega_{De}}{T_e m_e \omega_o^4 \gamma_{ek}}\frac{E_o^4}{B_o^2}\frac{(k_{\perp 0}c)^2}{(k_0 r_{De})^2} \tag{9}$$

It can be seen from (9) that the inverse relaxation time grows with increasing density gradient and pump wave intensity. We note also the sharp inverse relaxation time dependence on pump frequency $\left(1/\tau_{ei} \propto \omega_0^{-4}\right)$.

Comparing the expression (9) with the value of the inverse relaxation time between the electron and ion temperatures in magnetised plasma in the absence of a pump wave [2]

$$\frac{1}{\tau_{ei}^0} = \frac{2\sqrt{\pi} n e^4}{m_e m_i}\left(\frac{m_e}{T_e}\right)^{3/2} \ln\left(\frac{\Omega_e^2}{\omega_{pe}^2}\right)\ln\left(\frac{m_i}{m_e}\right) \tag{10}$$

we find

$$\frac{1}{\tau_{ei}}\Big/\frac{1}{\tau_{ei}^0} \approx \frac{\pi^2}{6\sqrt{\pi}}\frac{n r_{De}^3}{\ln\left(\frac{\Omega_e}{\omega_{pe}}\right)\ln\left(\frac{m_i}{m_e}\right)}\sqrt{\frac{m_i}{m_e}}\frac{\omega_{ek}\omega_{De}}{\gamma_{ek}\omega_{pi}}\frac{\mu^2}{(k_0 r_{De})^2}\left(\frac{V_E}{V_{T_e}}\right)^2 \tag{11}$$

In formula (11), $\mu = \dfrac{k_\perp E_0 c}{\omega_0 B_0}$ is a small parameter, $V_E = \dfrac{eE_0}{m_e \omega_0}$ and $V_{T_e} = \left(\dfrac{T_e}{m_e}\right)^{1/2}$ are the electron oscillation and thermal velocities, respectively. For the characteristic parameters of the tokamak plasma $n r_{De}^3 \approx 10^8$, $\mu = 5 \cdot 10^{-2}$, $\omega_{ek}/\gamma_{ek} \propto 10^3$, $\left(\dfrac{V_E}{V_{T_e}}\right) \cong 10^{-4}$, $k r_{De} \approx 10^{-1}$, $T_e = 1\,keV$, $B_0 = 50\,\text{kH}$ one can obtain that $\dfrac{1}{\tau_{ei}}\Big/\dfrac{1}{\tau_{ei}^0} \approx 10^3$.

Thus our results can be of interest for studying the efficiency of parametric absorption of lower hybrid radiation energy in the plasma devices. We also note that the presence of parametric instability leads to the relaxation time decrease, i.e. the velocity of the IeF plasma heating grows.

References

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