Influence of an Upper-Hybrid Pump on Temperature Relaxation Process in a Magnetized Plasma

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Abstract. By means of kynetic fluctuation theory, the relaxation process between the electron and ion temperatures in a magnetized homogeneous plasma is considered. The cases when external upper-hybrid pump wave excites convective and ion-acoustic waves are analyzed. The inverse relaxation time in the regime where the turbulent fluctuations are developed is calculated and its dependence on the pump wave and plasma parameters is deduced.

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The theory of temperature relaxation was developed in Refs. [1 - 3] for an isotropic and magnetized plasma and also for a plasma subjected to external electromagnetic radiation. It has been found in [4] that a high-frequency electrostatic field close to the lower-hybrid resonant frequency has a significant influence on the relaxation rate between the electron and ion temperatures in magnetized uniform plasma.

Consider electron-ion plasma in an external magnetic field $Bo\vec{z}$

Furthermore, the plasma is subjected to an HF pump field, wher electric field is directed perpendicular to the external magnetic field. For a long-wavelength $(k_0 = 0)$ pump wave we can write $\vec{E}(t) = E_0 \vec{y} \cos \omega_0 t$.

First, we consider the case when the pump wave frequency is close to the upper-hybrid frequency:

$$\omega_{UH1} \approx (\omega_{pe}^2 + \underline{O}_e^2)^{1/2} , \tag{1}$$

where ω_{pe} and $\underline{O}_e$ are the plasma and Larmour frequencies, respectively. Here $\omega_{pe} \gg \underline{O}_e$, i.e. we have the case of a weakly magnetized plasma.

We study the decay of the pump wave into an upper-hybrid wave and modified convective cells:

$$\omega_0 = \omega_{UH1} + \omega_c \tag{2}$$

Here $\omega_c = (m_i / m_e)^{1/2} \cdot \underline{O}_i \cdot \cos\Theta$ is the frequency of the modified convective cell, and γ_c is the decrement of the wave damping, $\gamma_c \approx \frac{1}{2}\nu_{ei}$, where ν_{ei} is the electron-ion collision frequency, Θ is the angle between $\vec{k}$ and $\overrightarrow{B_0}$. It should be noted that convective modes arise in magnetized plasma with a small ratio of the plasma pressure to the magnetic pressure, and can also occur in the ionospheric plasma [5].

The dipole approximation is assumed for the pump wave, because typical ionospheric plasma parameters satisfy the condition $k_0 / k_{0\perp} \ll 1$. Here, $k_0 = \omega_0 / c$ (with $\omega_0 \approx \omega_{pe}$ for the upper-hybrid wave) is the wave vector of the pump upper-hybrid wave, and the wave number $k_{0\perp}$ satisfies the decay condition (2) (we are assuming that $k_{0\perp} \leq 1/\rho e$). Thus, we have

$$\frac{k_0}{k_{0\perp}} \approx \frac{\omega_{pe} V_{Te}}{\Omega_e\, c} \ll 1$$

It is well known [4] that the connection between the inverse relaxation time and the power density for the plasma ion component is defined by the formula

$$\frac{1}{\tau_{ei}} \approx \frac{2W_i}{3n_e T_e}, \tag{3}$$

where we can present the power density in the form

$$W_i = \int \frac{d\vec{k}}{(2\pi)^3} \int \frac{d\omega}{2\pi} \frac{<\delta\vec{E}\delta\vec{E}>_{\omega,\vec{k}}}{4\pi} \omega \operatorname{Im} \chi_i^0 \tag{4}$$

where $<\delta\vec{E}\delta\vec{E}>_{\omega,\vec{k}}$ is the spectral density of the turbulent fluctuations of the electric field in the region above the instability threshold. The correlator $<\delta\vec{E}\delta\vec{E}>_{\omega,\vec{k}}$ near the natural plasma frequencies is obtained from the well-known expression [5] in which the plasma eigenmodes are $\omega_j \to \omega_j + i\nu_{eff}$ ($j = UH, C$ for the upper-hybrid wave and modified convective cell respectively). Here for the saturation of parametric instability we have introduced the effective collision frequency $\nu_{eff1} \approx \nu_{ei} E_0^2 / E_{th1}^2$, which defines the additional wave damping due to the scattering of charged particles by turbulent electric field fluctuations. Note that E_{th1} is the threshold electric field for the decay instability (2).

Substituting the redefined expression for the field fluctuation spectral density into (4) and integrating with respect to ω and $\vec{k}$, we obtain the formula that determines the power density absorbed in the plasma. Than taking into account the expression (3) we have

$$\frac{1}{\tau_{ei1}} \approx \frac{1}{12} \frac{e^2}{m_e T_e} \frac{m_i}{m_e} \frac{\Omega_e^2 \omega_c (kc)^2 E_0^4}{\omega_0^4 \nu_{ei} \omega_{UH1} B_0^2}. \tag{5}$$

It can be seen from (5) that the inverse relaxation time has a sharp dependence on the pump frequency and also is proportional to the pump wave intensity.

As our second example, we consider the decay of the pump wave into an upper-hybrid and ion-acoustic wave

$$\omega_0 = \omega_{UH2} + \omega_s, \tag{6}$$

where $\omega_s = k\text{v}_s$ and $\text{v}_s = (T_e / m_i)^{1/2}$ is the ion sound velocity. Consider an upper-hybrid wave satisfying the dispersion relation

$$\omega_{UH2} = \Omega_e \left(1 + \frac{\omega_{pe}^2 \sin^2 \Theta}{2\Omega_e^2} \right). \tag{7}$$

It should be noted that the expression (7) is valid in a strongly magnetized plasma for the case ω_{pe} □ $\underline{O}_e$. We assume that the damping rate of the upper-hybrid wave $\gamma_{UH} \approx \nu_{ei}$. Note also that the pump-wave frequency ω_0 must be slightly above ω_{UH2}, because ω_s □ ω_0, ω_{UH2}.

Taking into account that $\nu_{eff2} \approx (E_0^2 / E_{th2}^2)(\gamma_s \nu_{ei})^{1/2}$ when ν_{eff2} □ ν_{ei}, γ_s after lengthy but following expression for the relaxation velocity

$$\frac{1}{\tau_{ei2}} \approx \frac{1}{3} \frac{e^2 E_0^2}{m_e T_e \omega_0^2} \frac{E_0^2}{E_{th2}^2} (\gamma_s \nu_{ei})^{1/2} \quad (8)$$

It should be noted that E_{th2} is the threshold value of the parametric decay (6).

The results of this report can be of interest for plasma diagnostics and for considering the plasma heating efficiency.

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