RADIATION FROM PLASMA DUE TO PARAMETRIC EXCITATION OF CONVECTIVE CELLS

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On the basis of the fluctuations kinetic theory the process of plasma radiation is studied when the transformation of an longitudinal Langmuir wave into the transverse electromagnetic wave occurs. We consider the parametric decay of upper hybrid pump wave into the daughter wave and modified convective cells. The transformation coefficient is obtained. For typical ionospheric plasma parameters we show that the pump wave term can exceed by several orders of magnitude the analogous one for the case of stable plasma. The intensity of transverse waves radiation from turbulent plasma is calculated and its dependence on convective cells frequency and damping rate is found.

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INTRODUCTION

It is well known that investigations of wave transformation and scattering are important for studying the properties of matter, plasma diagnostics, wave transformation mechanisms in plasmas, measurements of the efficiency of high-frequency pump power dissipation.

Of prime actuality in the understanding of the role fluctuations play in scattering and transformation processes. We know that the thermal fluctuations can exist in ordinary plasmas. Obviously, the scattering intensity will be sufficiently large in a non-equilibrium plasma when the level of fluctuations is much higher that that of thermal fluctuations. In such turbulent plasma in which instability can develop, the scattering (transformation) intensity may considerably increase.

We note that the fluctuation theory for magnetized plasma in the presence of a pump wave was developed in [1-2].In the present paper we study the radiation processes when the transformation of incident Langmuir wave into the electromagnetic wave in magnetized plasma occurs. We have calculated the transformation coefficient for the case of non-equilibrium turbulent plasma. A pump wave is supposed to decay into daughter upper hybrid wave and convective cells. It is shown that the intensity of electromagnetic waves radiation from plasma depends explicitly on the convective cells frequency and damping rate.

We would like to clarify the main idea of the article. It is the transformation of eigen Langmuir waves into the transverse electromagnetic waves on superthermal (turbulent) plasma density convective modes fluctuations. The level of these fluctuations is much greater than the level of the thermal noise because we have the parametric instability due to decay of upper hybrid pump wave into daughter wave and convective oscillations.

RESULTS

Let us consider the transformation of the incident longitudinal Langmuir wave into the transverse electromagnetic wave by low-frequency coherent fluctuations. We neglect the interaction of the incident wave with the electron”s velocity and the electric field and take into account that the density fluctuations are dominant in comparison to the fluctuations of magnetic field. In this approximation we may write the following expression for the transformation coefficient [3] :

$$d\sum\nolimits_{l\to t} = \frac{1}{2\pi}\left(\frac{e^2}{mc^2}\right)^2 \frac{\omega'^4}{\omega_{pe}^4} N < \delta n_e^2 >_{\vec{q},\Delta\omega} \times$$
$$\times\, d\omega'' dO, \qquad (1)$$

where $\Delta\omega = \omega' - \omega''$, $\vec{q} = \vec{k}' - \vec{k}''$, $\omega', \vec{k}'$ and $\omega'', \vec{k}''$ are the frequencies and wave vectors of the incident and transformed waves respectively, O is the space angle, and $< \delta n_e^2 >_{\Delta\omega,\vec{q}}$ is the correlator of the electron density fluctuations at the combination frequency $\Delta\omega$.

The factor N in formula (1) is given by :

$$N = \frac{\eta''^3 \left| \vec{e}''^* (\hat{\varepsilon}'' - 1)\vec{k}' \right|^2}{\eta' \xi' (\vec{e}''^* \hat{\varepsilon}'' \vec{e}'')} \qquad (2)$$

where $\vec{e}, \eta, \hat{\varepsilon}$ are the polarization vector, refraxtion index, the tenzor of plasma permittivity for the incident $(')$ and transformed $('')$ waves, respectively.

The polarization of transformed waves which are under consideration is arbitrary and is taken into account by factor N determined by (2).

Consider an electron-ion plasma imbedded in an external magnetic field $B_0\vec{z}$. Furthermore, the plasma is subjected to an HF pump field , whose electric field is directed perpendicular to the external magnetic field. We can write $\vec{E}(t) = E_0\vec{y}\cos\omega_0 t$ where the pump frequency ω_0 lies in the upper hybrid resonance frequency defined by $\omega_{UH} \approx (\omega_{pe}^2 + \Omega_e^2)^{1/2}$. Here $\omega_{pe} > \Omega_e$, i.e. we have the case of a weakly magnetized plasma. The important role of parametric instabilities in the region of upper hybrid resonance was pointed out in [4].

We consider the decay of the pump wave into upper hybrid wave and modified convective cells:

$$\omega_0 = \omega_{UH} + \omega_c . \tag{3}$$

Here $\omega_c = (m_i / m_e)^{1/2} \Omega_i \cos\theta$ is the real part of the frequency of the modified convective cell, $\mathrm{Im}\,\omega_c \equiv \gamma_c \approx \frac{1}{2}\nu_{ei}$, where ν_{ei} is the electron-ion collision frequency and θ is the angle between $\vec{k}$ and $\vec{B}_0$. It should be noted that convective modes arise in a magnetized plasmas with a small ratio of the plasma pressure to the magnetic pressure and can occur in the ionospheric plasma [5].

The dipole approximation is assumed for the pump wave because the typical ionospheric plasma parameters satisfy the condition $k_0 / k_{0\perp} << 1$. 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 wavenumber $k_{0\perp}$ satisfies the decay condition (3) (we are assuming that $k_{0\perp} \le 1/\rho_e$). Thus, we have

$$\frac{k_0}{k_{0\perp}} \approx \frac{\omega_{pe} v_{Te}}{\Omega_e c} << 1. \tag{4}$$

In order to study the transformation in the plasma turbulence region (above the threshold of parametric instability) it is necessary to take into consideration the nonlinear stabilization mechanism that leads to saturation of the fluctuation level. This mechanism involving charged particles scattering by turbulent plasma fluctuations has been presented in detail in [1].

Using such stabilization mechanism and taking into account that the low-frequency convective oscillations make the main contribution to the correlator of the electron density fluctuations $< \delta n_e^2 >_{\Delta\omega,\vec{q}}$ (in formula (1)) in the region above the instability threshold after a little algebra we obtain the ratio of the differential transformation cross-section $d\sum_{l\to t} / dO$ to the corresponding cross-section due to thermal noise $d\sum_{l\to t}^0 / dO$:

$$\frac{d\sum_{l\to t} / dO}{d\sum_{l\to t}^0 / dO} \approx 1 + \frac{\mu^2}{8} \frac{\omega_{pi}^2}{\Omega_i^2} \frac{\omega_{pe}^2 \omega_c^2}{\omega_{UH}^2 \nu_{ei}^2 \sin^2\theta}, \tag{5}$$

where $\mu = E_0 kc / \omega_0 B_0$, $\mu << 1$.

For typical ionospheric plasma parameters in the F layer at about 250 km, $n_0=10^6$ cm^{-3} $T_e \approx T_i$=0.1 eV, B_0=0.45 G and $\nu_{ei} = 5\times 10^2 s^{-1}$ we show that the pump field term in (5) (proportional to pump wave intensity) become much greater than unity.

We note that the transformation of the longitudinal wave into the transverse one is of substantial interest as a possible mechanism of electromagnetic energy radiation from the plasma. The incident Langmuir waves always exist in the plasma with the amplitude which is defined by the electron temperature. Interacting with modified convective cells these waves may be transformed into transverse waves and then leave the plasma.

The intensity of such radiation is connect with the transformation coefficient by the relation

$$I \sim V \iint d\sum_{l\to t} \times S' \frac{d^3 k'}{(2\pi)^3} \frac{d\omega'}{2\pi} \tag{6}$$

Where V is the system volume, S' is the energy flow density of the incident Langmuir wave,

$$S' = \frac{v_{gr}}{16} \frac{\partial}{\partial\omega'} (\varepsilon^l \omega') \cdot (\delta\vec{E}^2)^l_{\omega',\vec{k}'} . \tag{7}$$

In formula (7) v_{gr} is the group velocity of Langmuir waves, $v_{gr} = 3\omega_{pe} r_{De}^2 k'$ and ε^l is known dispersion relation for the longitudinal oscillations in magnetized plasma.

We may assume that $\frac{\partial}{\partial\omega'}(\varepsilon^l \omega') \approx 1 + \frac{2\omega_{pe}^2}{\omega'^2} \approx 3$ for $\omega' \sim \omega_{pe}$ and recall that the transformed transverse wave has a much longer wavelength than the incident longitudinal wave, i.e. $k'' << k' \sim q$.

Using the fluctuation-dissipative theorem we obtain

$$\int (\delta\vec{E}^2)^l{}_{\omega',\vec{k}'} d\omega' \sim T_e . \tag{8}$$

Inserting the pump wave term of (5) into (6), carrying out the integration over k' and taking into account (8), finally we obtain the intensity of transverse wave radiation from turbulent plasma (leaving only the term depending on pump wave amplitude):

$$I \sim V (\frac{e^2}{mc^2})^2 N \frac{\omega_{pe} T_e^2 k'^2}{e^2} \frac{\mu^2}{32} \frac{\omega_{pi}^2}{\Omega_i^2} \frac{\omega_c^2}{\gamma_c^2} . \tag{9}$$

The calculations show that for typical parameters of ionospheric plasma the value of radiation intensity (9) can exceed the analogous one for the case of stable plasma by several orders of magnitude.

CONCLUSIONS

We would like to emphasize the following. In this paper we show that the main contribution to the transformation coefficient and the intensity of transformed wave"s radiation from turbulent plasma are given by pump field terms. Notice must be taken also that these values are essentially depend on frequency and damping rate of modified convective cells and intensity of pump wave. The results obtained in this paper allow us to clarify the influence of convective modes on the radiation processes in space and laboratory plasma.

REFERENCES

1. V.N. Pavlenko, V.G. Panchenko, S.M. Revenchuk. Turbulent conductivity of a magnetized plasma // *Sov. Phys. JETP*. 1986, v. 64, № 1, p. 50-59.
2. L. Stenflo. Scattering and transformation of waves in magnetized plasma // *Physica Scripta*. 2004, v. 107, p. 262-265.
3. A.I. Akhiezer, I.A. Akhiezer, et al. *Plasma Electrodynamics*. Oxford: "Pergamon, 1975.
4. V.N. Pavlenko, V.G. Panchenko. Scattering processes in magnetized plasmas with high-frequency pumps // *Physica Scripta*. 1999, v. 82, p. 109-112.
5. V.N. Pavlenko, V.G. Panchenko. Parametric absorption of lower hybrid waves in a nonuniform magnetized plasma // *Plasma Physics Reports*. 1999, v. 25, № 4, p. 288-292.

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ИЗЛУЧЕНИЕ ИЗ ПЛАЗМЫ ПРИ ПАРАМЕТРИЧЕСКОМ ВОЗБУЖДЕНИИ КОНВЕКТИВНЫХ ЯЧЕЕК

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На основе кинетической теории флуктуаций изучается процесс излучения из плазмы при трансформации продольной ленгмюровской волны в поперечную электромагнитную. Рассмотрен параметрический распад верхнегибридной волны накачки на дочернюю волну и модифицированные конвективные ячейки. Получено выражение для коэффициента трансформации. Для типичных параметров ионосферной плазмы показано, что член, обусловленный полем накачки, может превышать соответствующую величину для случая спокойной плазмы на несколько порядков. Вычислена интенсивность излучения поперечной волны из турбулентной плазмы и найдены ее зависимости от частоты и декремента затухания конвективных ячеек.

ВИПРОМІНЮВАННЯ ІЗ ПЛАЗМИ ПРИ ПАРАМЕТРИЧНОМУ ЗБУДЖЕННІ КОНВЕКТИВНИХ КОМІРОК

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На основі кінетичної теорії флуктуацій вивчається процес випромінювання із плазми під час трансформації повздовжньої ленгмюрівської хвилі в поперечну електромагнітну. Розглянуто параметричний розпад верхньогібридної хвилі накачки на дочірню хвилю і модифіковані конвективні комірки. Отримано вираз для коефіцієнта трансформації. Для типових параметрів іоносферної плазми показано, що член, обумовлений полем накачки, може перевищувати відповідну величину для випадку спокійної плазми на декілька порядків. Обчислена інтенсивність випромінювання поперечної хвилі із турбулентної плазми та знайдено її залежності від частоти і декременту загасання конвективних комірок.