EFFECT OF A HIGH-FREQUENCY MAGNETIC FIELD ON PLASMA INSTABILITY

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A method is presented for stabilization of a plasma in a magnetic field; the lines of force are made to execute small oscillations (with respect to their mean positions) at frequencies greater than the characteristic growth rates.

IT is shown in the present paper that a weak, high-frequency (RF) electromagnetic field can have an effect on waves and instabilities of a plasma in a magnetic field[1)]; this mechanism is associated with the oscillations, in time, of the lines of force about the average positions. We shall limit ourselves to two simple examples that are, however, important from the point of view of theory and experiment.

1. We first consider the drift-temperature instability [2] for a plasma column located in a fixed magnetic field $\mathbf{H}_0 = \{0, 0, H\}$ along which there flows an alternating current that produces a supplementary field $H_\varphi \ll H$; the frequency of the current satisfies the condition $\Omega \ll eH/Mc$.[2)] To describe the motion of the plasma particles we use the drift kinetic equation [4]

$$\frac{\partial \delta f}{\partial t} + iv_\parallel\left(k_z + k_\varphi \frac{H_\varphi}{H}\sin\Omega t\right)\delta f + \frac{c}{H}E_\varphi\frac{\partial f_0}{\partial r}$$
$$+\frac{e}{M}\left(E_z + E_\varphi\frac{H_\varphi}{H}\sin\Omega t\right)\frac{\partial f_0}{\partial v_\parallel} = 0, \qquad f_0 = f_0(v_\parallel, r),$$
$$\mathbf{E} = -\nabla\Phi, \quad v_\parallel = \mathbf{v}\frac{\mathbf{H}_0}{|H_0|} = v_z + o\left(\frac{H_\varphi}{H}\right)^2. \qquad (1)$$

Using (1) we find the Fourier components of the function δf with respect to t, z and φ for the condition $\omega \ll \Omega$:

$$f_k{}^\alpha = \Phi\left\{\frac{\partial f_0}{v_z\partial v_z}\frac{e^\alpha}{M^\alpha} - \frac{J_0{}^2(\mu v_z)}{\omega - k_z v_z}\left(\frac{c}{H}k_\varphi\frac{\partial f_0{}^\alpha}{\partial r} + \frac{e^\alpha}{M^\alpha}\omega\frac{\partial f_0{}^\alpha}{v_z\partial v_z}\right)\right\}, \quad (2)$$

where J_0 is the Bessel function $\mu = k_\varphi H_\varphi/\Omega H$, $\alpha = i, e$ denotes the particle species. The dispersion relation then follows from the neutrality condition

$$\sum_\alpha \int f_k{}^\alpha dv_z = 0.$$

The RF field has an effect on the waves when the argument of the Bessel function is greater than or of order unity, that is, when $(H_\varphi/H)k_\varphi v_{Ti}/\Omega \gtrsim 1$. At larger values of the arguments of the Bessel function the electron terms in the summation can be neglected compared with the ion terms. Hence, when $\omega \ll \Omega$ and $H_\varphi/H \gg \Omega/k_\varphi v_{Ti}$ the dispersion relation becomes

$$1 + \frac{T_i}{T_e} + \int\frac{J_0{}^2(\mu v_z)}{\omega - k_z v_z}\left[\frac{cT_i}{eH}k_\varphi\frac{\partial f_0}{\partial r} + \frac{T_i}{M_i}\omega\frac{\partial f_0}{v_z\partial v_z}\right]dv_z = 0. \qquad (3)$$

In the case of greatest interest $\mu v_{Ti} = (H_\varphi/H)k_\varphi v_{Ti}/\Omega \gg 1$ the dispersion equation (3) can be solved with accuracy to order $1/\ln \mu v_{Ti}$:

$$\omega = \omega^*\frac{A}{2-A}\left(\frac{\eta}{2} - 1\right), \qquad A = \int J_0{}^2 f_0\, dv_z,$$
$$\omega^* = -k_\varphi\frac{cT_i}{eH}\frac{d\ln n_0}{dr},$$
$$\gamma = -\sqrt{\pi}\frac{\omega^2}{|k_z|v_{Ti}}\frac{J_0{}^2(\omega\mu/k_z)}{A}\exp\left\{-\frac{\omega^2}{k_z{}^2v_{Ti}{}^2}\right\}\left[1 + \frac{\omega^2}{k_z{}^2v_{Ti}{}^2}\frac{\eta}{1-\eta/2}\right],$$
$$\eta = \frac{d\ln T_i}{d\ln n_0} \qquad (4)$$

It then follows, as in the absence of the RF field, that $\eta > 2$ always means instability. An investigation of stability in the general case shows that for all values of μ the plasma is always unstable when $\eta > 2$.

However, even for small-amplitude RF fields the frequency and growth rate are reduced appreciably. The changes occur for oscillations in the range of wave numbers k_φ from $k_\varphi \sim H\Omega/H_\varphi v_{Ti}$ (when $\mu v_{Ti} \sim 1$) to

$$k_\varphi = \Omega \Big/ v_{Ti}\rho_{\pi i}\frac{d\ln n_0}{dr},$$

determined from the applicability condition for (2) $\omega < \Omega$. The effect of the RF field on the drift temperature instability for perturbations with shorter wavelengths can be neglected since the growth rates of these perturbations is larger than Ω and these will grow more rapidly than the change in direction of the lines of force of the magnetic field.

2. The dispersion relation that describes the loss cone instability [5] in the presence of a small RF component of the magnetic field $H_y \cos\Omega t$ (an RF field of this kind can be produced in the plasma by exciting helicon waves) is of the following form

$$1 + \frac{\omega_{pe}{}^2}{\omega_{He}{}^2} = \frac{\omega_{pe}{}^2}{k^2v_{Te}{}^2}\left[1 - (\omega - \omega^*)\int\frac{J_0{}^2(\mu v_z)}{\omega - k_z v_z}f_0{}^e(v_z)dv_z\right]$$
$$+\frac{\omega_{pi}{}^2}{k^2v_{Ti}{}^2}F\left(\frac{\omega}{kv_{Ti}}\right). \qquad (5)$$

Here it is assumed that $\omega \ll \Omega$, $\mu = k_y H_y/\Omega H_0$ and the function $F(\omega/kv_{Ti})$ is defined in [5]. The effect of the RF field on the ions can be neglected. In order to compute the perturbations in electron density we use (2). Investigation shows that (5) does not admit of unstable solutions if

$$\int\frac{\omega J_0{}^2 f_0}{\omega - k_z v_z}dv_z < 1.$$

This condition can be satisfied if $H_y/H > \Omega/k_\perp v_{Te}$. The loss-cone instability can only be excited when $\omega/kv_{Ti} < 1$ while the RF field can have an effect on

1)A detailed investigation of the oscillation spectra for a uniform isotropic plasma in an alternating electromagnetic field is given in [1].

2)The effect of an RF field on certain instabilities of an inhomogeneous plasma has been studied earlier. [2,3]. The effect of rotation of the lines of force was not treated, however.

the instability if $\Omega > \mathrm{Im}\,\omega$. Hence, the loss cone instability with a given value of k can be suppressed by means of an RF field only if the condition $H_y/H > v_{Ti}/v_{Te}$ is satisfied.

The physical mechanism for the effect described above lies in the fact that if the line of force rotates with respect to the perturbation the particles moving along the magnetic field with thermal velocities (assuming that the condition $H_y/H > \Omega/k_\perp v_{T\alpha}$ is satisfied) can succeed in going several space periods. In the case of the drift temperature instability this leads to a resulting averaging of the effects of the electric field of the perturbation on the ions and a resulting reduction in the frequency and growth rate. In the case of the loss-cone instability the electrons shield the electric field arising in the perturbation of the ion density. In a uniform plasma $\omega^* = 0$ and in this case, in general irrotational oscillations characterized by $\omega < \Omega$ do not arise.

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195