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HIGH-FREQUENCY INSTABILITY OF A PLASMA IN A RADIAL ELECTRIC AND LONGITUDINAL MAGNETIC FIELD

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Ioffe et al. [1] realized a plasma with hot ions by applying a potential between an axial ion beam (serving as an internal electrode) and the walls, thus producing a radial electric field in the plasma. The potential difference was increased to its maximum value within times on the order of 2 μsec and maintained constant for 25 - 30 μsec, after which it dropped to zero in a time of the order of 0.2 μsec. All these characteristic times greatly exceed the time of ion cyclotron rotation ($\omega_{Bi}^{-1} = e_iB/M_ic \sim 10^{-2}$ μsec). The switching of the field on and off thus satisfies the adiabatic-approximation requirement ($\partial \ln E_r/\partial t \ll \omega_{Bi}$), and from the point of view of the adiabatic theory the ion energy should have approximately the same value after the field is switched off as before its application, i.e., several electron volts. However, an appreciable number of ions with energy of the order of hundreds of electron volts were observed in the experiment. This indicates that irreversible processes, which are beyond the scope of adiabatic theory, have taken place in the plasma.

It is therefore natural, when attempting to interpret the ion heating in these experiments, to ascertain which high-frequency instabilities ($\omega \gtrsim \omega_{Bi}$) are possible in a plasma situated in superimposed magnetic and radial electric fields.

To this end we consider the following idealized problem. Let a plasma with negligibly low particle temperature be situated in a magnetic field $\vec{B} \parallel \vec{z}$ and an electric field $\vec{E}$ $(\vec{E}_r, 0, 0)$. (As is well known, in the presence of a magnetic field a quasistationary electric field perpendicular to it is capable of penetrating the plasma.) The fields $\vec{B}$ and $\vec{E}$ are assumed to be static. We consider the perturbation of such a system, assuming that the perturbation of the electric field is potential, $\vec{E} = -\nabla\psi$. Choosing the space-time dependence of the perturbed quantities in the form $f = f(r)\exp(im\varphi + ik_zz - i\omega t)$ and putting $\omega_{Be} \gg \omega \gg \omega_{Bi}$ and $f(r) \sim \exp(i\int k_r dr)$, we obtain from the equations of two-fluid hydrodynamics the equation

$$k_\perp^2\left\{1 + \frac{\omega_{Pe}^2}{\omega_{Be}^2} - \frac{\omega_{Pi}^2}{[\Omega - \frac{m}{r}(v_i - v_0)]^2}\right\} - \left(k_z\frac{\omega_{Pe}}{\Omega}\right)^2 - \frac{m}{r}\frac{\frac{\partial\omega_{Pe}^2}{\partial r}}{\omega_{Be}\Omega} = 0, \qquad (1)$$

where

$$\Omega = \omega - \frac{m}{r}v_0, \quad k_\perp^2 = k_r^2 + \left(\frac{m}{r}\right)^2, \quad \omega_{P_\alpha}^2 = \frac{4\pi e_\alpha^2 n}{M_\alpha}, \quad \omega_{B_\alpha} = \frac{e_\alpha B}{M_\alpha c}, \quad v_0 = -\frac{cE_r}{B},$$

$$v_i = r\omega_{Bi}\left[-\tfrac{1}{2} + \sqrt{\tfrac{1}{4} + (v_0/r\omega_{Bi})}\right],$$

n is the plasma density, e_α and M_α are the charge and mass of the particles, and the subscripts i and e correspond to the ions and electrons (α = i, e).

1. When $k_z^2 \gg (m/r)(\partial \ln n/\partial r)(\Omega/\omega_{Be})$, Eq. (1) describes unstable oscillations (cf. [2]) whose maximum increment is reached when $k_z/k_\perp \sim (M_e/M_i)^{1/2}$ and $m/r \simeq \omega^*/(v_i - v_o)$, and has an order of magnitude ω^*, where $\omega^* = \omega_{Pi}(1 + \omega_{Pe}/\omega_{Be})^{-1/2}$. For these solutions to be valid it is necessary that the density gradient be not too large, $|v_i - v_o|(\partial \ln n/\partial r) < \omega_{Bi}$.

2. $k_\parallel^2 < (m/r)(\partial \ln n/\partial r)(\Omega/\omega_{Be})$, $|v_i - v_o| \sim v_o$. This is the case of a strong plasma inhomogeneity and a strong electric field. Here, too, Eq. (1) admits of unstable solutions whose increment, depending on the ratio m/r, lies in the interval from ω_{Bi} to ω^*.

Our analysis shows that the interpretation of the ion heating in the experiments of [1] can be as follows. Owing to the centrifugal force resulting from the finite mass of the ions, the electrons and ions drift in the crossed electric and magnetic field with different velocities. The relative motion of the plasma components leads to an instability, whose increment is comparable with or larger than the ion-cyclotron frequency, and has a maximum of the order of the ion Langmuir frequency. The instability develops until the ion velocities due to the fluctuating fields become of the same order as the difference between the electron and ion drift velocities. Owing to the random phases of the fluctuations, the energy acquired in this manner has the same character as thermal energy. It is therefore retained by the particles even after the electric field that had initiated the instabilities is switched off. The ion energies can reach values of the order of $M_i v_o^2/2$. Substitution of the concrete values of B and E_r characteristic of the conditions of [1] leads to an ion energy that agrees in order of magnitude with those observed.

At the same time, one cannot exclude the possibility that the mechanism of ion acceleration in [1] is connected with some other instability which lies beyond the scope of the theoretical model assumed here. On the other hand, the instability considered here can have a bearing also on other experiments, in which the radial electric field is produced specially or spontaneously.

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INVESTIGATION OF HIGH-FREQUENCY OSCILLATIONS IN SINGLE-CRYSTAL MAGNESIUM MANGANESE FERRITE

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It is known that nonlinear processes in yttrium iron garnets (YIG) are accompanied by oscillations [1-3]. It can be shown that the oscillations due to nonlinear ferromagnetic resonance should be observed in all ferrites. We have experimentally observed and investi-