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PARAMETRIC EXCITATION OF DRIFT WAVES WITH THE PUMP NEAR THE ION CYCLOTRON FREQUENCY IN A TWO-ION-SPECIES PLASMA*

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Parametric excitation of drift waves in a multi-ion species plasma is observed in a range of pump frequencies, $\omega_{pi}/\Omega_i >> \omega_o/\Omega_i \approx 1.3 - 1.6$ and the ion concentration ratio, N(He):N(Ne) = 8:2 - 3:7. The dispersion relation and the excitation mechanism are verified.

The most unique feature of parametric instability near the ion cyclotron frequency is in the ability for the ion drift motions to excite parametric instability. In a two-ion species plasma, as the pump frequency approaches the ion cyclotron frequency, the relative ion drift velocity becomes comparable (or even larger) to the electron E × B drift velocity and can provide a strong parametric coupling. This relative ion drift motion gives a rise to a new possibility of parametrically exciting the decay waves both of which are kinetic modes $[\omega_1/k_{1\parallel}, \omega_2/k_{2\parallel} < V_{Te}]$ with relatively low threshold.

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The first experimental observation of such instability was reported previously for parametric excitation of the electrostatic ion cyclotron waves [1]. In this letter, we present theoretical and experimental investigation of parametric excitation of drift waves by a relative-ion drift motion with the pump near the ion cyclotron frequency in a two-ion-species plasma. This type of instability may become important during radio frequency heating near the ion cyclotron frequency of a multi-ion species plasma such as a deuterium-tritium fusion reactor plasma.

Since the RF frequency of interest ω_0 is near the ion cyclotron frequency Ω_i, it is usually appropriate to assume that $\omega_0 \ll \omega_{pi}$ (the ion plasma frequency) for most plasmas in the drift wave region. In this parameter regime, one of the natural modes of plasma is the electrostatic ion cyclotron wave (or the neutralized ion Bernstein wave) [2]. One can write a dispersion relation of parametric coupling of such waves with drift waves in the following form:

$$\varepsilon = \frac{1}{\varepsilon^-} \sum_\sigma \frac{\mu_\sigma}{2} (\chi_\sigma - \chi_\sigma^-) \sum_\sigma \frac{\mu_\sigma^*}{2} (\chi_\sigma - \chi_\sigma^-) + \frac{1}{\varepsilon^+} \sum_\sigma \frac{\mu_\sigma}{2} (\chi_\sigma - \chi_\sigma^+) \sum_\sigma \frac{\mu_\sigma^*}{2} (\chi_\sigma - \chi_\sigma^+), \quad (1)$$

where $\varepsilon = 1 + \sum_\sigma \chi_\sigma$ is the dielectric constant for the low frequency drift wave and ε^-, ε^+ are those for the lower and upper sideband modes. The summation σ is over electron and ion species. Here, $\mu_\sigma \ll 1$ is the ratio of drift-excursion (by the pump electric field E) of species σ to the decay wave length. From eq. (1), one can show that parametric coupling is weak for a single ion species plasma. However, with the addition of a second ion species the relative ion drift motion can provide strong parametric coupling between drift waves and ion cyclotron waves. Thus eq. (1) can be written in the following form:

$$\varepsilon = \frac{U^2}{4}\frac{k^2}{\omega_o^2}\left[(\chi_1 - \chi_1^-)^2/\varepsilon^- + (\chi_1 - \chi_1^+)^2/\varepsilon^+\right] , \qquad (2)$$

where $U = c(E/B)\ \omega_o(\Omega_2 - \Omega_1)(\omega_o^2 + \Omega_1\Omega_2)[(\omega_o^2 - \Omega_2^2)(\omega_o^2 - \Omega_1^2)]^{-1}$ is the relative ion drift velocity. Subscripts 1 and 2 designate the ion species with the lower and the higher ion cyclotron frequencies, respectively. In obtaining eq. (2) the relation $\chi_1 - \chi_1^{\pm} = -(\chi_2 - \chi_2^{\pm})$ was used.

In order to test this theoretical prediction we performed an experiment in the Princeton L-4 linear research device [1]. The experimental parameters used were as follows: the magnetic field $B_o \lesssim 4.2$ kG; f_{ci}(He) $\lesssim 1.6$ MHz; the plasma density at the drift wave region, $n = 5 \times 10^9 \sim 10^{10}/cm^3$, the temperatures, $T_e = 2.5 - 5.0$ eV and $T_i < 0.1$ eV; the neutral gas filling pressure in the experimental region, $P \simeq 3 \times 10^{-4}$ Torr. A ten turn, Faraday shielded, $m = 1$, RF induction coil was used to impress a radially uniform electric field (azimuthal mode number $m = 1$) of up to 15 V/cm in the plasma.

As the pump power was increased above threshold level, we observed a sudden onset of parametric decay in the region of the large density gradient when an appropriate amount of second ion species was added to the plasma. In fig. 1(a), a typical decay frequency spectrum observed in a helium-neon plasma is shown. (We have also observed similar decay spectra in helium-argon as well as helium-krypton plasmas.) The following data and analysis were done in a helium-neon plasma since we have previously carried out detailed ion concentration ratio measurements in such plasma [1]. In fig. 1(a), the observed decay amplitude is shown as a function of the ion concentration ratio, with the magnetic field as a variable parameter. In this plot, the pump electric field is held constant at E = 8 V/cm. As shown in the figure, the decay region moves systematically with the magnetic field and the ion concentration ratio. In accord with predictions of our theory, the decay spectra disappeared when either of the ion species was removed in the experimental region. The frequency of the observed low frequency mode as a function of magnetic field is shown in fig. 2(a), with the ion concentration ratio as a variable parameter. Although the neighboring drift modes can be successively excited as the plasma parameters are being changed, in fig. 2(a) we only show the dominant decay modes. The important, essential plasma parameters were monitored by using similar techniques as in Ref. 1 and 3. We note that as the magnetic field was varied for a given ion concentration ratio, the density, temperature, and density gradients showed little change during these measurements.

Using interferometric techniques, we have measured the parallel, radial, and azimuthal wavelengths of the decay modes. From the measured dispersion relations, we concluded that the lower sideband was an electrostatic ion cyclotron wave , and the low frequency mode was a drift wave in a multi-ion species plasma. We note that excitation of the electrostatic ion cyclotron waves in a multi-ion species plasma has already been reported previously [1]. Assuming that $\omega << \Omega_i$ the drift wave dispersion relation in a multi-ion species plasma can be written in the following form:

$$\omega = k_\theta V_D/(1 + k^2\lambda_{De}^2 + k^2\lambda_{De}^2 \sum_i \omega_{pi}^2/\Omega_i^2) \ , \qquad (3)$$

where k_θ is the azimuthal wave number, $V_D = c\,T_e/eBL$ is the drift velocity, $L = n/|\partial n/\partial r|$ is the plasma density gradient scale length, k is the perpendicular wave number, and λ_{De} is the electron Debye length. In our experiment the typical wave numbers are as follows: $k_\theta = 4.2\ cm^{-1}$ (which corresponds to the azimuthal mode number $m = 6$), $k \simeq 10.5\ cm^{-1}$ and $L \simeq 0.6$ cm.

In order to quantitatively assert the excitation mechanism for this decay, using the experimental parameters we calculated the threshold described by eq. (2) [4]. In fig. 2(a) we plot the theoretical threshold contours with solid and dotted curves for various pump electric fields (as labeled). The shaded region is a parametrically stable region which is predicted by the theory. The region bounded by the threshold contour is the region of expected decay activity for corresponding pump electric field. As shown by the figure, the experimentally observed decay region represented by the dots ($E = 8$ V/cm) agree quite well with that of the theory. Experimentally, we observe that this decay region shrinks as on decreases the RF electric field in accord with the theoretical prediction.

In fig. 2(b) the dots represent the experimentally measured values of the drift wave frequency as a function of the ion concentration ratio. The solid curve in the same figure shows the corresponding theoretically obtained drift wave frequency. Since there was some experimental uncertainty in the plasma parameters which were used in the theory, we shaded the region around the theoretical curve representing a region of uncertainty. From such a plot, we conclude that the observed drift wave frequency agrees reasonably well with the one predicted by the theory. In particular, the quantitative dependence of the drift wave frequency upon the ion concentration ratio shows good agreement with the theory.

In conclusion, we have observed parametric excitation of drift waves in a two-ion species plasma by an RF induction coil for $\omega_o/\Omega_{He} \simeq 1.3 - 1.6$, and for a wide range of concentration ratio. The dispersion relation of drift waves in a two-ion species plasma has been measured and shown to agree well with the theory. The parametric coupling mechanism of this decay has been verified by observing the threshold behavior in the magnetic field and the ion concentration ratio parameter space.

A detailed treatment of the present decay shall be reported elsewhere.

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FIGURE CAPTIONS

Fig. 1. (a) Parametric Decay Spectrum. (10 kHz/DiV, 1 kHz bandwidth, B_o = 3.7 kG, f_o = 2 MHz, He:Ne = 5.5:4.5). (b) Observed decay wave amplitude (for E = 8 V/cm) versus the ion concentration ratio indicated by the dots. The magnetic field strengths are as labeled.

Fig. 2. (a) Observed frequency of the excited drift wave versus the magnetic field strength (shown by the dots) for various ion concentration ratio, He:Ne. The theoretical threshold contours are shown by solid and dotted curves (the pump electric field as labeled). (b) Observed frequency of the excited drift wave as a function of the ion concentration ratio indicated by the dots. The solid line shows the corresponding theoretical drift wave frequency.

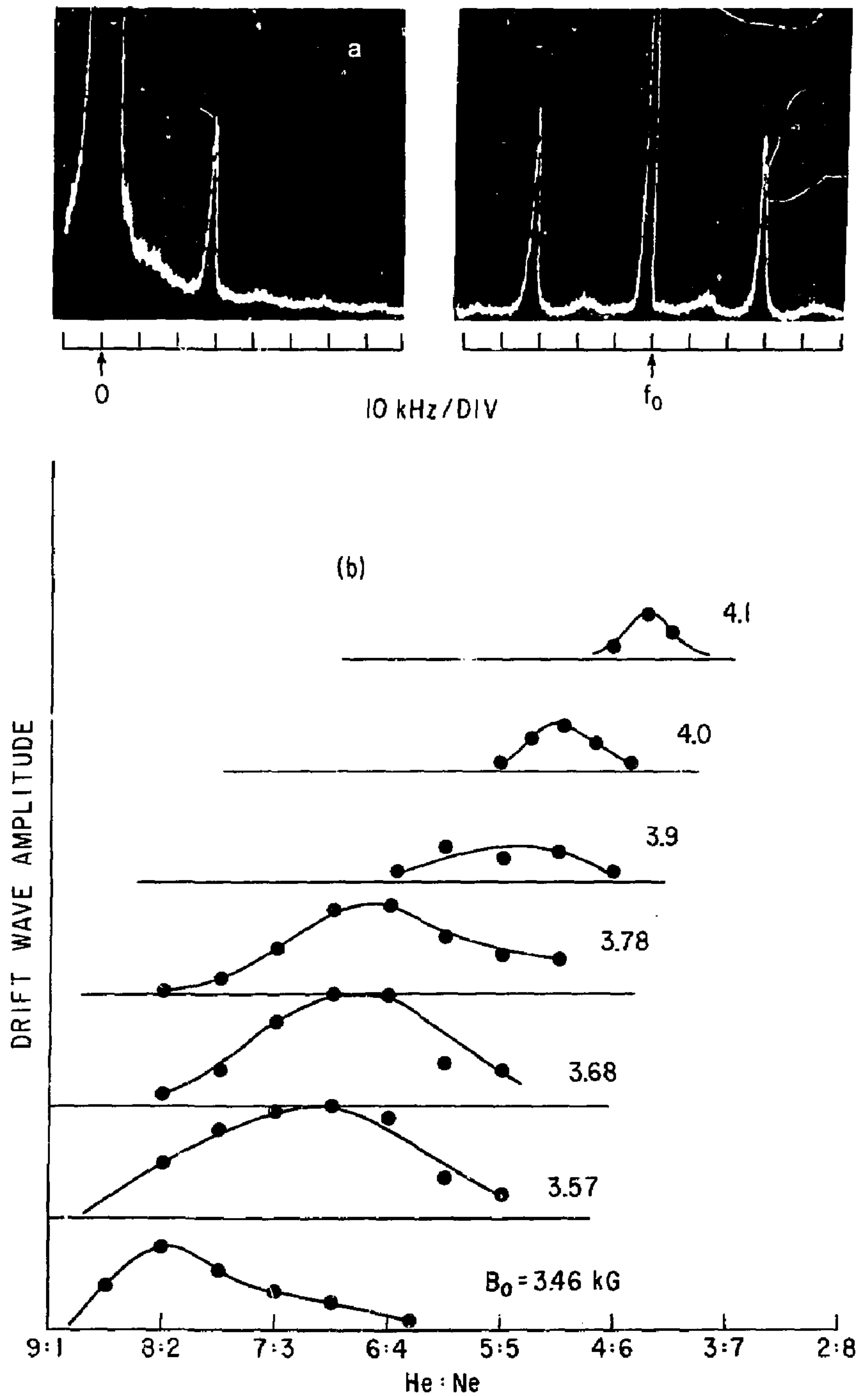
a
0
10 kHz/DIV
f_0
(b)
DRIFT WAVE AMPLITUDE
4.1
4.0
3.9
3.78
3.68
3.57
B_0=3.46 kG
9:1
8:2
7:3
6:4
5:5
4:6
3:7
2:8
He : Ne

Fig. 1. 783304

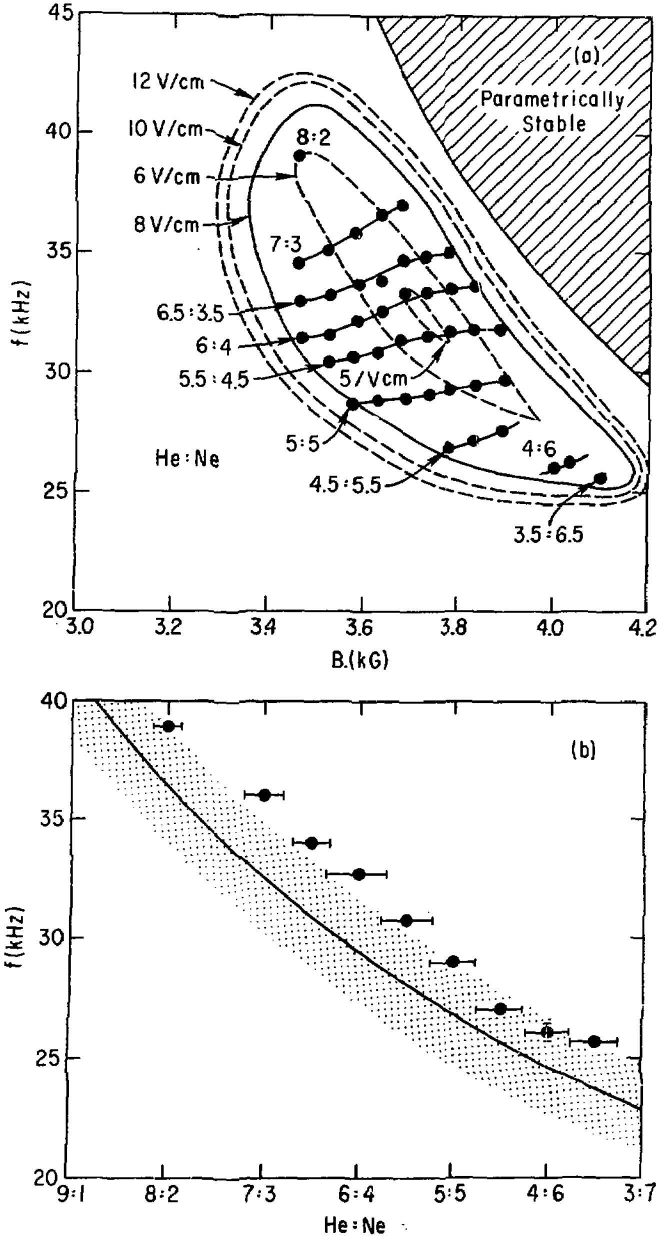
(a)
Parametrically Stable
12 V/cm
10 V/cm
6 V/cm
8 V/cm
8:2
7:3
6.5:3.5
6:4
5.5:4.5
5/Vcm
5:5
4.5:5.5
4:6
3.5:6.5
He:Ne
f(kHz)
B.(kG)
(b)
f(kHz)
He:Ne

Fig. 2. 783305