OBSERVATION OF A PARAMETRIC INSTABILITY NEAR
THE LOWER HYBRID FREQUENCY.*

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ABSTRACT

We have observed a parametric instability at frequencies close to and somewhat above the lower hybrid resonance frequency. The threshold for this decay occurs when the rf electron drift velocity is of the order of the ion sound speed.

The possibility of heating plasma at the lower hybrid resonance frequency has been recognized for a number of years.^{1,2} There are, in fact, experimental results which show electron and ion heating at this frequency.^{3,4} The mechanisms responsible for the plasma heating remain unclear, however.

In lower hybrid heating experiments the required radio frequency electric field intensity, E_{RF} , is such that the $E_{RF} \times B_0$ velocity of the electrons becomes comparable with or considerably greater than the plasma sound speed, V_S . Thus an instability involving the generation of ion-acoustic waves is a possibility. Recently Kindel, Okuda and Dawson⁵ have predicted theoretically and observed in computer simulations a decay instability that occurs near the lower hybrid resonance frequency. They observed that ion acoustic waves are generated in a direction parallel to the electron drift velocity, $E_{RF} \times B_0 / B_0^2$. They find the threshold for this decay to be given by

$$\frac{V_D}{V_S} = 4 \frac{\omega_p}{\omega_0} \left(\frac{\gamma_L \gamma_H}{\omega_L \omega_H} \right)^{1/2} \quad (1)$$

where V_D is the electron drift velocity, ω_p is the frequency of the pump wave, $\omega_{H,L}$ and $\gamma_{H,L}$ are the frequency and damping rates of the high and low frequency decay waves and ω_0 is the lower hybrid frequency.

At PPL we have studied the propagation of waves near the lower hybrid frequency. A schematic diagram of the experimental arrangement is shown in Fig. 1. Waves are coupled to the plasma with 70-cm long plates which are driven electrostatically by a balanced rf system. A doubly shielded rf probe travels in the radial direction and is

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used to detect the plasma oscillations. Not shown is a rotary probe capable of moving 360° in the $\hat{\theta}$ direction at a fixed radius. The magnetic field is typically 1000 gauss, the electron density is approximately 10^{10} cm^{-3} and the electron temperature is roughly ten times higher than the ion temperatures. The applied frequency is 15 MHz and the rf power is always less than 100 watts. Helium gas is used in the experiments at a pressure ranging up to about 10^{-3} torr. The plasma is generated by a helical Lisitano coil⁶ or, in some cases, by the wave generation plates only.

If the applied frequency is near but slightly higher than the maximum value of the lower hybrid frequency in the plasma, waves generated by the plates penetrate radially to the center of the plasma with relatively little attenuation, so that a standing wave pattern is generated in the radial direction.⁷ These modes constitute the pump wave in these experiments.

The generating plates create an $m = 1$ vacuum electric field, and the driven plasma oscillations are observed to have $m = 1$. Here m is the mode number in the $\hat{\theta}$ direction.

At a critical power level, typically around 1 W, a sudden widening of the frequency spectrum occurs on the low frequency side of the pump wave frequency [Fig.2]. Very low frequency oscillations appear simultaneously, and the observed selection rule is $\omega_p = \omega_L + \omega_H$.

Wavelength measurements of the decay modes show that these waves always propagate in the $\hat{\theta}$ direction, i.e., in the $\vec{E} \times \vec{B}_0$ direction, where $\vec{E}$ is the electric field of the pump wave. The phase velocity of the low frequency waves equals the plasma sound speed, while the high frequency decay mode appears to obey the same dispersion relation as the pump wave.

The peaks in the spectrum in Fig. 2 are found to correspond to integral values of the azimuthal mode number m , measurements of which can be made with the rotary probe. The low and high frequency decay waves always differ by unity, the azimuthal mode number of the pump wave. By driving both plates in Fig. 1 in phase instead of 180° out of phase, we are able to generate an $m = 0$ pump wave. In this case the m numbers of the decay waves are observed to be equal. Thus, we see that the angular momentum in this decay process is conserved. We observe that the selection rules for the angular momenta to be $m_H = m_p + m_L$ where the m 's are all positive integers.[Fig.3]

Even though these waves are basically electrostatic, they do produce currents with corresponding magnetic fields.

Therefore, if we can measure this magnetic field with a magnetic probe, along with the density, we have a direct

measure of the absolute value of the electron drift velocity.

We have constructed a doubly shielded magnetic probe which is carefully designed to discriminate against electrostatic signals. With this magnetic probe we find that the electron drift velocity at threshold power levels is typically somewhat less than the plasma sound speed. At low densities such that $\omega_p \gg \omega_{ip}$, however, we see that the threshold drift velocity is larger than the sound speed. In Fig. 4 we show the observed threshold velocity as a function of the neutral pressure. The solid curve is a plot of Eq. (1) wherein we assume that the high frequency waves are damped by electron-neutral collisions and the low frequency waves by electron-Landau damping parallel to B_0 .

At power levels an order of magnitude above the threshold level we find a considerable energy content in the decay modes. From measurements of the wave number, k , and the measure of the amplitude of the rf floating potential from the spectrum analyzer, we can compute the energy spectrum and estimate the energy in the high frequency daughters of the decay relative to the pump-wave energy. We find typically around 10% as much energy in the decay modes as in the pump mode. By careful adjustment of the plasma parameters, however, the integrated energy in the decay in some cases was observed to exceed that in the pump wave by a factor of 2.

Because of the relatively small threshold powers and large saturation amplitudes of the decay waves, we believe this decay instability must be considered in the dynamics of the wave damping and plasma heating processes at these frequencies.

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FIGURE CAPTIONS

- Fig. 1. Schematic of experimental setup. The electrostatic triaxial probe moves radially through a hole in the wave generating plate. Not shown is a rotary electrostatic probe which can move 360° in the direction and a magnetic radially moving probe diametrically opposite the electrostatic probe. The arrows indicate the electric field of the $m = 1$ pump waves.
- Fig. 2. Frequency spectrum of the pump wave and the decay waves. The m values are the azimuthal mode numbers measured with the rotary probe.
- Fig. 3. The sum of the signals from a fixed electrostatic probe used as a reference and the signal from the rotary probe as a function of the angular position of the rotary probe. The m values obtained from this technique agree with those obtained with the rf interferometer.
- Fig. 4. The observed rf drift velocity as a function of neutral pressure. The solid curve is a plot of Eq. (1) assuming the conditions described in the text. The sound speed for this condition is $\sim 2 \times 10^6$ cm/sec. The plasma density is the same for each pressure.

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