*Fifth European Conference on
Controlled Fusion & Plasma Physics,
Aug. 21-23, 1972, Grenoble, France*

GRENOBLE 1972

Observation of Non-Linear Effects Near the Lower

Hybrid Resonance Frequency

Conf-720804-13

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Abstract: Waves near the lower hybrid resonance frequency are electrostatically generated with plates just outside a cylindrical plasma column. These waves penetrate radially and, above a threshold power, are observed to undergo a parametric decay into two lower frequency waves.

Introduction: The potential importance of heating plasmas with radio frequency power near the lower hybrid resonance has been emphasized for many years. However, the exact nature of the heating mechanisms remains unclear. From linear theory it is known [1], [2], that near the lower hybrid resonance region the waves will convert into a very short wavelength electrostatic mode which can heat plasma, for example, through ion Landau damping.

We wish, however, to indicate in this paper that, at the powers used in heating experiments, non-linear processes will likely dominate the dynamics of the wave damping.

Since the wave frequency, ω , is much higher than the ion cyclotron frequency, ω_{ic} , and lower than the electron cyclotron frequency, ω_{ec} , the radial electric field of the wave, E_R , drives currents with a drift velocity of $\frac{E_R}{B_0} c$ in the $\hat{\theta}$ direction of a plasma cylinder. At power levels sufficient to heat a plasma this electron drift velocity becomes compara-

ble to the ion sound speed before one reaches the linear mode conversion point. Under these conditions the generation of a parametric or decay instability might be expected.

Kindel, Okuda and Dawson [3] have, in fact, discovered in theoretical calculations and observed in computer simulations a parametric decay process with a very low threshold which leads to ion and electron heating at frequencies near the lower hybrid resonance. They observe that the high frequency (pump) wave decays into an ion acoustic wave traveling parallel to the RF drift currents and another high frequency wave near the lower hybrid resonance frequency.

Experiment: The experimental arrangement for coupling to the plasma oscillations

is shown in Fig. 1.

The plates are driven by a balanced RF system. A doubly shielded probe travels in the radial direction

Fig. 1

and is used to detect the plasma waves. Not shown is another probe which is capable of moving 360° in the $\hat{\theta}$ direction of the plasma cylinder. Wavelengths are measured with an amplitude-insensitive RF interferometer. Electrostatic generation and detection, are used since these waves are essentially electrostatic. The magnetic field is typically 1000 gauss, and the peak electron density ranges up to 10^{11} cm^{-3} . The applied frequency is around 20 MHz, and the gas used is helium.

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We observe that the electric fields penetrate if $\frac{\lambda L}{\pi} \geq v_{the}$ where L is the plate length and v_{the} is the electron thermal velocity. If in addition, $\omega > \omega_{LH}$, the lower hybrid resonance frequency, the waves penetrate readily to the center of the plasma. However at $\omega \approx \omega_{LH}$ there is a resonance in the index of refraction and the waves damp rather sharply [4]. In the experiments reported below the applied frequency is close to, but slightly higher than, the maximum value of ω_{LH} in the plasma. We observe in the plasma, under these conditions, a partially damped wave penetrating to the center of the plasma. As is the case for the vacuum field of the plates, this mode is observed to be an $m = 1$ mode in the $\hat{\theta}$ direction. The largest component of k is in the radial direction, and the radial wavelengths are typically 1 to 2 cm in a 7-cm diameter plasma.

Above a very low threshold power (<1 watt) the pump wave decays into two lower frequency waves,

Fig. 2
and the frequency spectrum develops the characteristics shown in Fig. 2. The pump frequency ω_0 develops a sideband, ω_H , on the low frequency side and simultaneously low frequency waves, ω_L , appear. We find the selection rule $\omega_0 = \omega_H + \omega_L$ is always satisfied. The low frequency waves are observed to travel with very nearly the sound speed in the $\hat{\theta}$ direction at right

angles with respect to the pump radial electric field. The m numbers in Fig. 2 refer to the observed number of wavelengths in the $\hat{\theta}$ direction of the plasma cross section.

Wavelength measurements in the $\hat{\theta}$ direction show that angular momentum is conserved through the selection rule $k_H = k_O + k_L$. The threshold value for the drift velocity of the cross-field current is observed to be a small fraction of the ion sound speed, in agreement with the work of Kindel et al. [3], who show that the threshold drift velocity for the RF electron current is given by

$$V_D = \frac{4\omega_O}{k} \frac{1}{\omega_{pi}} \left(\frac{\gamma_L \gamma_H \omega_L}{\omega_H} \right)^{1/2}$$

where, k is the wavenumber of the decay waves, ω_{pi} the ion plasma frequency and $\gamma_{L,H}$ the damping rate of the low and high frequency decay waves.

The power in the high frequency daughter of the decay ranges up to a factor of two greater than that in the pump mode itself. This severe pump depletion indicates that this decay process plays a primary role in the damping of oscillations at these frequencies.

*Work supported by the U. S. Atomic Energy Commission under Contract No. AT(30-1)-1238.

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