Ion Acoustic Waves in an Electron Cyclotron Resonance Plasma*

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Ion acoustic waves have been generated in an electron cyclotron resonance plasma. The plasma was produced in a long microwave cavity at the heating frequency of 3.025 Gc/sec. When the resonance condition $\omega_p^2=2\omega(\omega-\omega_b)$ is approached, the plasma constricts, corresponding to present theory. The waves appeared when the magnetic field was increased slightly above the value necessary to achieve the resonance condition. The waves were observed by means of a photomultiplier, a Langmuir probe, and a shift in frequency of a higher order cavity mode. Harmonics of the waves up to and including the 4th have been seen.

STRONG ion acoustic waves[1] have been observed in an electron cyclotron resonance plasma.[2] They have been seen up to and including the 4th harmonic from the fundamental expression shown in Eq. (1).

$$N=(1/2L)(\gamma kT_e/m_i)^{1/2}, \quad (1)$$

where N is the frequency of the waves, γ is the ratio of the electron specific heats, L is the length of the discharge column T_e the electron temperature, and m_i the mass of the ions. This expression is valid if the Debye length can be neglected with respect to the wavelength of the oscillation.

The geometry of the electron cyclotron resonance apparatus is shown in Fig. 1. A QK-61 magnetron is used for the main excitation in a long cavity. The frequency of the magnetron could be aimed at either the TM_{011} or TE_{111} modes, but because of its length, there were undoubtedly other modes appearing. Breakdown occurred in the evacuated Pyrex tube under the magnetic field coils when the electron-cyclotron frequency determined by the current flowing in the field coils was equal to the rf heating frequency.

A 3.875 kMc/sec klystron was coupled into the main microwave line and the reflected power at this frequency was measured with a stub tuner to tune out the main rf power and a precision wavemeter detector combination. This system was used to determine the frequency shift of a higher order mode.

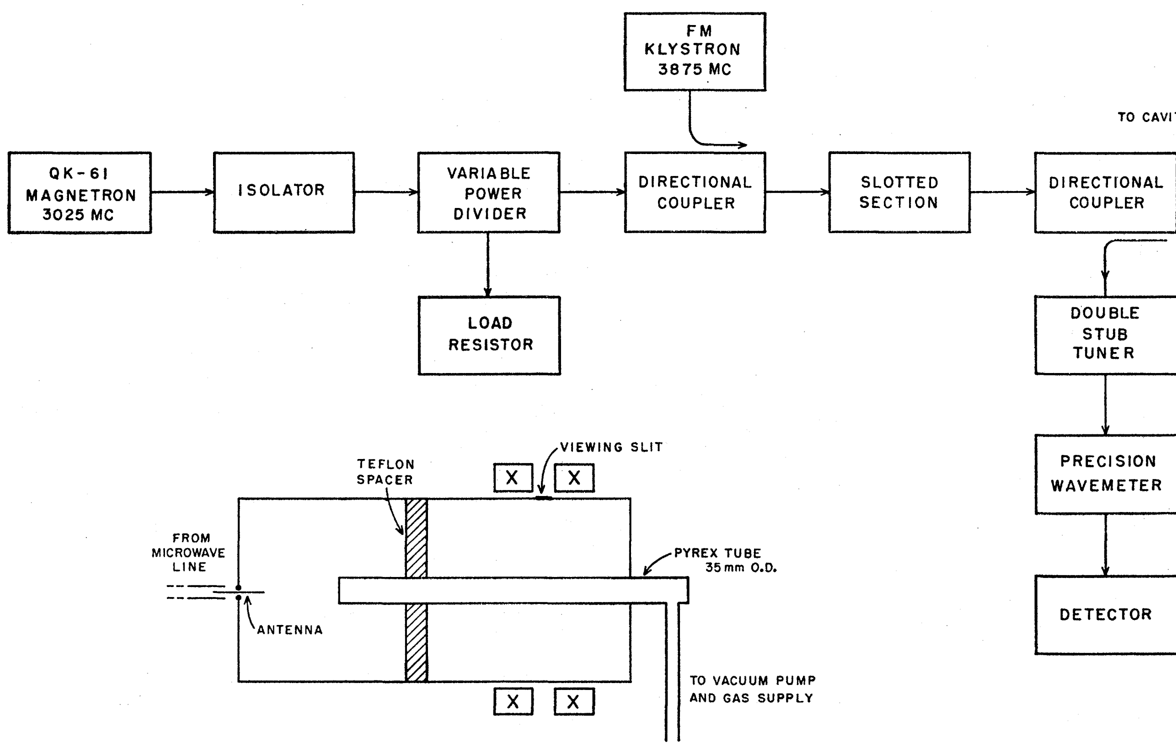

FIG. 1. Block diagram of experimental apparatus.

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[1] I. Alexeff and R. V. Neidigh, Phys. Rev. **129**, 516 (1963).
[2] J. L. Shohet, Bull. Am. Phys. Soc. **9**, 494 (1964).

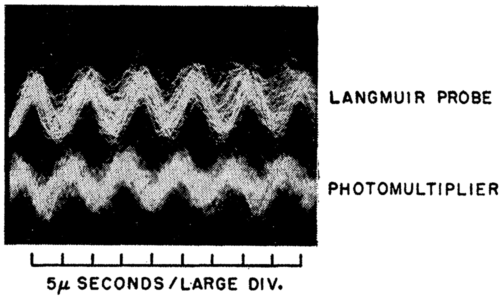


FIG. 2. Photomultiplier and Langmuir probe outputs for the 4th harmonic of helium. Pressure 5×10^{-4} Torr.

A Langmuir probe, not shown in Fig. 1, was mounted on the end of a copper rod and inserted axially down the plasma column from the right when looking at Fig. 1. The grounded face of the probe, from which a small glass beaded sensing element projected, was large enough to cover a fair percentage of the discharge cross section.

Ericson, Ward, Brown, and Buchsbaum[3] developed a theory for this type of plasma which showed that under certain conditions the plasma constructed into a long thin pencil. The condition for construction was found to be:

$$\omega_p^2 = 2\omega(\omega - \omega_b), \qquad (2)$$

where ω_p is the electron plasma frequency, ω is the applied frequency of rf, and ω_b is the electron cyclotron frequency. Note that the electron cyclotron frequency must be decreased to achieve this condition. If the magnetic field was then increased slightly, the plasma appeared to break into oscillation, as shown by the results in Fig. 2.

A photomultiplier was utilized to observe the discharge at the viewing slit along with the Langmuir probe. Note that there is a phase difference between the two signals which varied as the probe was moved to various positions down the discharge tube. The plasma could be made to oscillate up to and including the 4th harmonic of the fundamental frequency by either varying the magnetic field slightly or changing the position of the Langmuir probe.

Three gases were initially used. They were helium, nitrogen, and argon. The ambient pressure when the discharge was operating was about 10^{-4} Torr. The vacuum system had the capability of 10^{-7} Torr when not under gas flow conditions.

Electron-temperature measurements with the Langmuir probe agree fairly well with expected values for electron-cyclotron resonance plasmas.[2] They were 70 eV for helium, 30 eV for nitrogen, and 25 eV for argon. Assuming a 24-in. discharge length (the distance between far ends of the coils) the fundamental resonant frequency for helium was 33 kc/sec, for nitrogen 16 kc/sec, and for argon 8 kc/sec. All of these fundamental frequencies have been seen. No frequency below these fundamentals was ever observed. Figure 2 shows the 4th harmonic for helium, about 120 kc/sec. The probe voltage showed swings of up to 20 V in magnitude.

The third harmonic of nitrogen (about 50 kc/sec) was followed as the probe was moved in axially. The face of the probe holder was wide enough so that it caused the oscillations to have a node at its position. As the probe moved into the center of the field region, the wavelength should be shortened. This should be observed as an increase in frequency of the oscillation. Figure 3 shows a good linear relationship between the axial position of the probe and frequency.

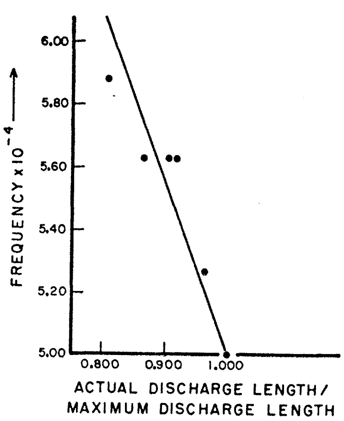


FIG. 3. Frequency shift versus axial position of probe for the 3rd harmonic of nitrogen. Pressure 5×10^{-4} Torr.

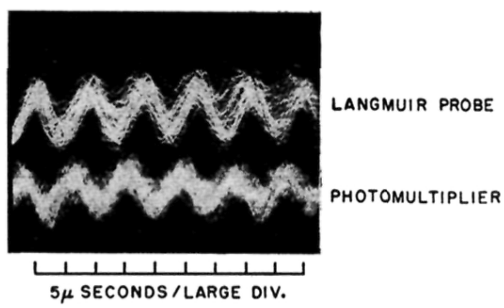
The shift in frequency of the higher order mode was observed to follow the same frequency variation of the oscillations themselves. The frequency of the oscillations was also independent of the rf power input, which was varied by utilization of the power divider shown in Fig. 1.

The Debye length which was obtained from probe electron density and temperature measurements[4] was determined to be less than 1 mm for all three gases. The measured probe densities were about 10^{10} particles/cm.[3]

The oscillations have shown good agreement with the defining Eq. (1).

[3] M. Ericson, C. S. Ward, S. C. Brown, and S. J. Buchsbaum, J. Appl. Phys. **33**, 2429 (1963).

[4] S. Glasstone and R. Lovberg, *Controlled Thermonuclear Reactions* (D. Van Nostrand Company, Inc., Princeton, New Jersey, 1960).



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