CLM - P 95

CLM - P 95

United Kingdom Atomic Energy Authority

RESEARCH GROUP

Preprint

# SCATTERING OF ELECTROMAGNETIC WAVES BY ELECTROACOUSTIC PLASMA WAVES

P. F. LITTLE
S. M. HAMBERGER

Culham Laboratory,
Culham, Abingdon, Berkshire
1965

UNCLASSIFIED
(Approved for Publication)

CLM - P 95

# SCATTERING OF ELECTROMAGNETIC WAVES BY ELECTROACOUSTIC PLASMA WAVES

by

P.F. LITTLE
S.M. HAMBERGER

(Submitted for publication in Nature)

## ABSTRACT

In this experiment a beam of 8 mm microwave is scattered by self-excited longitudinal oscillations in a plasma column. From the frequency shift and the angular dependence of the scattered radiation we deduce a dispersion plot for the plasma waves. This agrees with an independently measured dispersion plot obtained using two Langmuir probes to observe the density fluctuations directly.

U.K.A.E.A. Research Group,
Culham Laboratory,
Nr Abingdon,
Berks.

December, 1965

We report here some preliminary measurements of the scattering of an incident beam of microwaves by self-excited plasma waves in a mercury arc column; from these results we derive an experimental dispersion curve for the plasma waves which we compare with a dispersion curve measured directly with Langmuir probes in the column. In this manner we identify the waves responsible for the scattering as propagating electroacoustic waves, which are known to be present in the positive column of low density arcs. Both self-excited and externally-excited waves of this type have been observed[1,2]. Their phase velocity is approximately $c_s = (KT_e/M)^{1/2}$ where $KT_e$ is the electron thermal energy and M the ion mass: in our plasma $c_s \approx 10^5$ cm/sec.

Let us write for the incident electromagnetic wave the frequency and wave vector $\omega_1$ and $\underline{k}_1$; the fluctuations in plasma density may be represented by a spectrum of frequencies $\omega_s$ and wave vectors $\underline{k}_s$. Then as a result of non-linear interactions in the plasma the scattered microwave spectrum will be described by typical quantities $\omega_2$, $\underline{k}_2$ such that

$$\omega_1 \pm \omega_s = \omega_2 \tag{1}$$

$$\underline{k}_1 \pm \underline{k}_s = \underline{k}_2 \tag{2}$$

From (1) we may equate the frequency shift $|\omega_1 - \omega_2|$ on scattering to the scattering frequency $\omega_s$. From (2) we would expect the scattered wave observed at a particular angle to be due to a particular value of $\underline{k}_s$. More specifically, since we are interested in $k_{\parallel}$, the component of $\underline{k}_s$ along the column, equation (2) becomes (see Fig. 1)

$$k_1 \sin \varphi \pm k_2 \sin \theta = k_{\parallel}$$

or, since $k_1 \approx k_2 = 2\pi/\lambda_0$, where $\lambda_0$ = free space wavelength of the incident waves,

$$k_{\parallel} = \frac{2\pi}{\lambda_0} (\sin \varphi \pm \sin \theta) \tag{3}$$

In our experiment the plasma was the column of a 5 cm. diameter low pressure mercury arc, as previously described[1], which was operated at 9 amps discharge current and a pressure of 0.4mTorr. A beam of millimetre microwaves ($\lambda_0 = 8.65$ mm) at a power level of a few mW was used to illuminate a short section of the arc (Fig.1). The receiver could be oriented to observe the same section from different angles. A single klystron provided both the probing signal and the local oscillator drive to the balanced mixer, whose output therefore consisted of a signal at a frequency $|\omega_1 - \omega_2|$ i.e. at $\omega_s$, which could be observed directly with a low frequency spectrum analyser.

Fig.2 shows the spectrum analyser display of the amplitudes of the various frequency-shifted components of the scattered radiation at several different angles to the column, when illuminated at normal incidence ($\varphi = 0$). It is obvious from the sequence of spectra shown that there is a large signal around 52 kc/s which has a maximum intensity when the scattering angle $\theta$ is about $20^o$. To obtain a more accurate measure of the optimum scattering angles for a wide range of frequencies $\omega_s$ the mixer output was passed through a filter, rectified, and plotted on a chart recorder, while the angle $\theta$ was varied between $+30^o$ and $-50^o$ by rotating the receiver on a turn-table driven by a synchronous motor. Disregarding some spurious maxima associated with the optical system (which did not change with the selected frequency) a maximum or sometimes two maxima corresponding to the $\pm$ signs in equation 3 could be found for each frequency in the range 20 - 70 kc/s. Fig.3 shows the result obtained for a filter tuned to accept 50 kc/s. From values of $\theta$ corresponding to the maxima the values of $k_{\parallel}$ were calculated from equation (3). The results are shown as a dispersion plot in Fig.4 for normal incidence ($\varphi = 0$) and for $\varphi = 20^o$.

For comparison we also give in Fig.4 the measured values of $\omega_s$ and $k_{\parallel}$ for electro-acoustic waves excited in the same plasma by an external coil and detected by a Langmuir probe[3]. A third independent set of observations is obtained by applying the correlation technique used with photomultipliers in earlier work here[1] to the signals from two Langmuir probes, one fixed and one moving. This is an analysis of self-excited waves in the column, leading to the results shown.

Within the limits of experimental accuracy all the points lie on a common curve except those for microwaves incident at $\theta = 20^{\circ}$. For these the dispersion plot appears to be displaced by a small systematic error possibly due to refraction at the tube walls.

Using the theory of Woods[4] and the measured electron temperature $KT_e = 3.4 \pm 0.2$ eV we derive the theoretical dispersion curve for the (0,1) mode shown in Fig.4. It is in excellent agreement with observation at low frequencies, but at higher frequencies lies above the experimental values, as previously reported[3].

It should be noted that a small but finite value of $k_{\perp}$ is essential to satisfy equation (2) with this experimental arrangement unless $\varphi = \theta$. The finite size of the plasma alone makes $k_{\perp} \neq 0$, and in addition the wave fronts of the acoustic waves are curved[3]. A range of $k_{\perp}$ values, different for each frequency $\omega_s$, is needed to describe such waves. Hence values of $k_{\perp}$ to satisfy (2) can always be found.

These experiments depend on non-linear interaction between certain plasma waves and electromagnetic radiation leading to a frequency-shift on scattering. Other experiments demonstrating this effect have been reported[5]. However, our studies of the angular dependence of the scattered wave intensity provide information also about the wavelength spectrum in the plasma, thus enabling us to identify the scattering wave. This non-perturbing technique may find application in other plasmas.

Our thanks are due to Mr. H.G. Jones for valuable assistance with the experimental work.

# REFERENCES

1. LITTLE, P.F., and JONES, H.G. Proc. Phys. Soc. 85, 979 (1965)

2. CRAWFORD, F.W. Phys. Rev. Lett. 6, 663 (1961): ALEXEFF, I. and NEIDIGH, R.V. Phys. Rev. 129, 516 (1963).

3. WOODS, L.C., LITTLE, P.F., and JONES, H.G. Proc. 7th Int. Conf. Ionization Phenomena, Belgrade, 1965.

4. WOODS, L.C., J. Fluid Mech. 23, 315 (1965).

5. KERZAN, B., ABRAHAMSEN, K., and WEISSGLAS, P. App. Phys. Lett. 7, 155 (1965): ARANUSALAM, V. and BROWN, S.C. Phys. Rev. 140, A271 (1965): HAMBERGER, S.M., Plasma Physics (J.N.E. Part C) 7, 445 (1965).

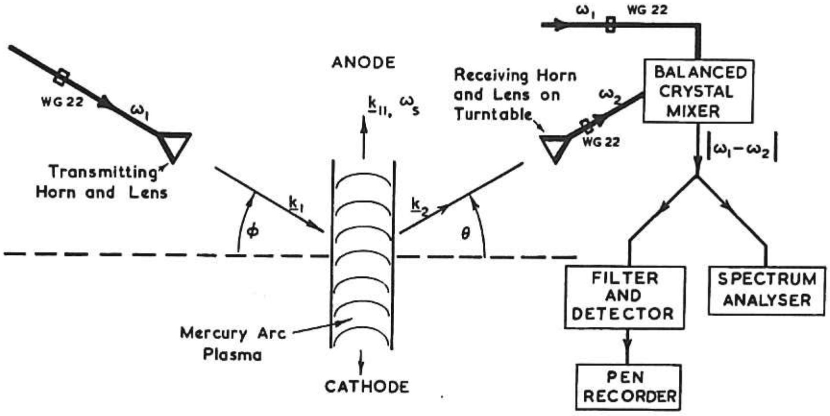

Fig. 1. Schematic arrangement of apparatus

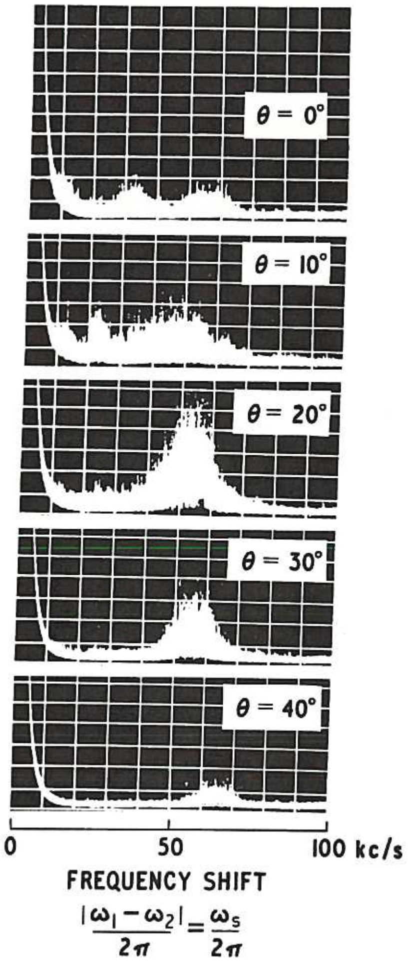

Fig. 2. Spectrum of scattered radiation.
Each photograph consists of 20 superimposed traces showing the scattered intensity as a function of frequency shift. The sequence shows how the received spectrum depends on the angle of observation $\theta$, for $\varphi = 0$.

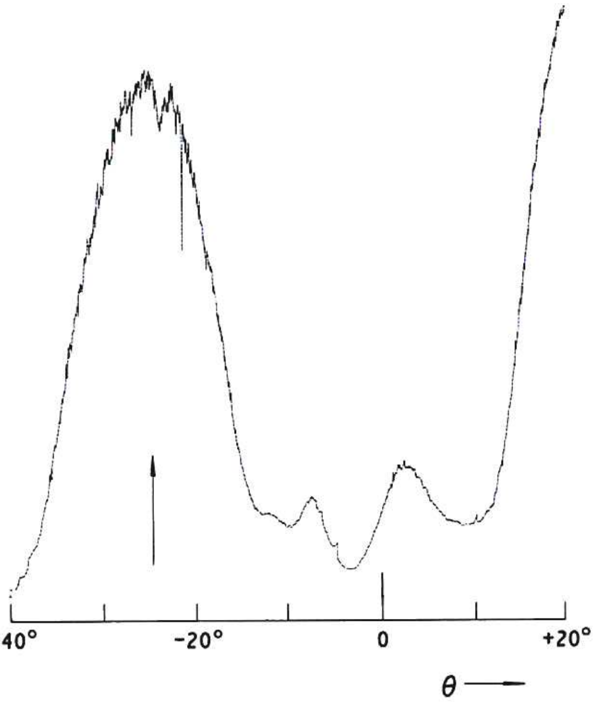

Fig.3. Pen recorder trace showing the variation of 50 Kc/s component of the mixer output with angle of observation $\theta$. The peak at $\theta = -24^0$ corresponds to a value of $k_{\parallel} = 2.9\ \mathrm{cm}^{-1}$. The structure at $\theta = 0^0$ appears at all frequencies and is attributed to geometrical effects.

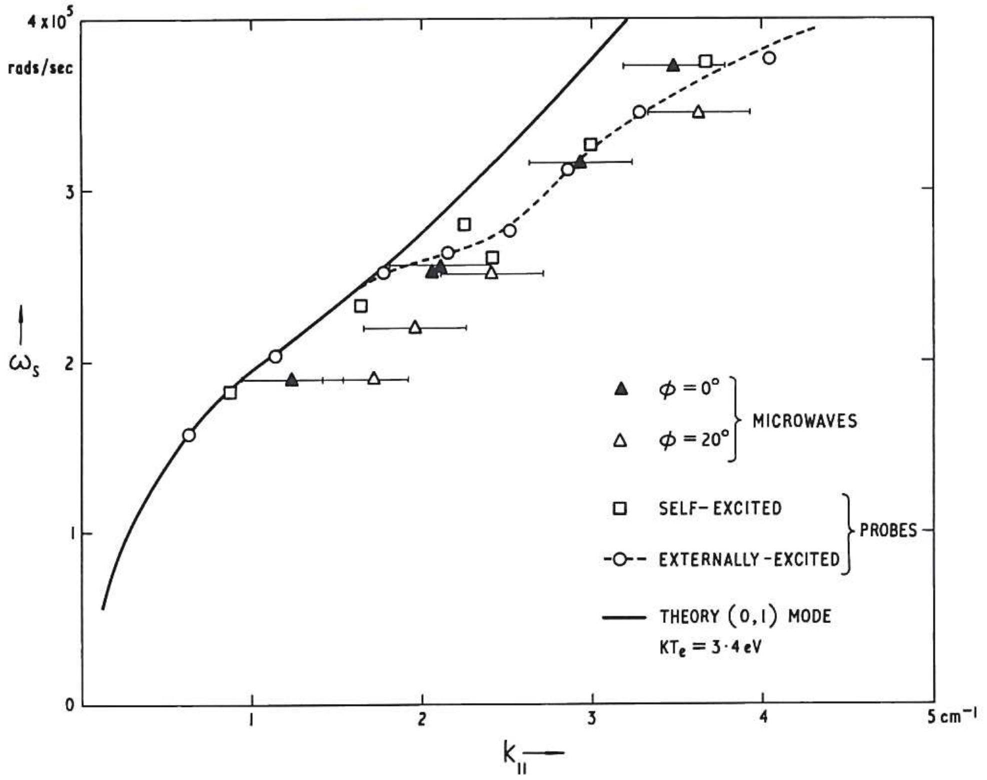

Fig.4. Dispersion plot for waves in mercury arc column.

▲ for self-excited waves using microwave scattering $\varphi = 0$

△ for self-excited waves using microwave scattering $\varphi = 20^0$

□ for self-excited waves using Langmuir probes

-○- for externally excited waves using Langmuir probes

— theoretical curve for (0,1) mode, KTe = 3.4 eV.