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## PROPAGATION AND DAMPING OF ION ACOUSTIC WAVES IN HIGHLY IONIZED PLASMAS


A. Y. Wong, N. D'Angelo, and R. W. Motley
Plasma Physics Laboratory, Princeton University, Princeton, New Jersey


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Several observations have been reported on ion acoustic waves in plasmas. In some of the experiments the oscillations occurred naturally in the generation of the plasma.[1] Recently, however, ion waves have been excited in weakly ionized plasmas by means of coils or grids.[2] We describe here experiments on the generation, propagation, and damping of ion waves in highly ionized cesium and potassium plasmas produced by surface ionization of atoms on a hot tungsten plate.

The plasma is confined by a longitudinal magnetic field (6000 gauss with potassium and 12 000 gauss with cesium) in a column 90 cm long and ~3 cm in diameter. At the second end of the plasma column there is another hot tungsten plate which confines the plasma longitudinally. Ion and electron temperatures are believed to be close to the temperature of the tungsten plates (2300°K). With ion densities in the range $5\times10^{10}$ cm$^{-3}$ to $10^{12}$ cm$^{-3}$, as measured by Langmuir probes, the percentage ionization is always above 30%. The diffusion of this plasma across the magnetic field has been shown to obey the classical laws and its properties are believed to be reasonably well understood.[3]

A tungsten grid 5 cm in diameter made of 0.001-in. diameter wire spaced 0.030 in. apart is immersed in the plasma column perpendicular to the axis, 40 cm from the tungsten plate where the plasma is produced. The grid is biased at -20 volts to draw ion current. A sinusoidal voltage is applied periodically to the grid for ~1 msec, to modulate the ion density. A similar grid, which can be moved longitudinally and is also biased at -20 volts, detects the waves excited by the first grid. A time delay in the reception of the signal, proportional to the distance between the grids, provides evidence that the pickup signal is not caused by current flow, but represents actual wave propagation. By moving the second grid along the axis of the column, we have measured both the phase velocity and the attenuation of the waves. In Fig. 1 the results of the phase measurements in cesium and potassium are shown. The phase velocities, $1.3\times10^5$ cm/sec in cesium and $2.5\times10^5$ cm/sec in potassium, are independent of frequency in the 10-100 kc/sec range, and of ion density between $6\times10^{10}$ cm$^{-3}$ and $5\times10^{11}$ cm$^{-3}$. Fried and Gould[4] predict a phase velocity for a collisionless plasma $v = K(\kappa T/m_i)^{1/2}$, where $T$ is the ion and electron temperature, $m_i$ the ion

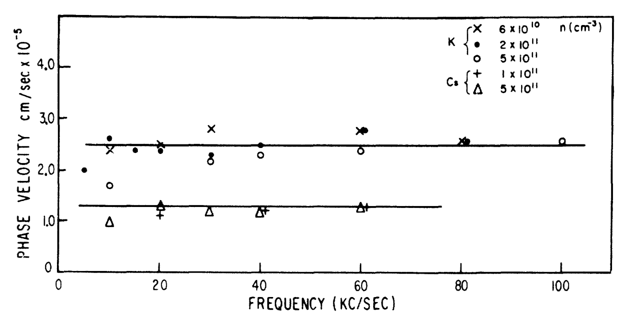


FIG. 1. Phase velocity of ion waves vs frequency, for cesium and potassium.

mass, and $K = 2.0$.

The measured phase velocities are 70% higher than the theoretical value, with no measurable dispersion, but the ratio of the velocities $v_K/v_{Cs} = 1.9$ is in good agreement with the theoretical value of 1.85. The reason for the high phase velocities is unknown, but may result from plasma temperatures higher than 2300°K or, possibly, from the finite size of the plasma column.

The results of the measurements of the damping distance $\delta$ are given in Fig. 2. We find the following:

(a) $1/\delta$ varies linearly with frequency, both in Cs and K. This means that the damping distance is a constant fraction of a wavelength (0.6 in cesium and 0.7 in potassium).

(b) $\delta$ is independent of plasma density between $n = 6\times10^{10}$ cm$^{-3}$ and $n = 5\times10^{11}$ cm$^{-3}$.

(c) $\delta_K/\delta_{Cs} = 2.2 \pm 0.3$, i.e., approximately in the ratio $(m_{Cs}/m_K)^{1/2}$.

The damping measurements would seem to exclude wave damping by either ion-electron, ion-ion, or ion-neutral collisions. Resistive damping would provide attenuation lengths $\delta$ orders of magnitude larger than the observed ones. As for the damping from ion-ion collisions, one would expect $\delta$ to depend on the plasma density, and exhibit quite a different dependence on frequency than the measured one.[5] Damping by collisions of ions with neutrals seems to be excluded also on the basis of the attenuation measurements and by the additional fact that in no case was the percentage ionization of the plasma below 30%.

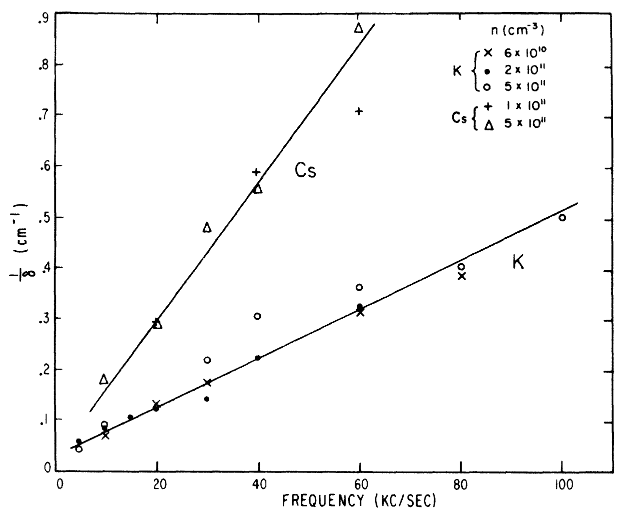


FIG. 2. $1/\delta$ vs frequency, for cesium and potassium; $\delta$ = damping distance.

It is somewhat surprising that, as for the case of excitation of electrostatic waves near the ion cyclotron frequency,[6] in the present experiment also collisions do not seem to play a major role. In the case of cesium, for instance, at a density $n = 10^{11}$ cm$^{-3}$, one would expect a frequency of ion-ion collisions of about $2\times10^4$ sec$^{-1}$, which is comparable with the applied frequencies.

On the other hand, Fried and Gould predict from the collisionless Boltzmann equation that in plasmas of equal ion and electron temperatures the amplitude of ion waves should decay by $1/e$ by Landau damping in 0.4 wavelength, in fairly good agreement with our results. They also would predict independence of $\delta$ on plasma density and $\delta_K/\delta_{Cs} = (m_{Cs}/m_K)^{1/2}$. Our results, therefore, appear as experimental evidence for collisionless damping of ion waves.

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