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April 1966 R-6

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This work was supported by the
National Aeronautics and Space Administration
under grant NGR 05-007066

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In this paper we wish to report preliminary results of the interaction between a low energy cesium ion beam (1 to 30 ev) and a thermal cesium plasma (0.25 ev). In particular we are attempting to determine the stability limits for ion acoustic waves due to the interaction between the beam and the plasma. Such stability limits have been predicted theoretically in a paper by Fried and Wong.[1]

EXPERIMENTAL SETUP.

A schematic of the system used is shown in figure 1. The ion gun is essentially the same one developed by Sellen et al.[2,3] The ions are formed on the surface of a porous tungsten plug which is fed by a beam of Cs atoms from an oven behind the plug. The Cs ions are then accelerated by the accelerating grid and then decelerated to the plasma potential. The energy of the ions is just the difference between the applied voltage on the tungsten source and the plasma potential. This ion gun is inserted into one end of a Q-machine.[4] The other end contains a tungsten plate and a Cs oven by which we can produce a thermal Cs plasma. In addition, when the tungsten plate is heated to its normal operating temperature of about 2,300°C, the plate serves as the source of neutralizing electrons for both the background plasma and the ion beam. In this manner we are able to study the beam-plasma interaction.

BEAM AND PLASMA CHARACTERISTICS

The density profile of the beam measured on a Langmuir probe showed a beam width of approximately 2.5 cm which is the width of the tungsten plug. This occurred for magnetic fields of 1000 gauss and above. In addition, for fields of this order very little spreading of the beam was noted over the length of the machine. All this indicated very good confinement of the beam. The beam was operating in the emission limited regime meaning that J, the current density, was constant for different beam energies. This meant that the beam density decreased as we increased the beam velocity. The maximum beam density we could achieve was 10^{10} particles per cc. The background plasma density ranged from 10^{9}/cc to 10^{11}/cc. The former density was due to beam ions which were neutralized and reemitted by the tungsten plate which was being used as the source of neutralizing electrons. The Cs oven was turned off and shielded from the plate when we ran the beam by itself, so this was the minimum background density we could achieve under these circumstances.

AXIMUTHIAL OSCILLATIONS

When running the ion beam by itself under the conditions just described, we found that for certain values of source voltage (beam energy) and tungsten plate power (electron temperature), large noise signals of about 20% of the total probe signal appeared at the steepest part of the density profile. These conditions are shown in figure 2. Generally, we found that an inverse relationship between plate power and beam energy existed in order to achieve instability. Upon further examination these noise signals were found to correspond to oscillations in the beam. These oscillations were found to propagate in the aximuthial direction and in the direction of the electron density gradient drift. We observed both the fundamental and first harmonic of this wave. The frequency range for the fundamental mode varied from 4.5kc to 6.5kc over a range of magnetic field of 1750 gauss to 4200 gauss. For the first harmonic the variation was from 9kc to 13.5kc over the same range in magnetic field. This variation is shown in figure 3. Phase measurements of these two modes were made by probes placed at right angles to each other with each probe positioned 1.2 cm from the center of the beam along the probe's respective radius. This was the position of maximum amplitude of the wave and of steepest gradient of the density profile. These measurements showed the fundamental to have a wavelength corresponding to an m=1 mode and the first harmonic a wavelength corresponding to the m=2 mode.

In order to compare our experimentally observed values of frequency with theory, we used the expression derived by several authors for the frequency of drift waves of $\omega = k_\perp \frac{kT_e}{eB} \frac{1}{n} \frac{dn}{dx}$.[5] In this expression $K_\perp$ is the wave number perpendicular to B and is about $1 cm^{-1}$ for the m=1 mode. T_e is the electron temperature and is about 2500°K. $\frac{1}{n} \frac{dn}{dx}$ is the density gradient divided by the density and is approximated by $\frac{1}{1.2} cm^{-1}$. From these we calculate a frequency of about 3kc for B-2500 gauss. This is lower than the observed value but this is probably due to our inaccuracy in obtaining a correct value for $\frac{1}{n} \frac{dn}{dx}$. We further note that ω varies as $\frac{1}{B}$ in the above expression. The curves in figure 3 do not show a strict $^1/_B$ variation with ω but this discrepancy is probably due to the increase in $\frac{dn}{dx}$ as B is increased.

We found no radial phase shift for this wave. The longitudinal phase shift was difficult to measure since a small shift in the lognitudinal probes angular position caused a large phase shift to appear. However, we were able to see that the longitudinal wave length was at least 100cm.

In addition to this wave a second oscillation was observed propagating in the azimuthial direction with about the same frequency as the drift wave. This latter wave reached its maximum amplitude at about 2.0 cm from the center of the beam. This corresponded to a position at the edges of the density profile. We have not yet made a detailed investigation of this wave but it appears to correspond to the magneto-ionic sound wave discovered by the Stanford group.[6]

LONGITUDINAL MODE

As mentioned previously when certain combinations of beam energy and tungsten plate power were met, the beam became noise free and no azimuthial oscillations appeared. Using these conditions we were able to study the longitudinal or m-0 mode. These waves were produced in the beam by modulating the accelerating grid with a tone burst generator, as shown in figure 1, at various frequencies. The frequencies we used ranged from 30°kc to 100kc. Our procedure here was to vary the beam energy from 0 to 10ev for a constant beam-plasma density ratio and look for growing oscillations by observing the amplitude of the wave as a function of distance over a distance of from 2 to 22cm from the source. We then swept various values of the density ratio and repeated the experiment at each value of $n = n_b/n_p$. In this way, we hoped to plot a stability limit curve of density ratio vs. beam velocity in order to compare with the theory.[1]

Our density ratios ranged from n= $\frac{1}{10}$ to n = 2. We observed for low values of n(n~$\frac{1}{10}$) that the wave continually damped out as we moved along the beam axis away from the source. This is seen in figure 4. As we increased the density ratio (n~$^{1}/3$) we noted that the oscillations still damped initially but for some beam energies, as we moved further from the source, a rise in amplitude followed by further damping appeared. This is seen in figures 5 and 6.

In analyzing these results, we noted that the phase velocity of the wave in the beam frame was about 0.9 x 10^5cm/sec. To the background plasma in the lab frame this wave was travelling at about 2.5 x 10^5cm/sec for a lev beam. The thermal spread of the plasma ions was about 0.25ev so this wave velocity was well out in the tail of the velocity distribution of the plasma ions. This would preclude any interaction between the wave and the plasma. In addition, the parallel ion temperature of a lev ion beam about 40°K and therefore the thermal spread in the parallel direction for the beam is about $\frac{1}{300}$ ev which corresponds to 4 x 10^2 cm/sec. Thus the wave velocity in the beam frame is also well out in the tail of the beam ion velocity distribution and we have no interaction between the wave and beam. Thus for this situation we can not make any comparisons to the theory presented by Fried and Wong.[1] In order to do this it appears necessary to excite the wave in the background plasma and not on the beam ions. We are presently investigating this possibility.

Figure Captions

1. Schematic diagram of ion beam gun and Q-machine with test equipment.

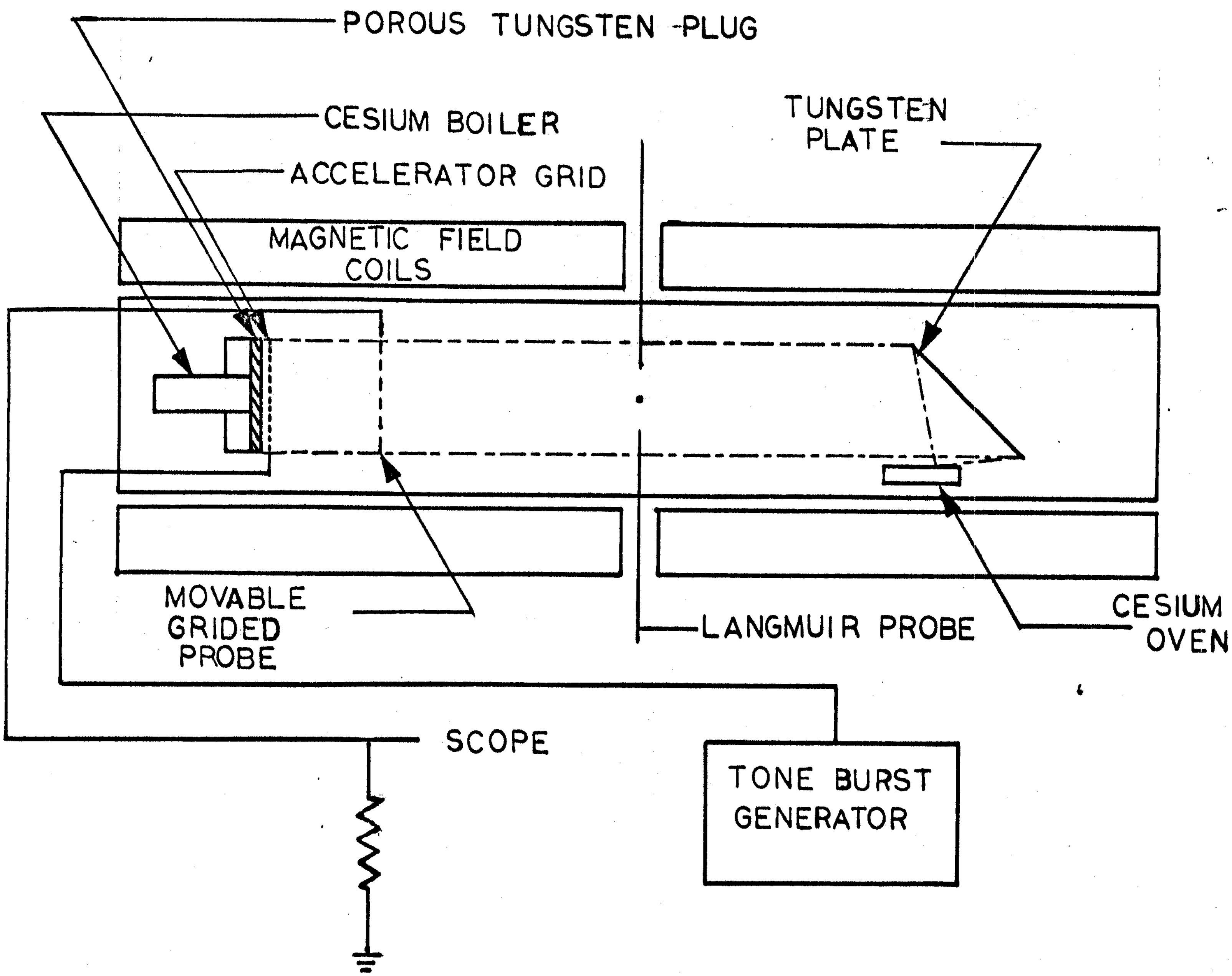
2. Stability curves for azimuthial drift waves.

3. Variation of frequency of azimuthial drift waves with magnetic field. The bottom curve is the fundamental while the top curve is the first harmonic.

4. Longitudinal ion wave amplitude vs. axial distance for various beam energies for the case of low beam to plasma density ratio.

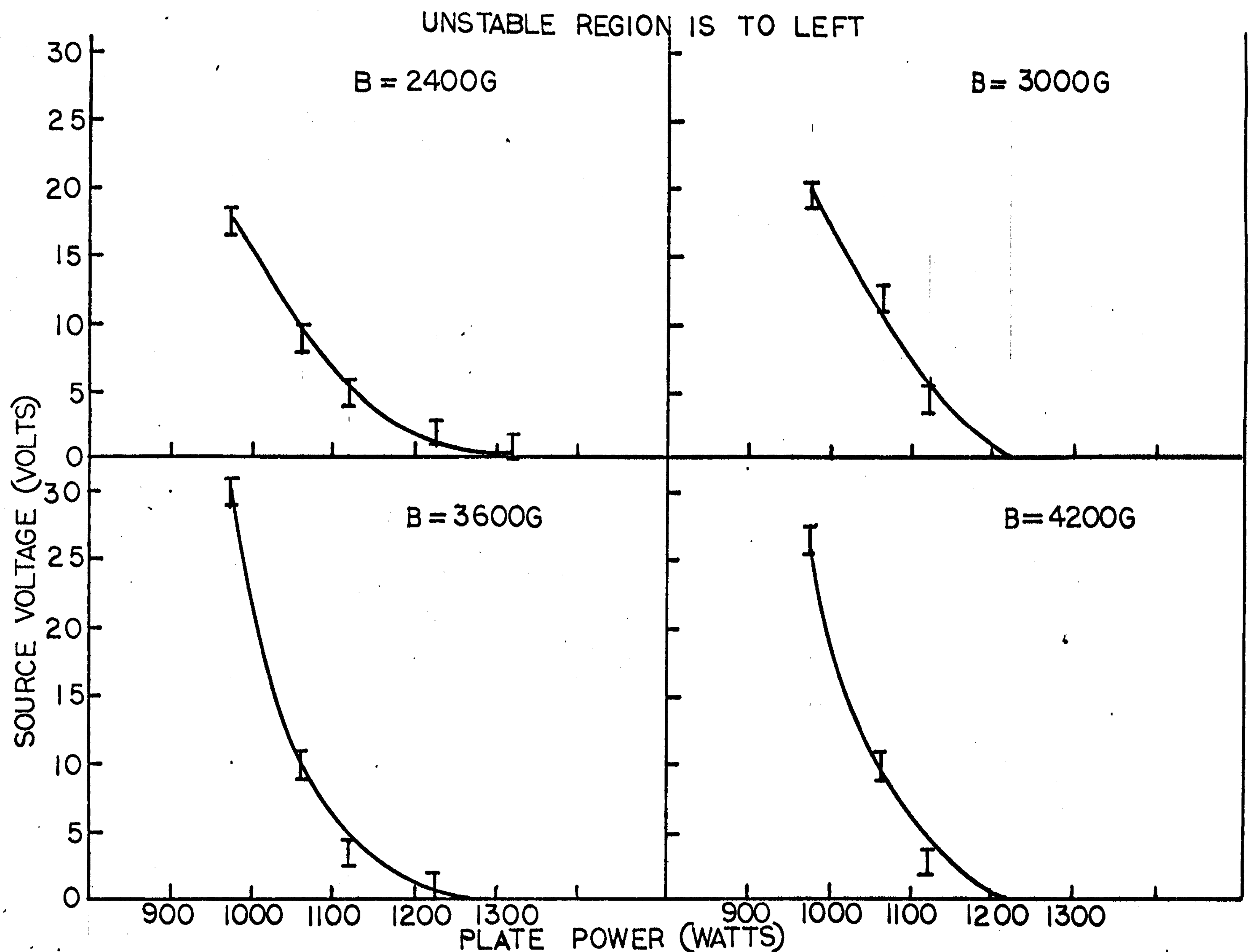
5. Longitudinal ion wave amplitude vs. axial distance for various beam energies for the case of high beam to plasma density ratio.

6. Scope traces showing the amplitude of the wave as the pickup probe is moved axially away from the ion beam source.



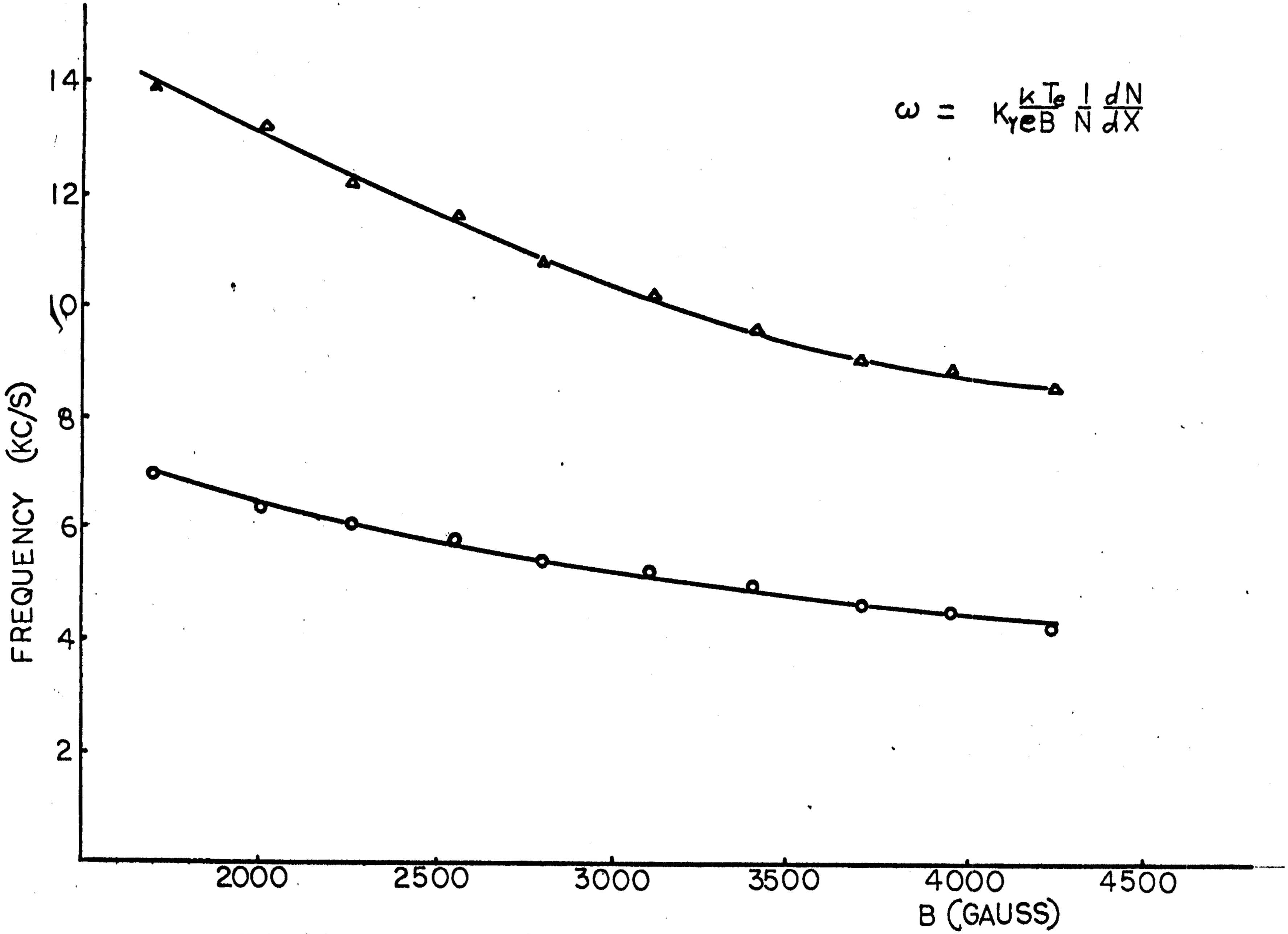
SCHEMATIC DIAGRAM OF APPARATUS

FIG 1



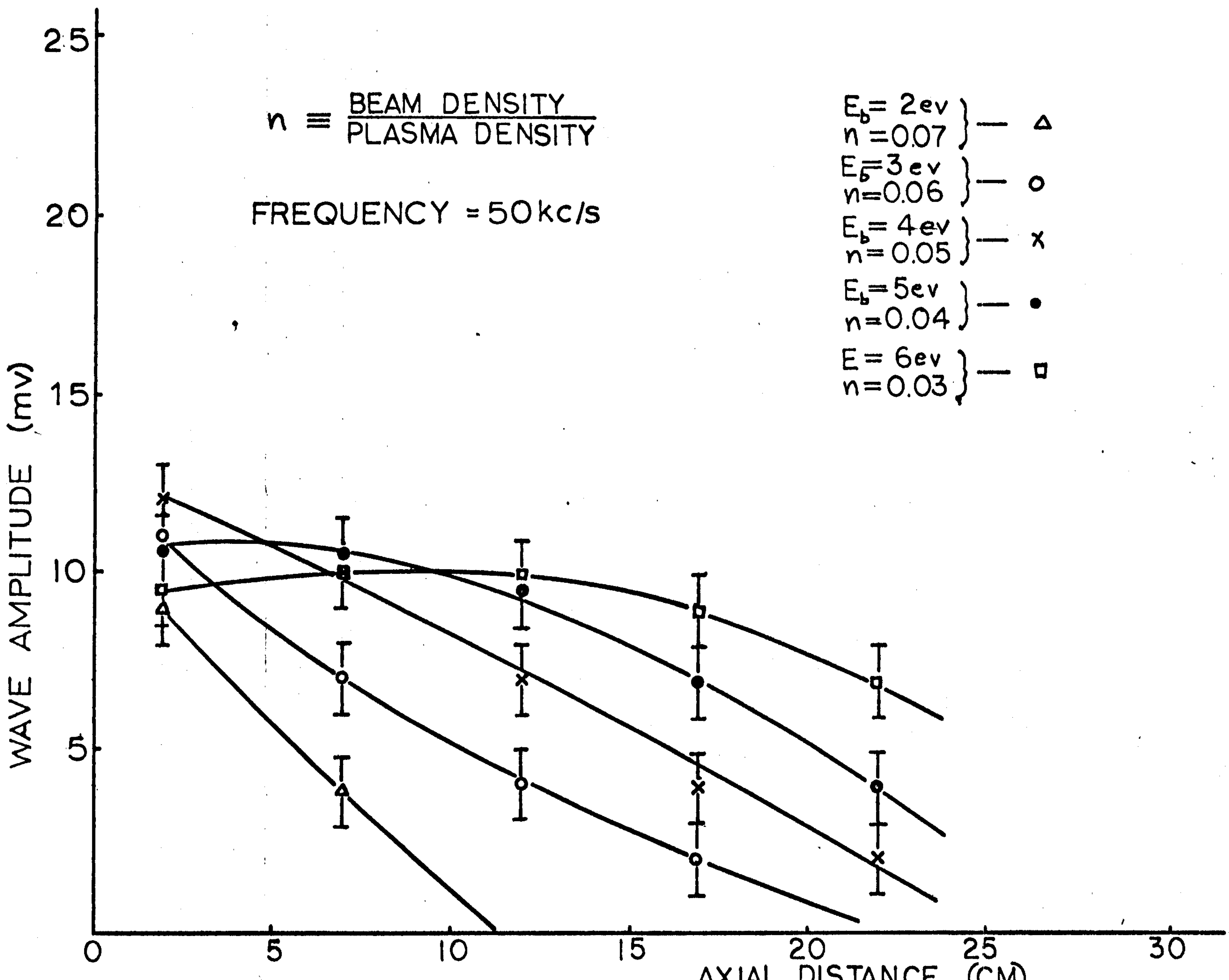
STABILITY CURVES

FIG 2



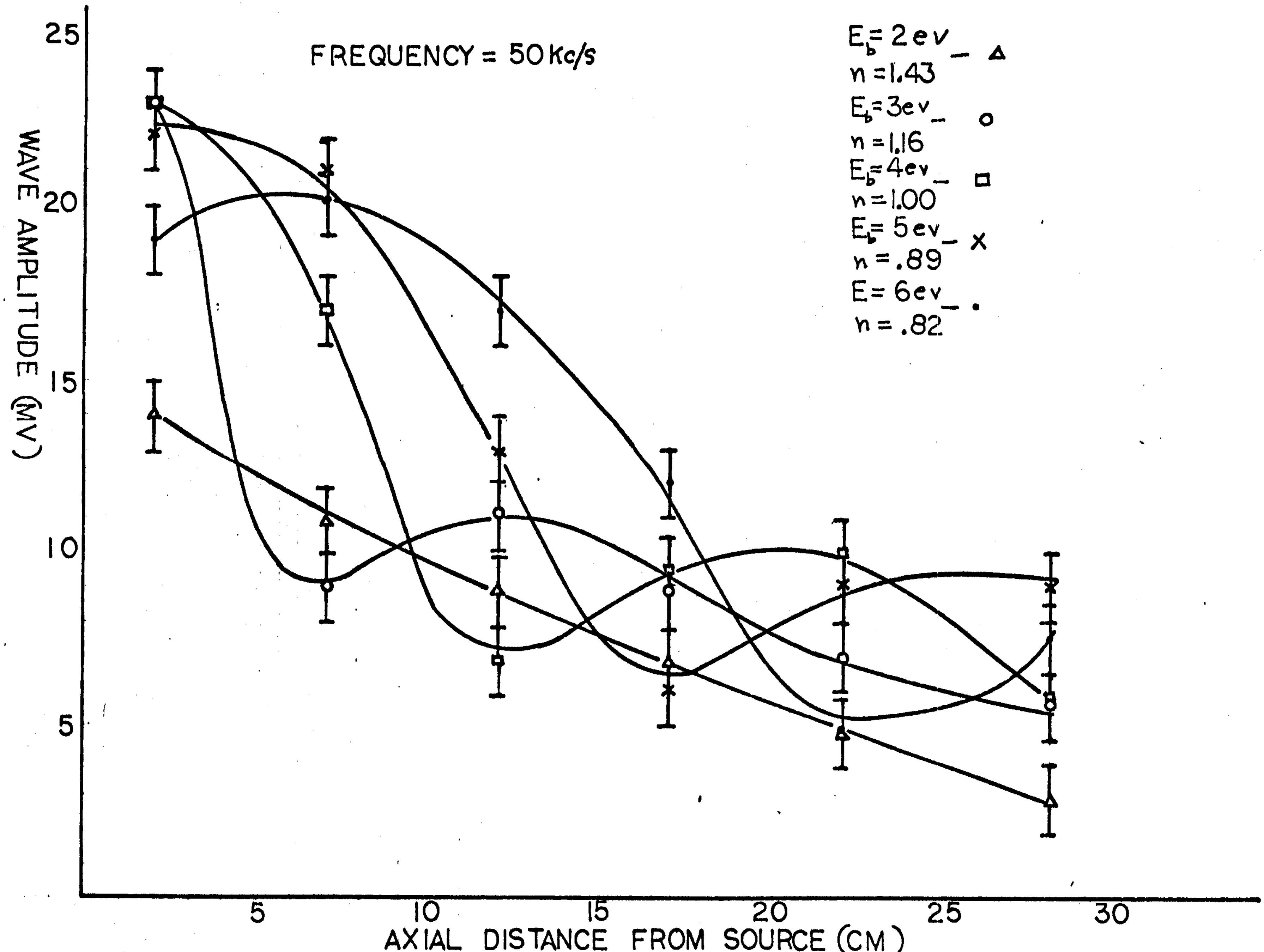
FREQUENCY VS. MAGNETIC FIELD

FIG. 3



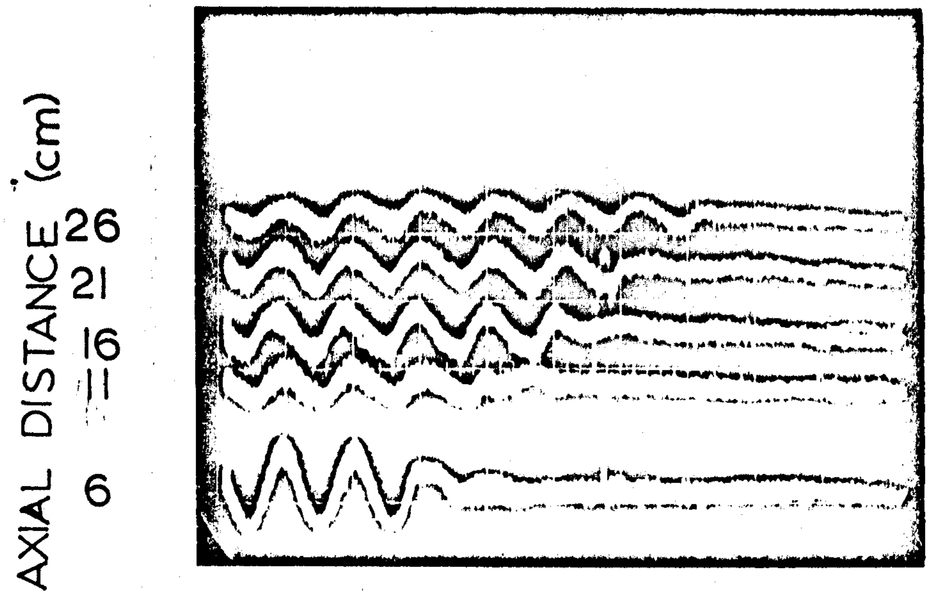
LONGITUDINAL ION WAVE AMPLITUDE – LOW n

FIG 4



LONGITUDINAL ION WAVE AMPLITUDE – HIGH $N_B/N_P = n$

FIG. 5



WAVE AMPLITUDE VS.
AXIAL DISTANCE
E = 3ev f = 50kc n = 1.2

FIG 6

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