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EFFECT OF COULOMB COLLISIONS, LANDAU DAMPING AND PARTICLE TRAPPING ON LINEAR AND NONLINEAR ION ACOUSTIC WAVES

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We have performed a series of experiments to study the damping effect of the ion acoustic waves. The experimental results have been analyzed both qualitatively and quantitatively based on the theory by Basu and Jasperse[1]. The analysis shows that the theoretical and experimental results agree very well under certain conditions.

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1. INTRODUCTION

Our project is to investigate experimentally the effect of Landau damping and particle collisions on the ion acoustic waves. For the collisionless current-free plasma, linear Vlasov theory predicts that ion acoustic waves are Landau damped and plasma is stable. For the weakly collisional plasma, a recent theory[1] indicates that electron-ion collisions have an undamping effect on the ion acoustic waves. If this undamping effect exceeds other damping effects, the plasma will be unstable. We have performed a series of experiments to study the damping effect of the ion acoustic waves. The experimental results are also explained qualitatively and quantitatively based on the reference [1].

2. PROGRESS SUMMARY

A series of experiments have been performed during last fiscal year. The experimental results have been analyzed both qualitatively and quantitatively based on the theory by *Basu and Jasperse*[1]. The analysis shows that the theoretical and experimental results agree very well under certain conditions.

3. PROGRESS REPORT

3.1. Experimental Setup

The experiments were performed in a double plasma chamber as shown in Figure 1. The plasma was produced by impact ionization from hot filament cathodes at the top and bottom ends. The plasma potential, the electron temperature and density were measured with a movable Langmuir probe and the ion temperature was measured with a grided energy analyzer. A program has been written to extract the plasma parameters from the I-V curve of Langmuir probe automatically. Figure 2 shows a set of measured I-V curves and also the extracted plasma parameter values. Usually we measured one I-V curve for every 5cm and totally four curves (at x=5cm, 10cm, 15cm, and 20cm). The typical plasma parameters used in the experiment are as follows: electron temperature T_e=1~2eV, ion temperature T_i≈0.1~0.2T_e, electron density $n_e=10^8\sim10^{10}cm^{-3}$, total argon gas pressure p≈10^{-4} Torr, and base pressure p_b≈10^{-6} Torr.

Waves were launched externally with a signal grid (30cm in diameter, 34cm away from the bottom end) and were detected by the movable Langmuir probe. An example of the measured waves is shown in Figure 3. Notice that for each frequency we took two sets of data.

3.2. Theory and Experiment on the Ion Acoustic Waves

For the collisional plasma, *Basu and Jasperse*[1] gave the following approximate formulas for the ion acoustic waves:

$$k_r\lambda_e = \frac{\omega}{\omega_{pi}}\left(1+\frac{3}{\theta}\right)^{-1/2} \quad (1a)$$

$$(k_i\lambda_e)^{Landau} = \frac{\omega}{\omega_{pi}}F(\theta) \quad (1b)$$

$$(k_i\lambda_e)^{ei} = -\frac{1}{4}\frac{\nu_{ei}}{\omega_{pi}}\left(1+\frac{3}{\theta}\right)^{-1} \quad (1c)$$

$$(k_i\lambda_e)^{in} = \frac{1}{2}\frac{\nu_{in}}{\omega_{pi}}\left(1+\frac{3}{\theta}\right)^{-2} \quad (1d)$$

where

$$F(\theta) = \left(1+\frac{3}{\theta}\right)^{-1}\left(\frac{\pi}{8}\right)^{1/2}\left[\left(\frac{m_e}{m_i}\right)^{1/2} + \theta^{3/2}\exp\left(-\frac{\theta}{2}-\frac{3}{2}\right)\right], \quad \theta = \frac{T_e}{T_i},$$

ν_{ei} and ν_{in} are electron-ion and ion-neutral collision frequency, ω_{pi} is the plasma frequency of ion, λ_e is the Debye length of electron, and perturbations are taken as $e^{i(kx-\omega t)}$. The wave number and the Landau damping can also be approximated from the collisionless kinetic equation which is given as:

$$\varepsilon(\omega,k) = 1 - \frac{1}{2k^2\lambda_e^2} Z'(\frac{\omega}{ka_e}) - \frac{1}{2k^2\lambda_i^2} Z'(\frac{\omega}{ka_i}) = 0 \qquad (2)$$

where λ_i a_e, a_i and Z' denote the Debye length of ions, the thermal velocities of electron and ion, and the derivative of the plasma dispersion function respectively. In Figure 4, both results are shown. The solid line in the figure is calculated from Formula (1a) and (1b) and the dashed line is calculated from Equation (2). It is obvious that the formulas give good approximate values when T_i/T_e is small, but there are large differences between the approximate formula and the solutions from the kinetic equation when T_i/T_e is large. Since we usually have $T_i/T_e \geq 0.1$ in our experiments, Equation (2) was used to calculate the wave number and the Landau damping rate.

For the wave data shown in Figure 3, Figure 5 shows the results of wave number and damping rate obtained from the curve fitting. From the theory we know that the wave number and the damping rate are approximately a linear function of the frequency. By line fitting the data in Figure 5 we derive the wave parameters, which are shown in Table 1. Note that when the frequency is less than 70kHz the experimental damping rate does not follow the theoretical prediction. Two reasons may contribute to this disagreement: we note that this occurs when the wave frequencies are near or less than the electron-ion collision frequency which is about 61kHz and the wavelength is near the size of our chamber. We can see that the theoretical and experimental values are very close to each other. The parameters we used are: $n_n \approx 4.62\times10^{12}$ cm^{-3}, $n_o \approx 1.27\times10^9$ cm^{-3}, $T_e \approx 0.84$ eV, and $T_i \approx 0.16$ eV.

We also measured the ion acoustic waves in different plasma densities. Figure 6 show the results of wave numbers and damping rates in three different density cases. From Figure 6a, we find that the wave speeds for three density cases are quite close. From Figure 6b, we find that the damping rate decreases as the density increases just as the theory predicts. However, in the high density region, we find that the damping rate becomes flat versus frequencies.

4. PROPOSED RESEARCH

In the future, we propose to study the effect of Landau damping and particle collisions in detail. Experimentally, we will measure the ion acoustic waves in a variety of different situations including different neutral pressures and plasma densities.

REFERENCES

[1]. B. Basu and J. R. Jasperse, Marginal stability of ion-acoustic waves in a weakly collisional two-temperature plasma without a current, *Phys. Rev.*, 38, 3785, 1988.

Table 1. Experimental and theoretical wave parameters

	experiment	theory
wave velocity (km/s)	1.86	1.90
Landau damping rate (cm^{-1})	0.0025×f(kHz)	0.0024×f(kHZ)
collisional damping rate (cm^{-1})	–0.0735	i-n: 0.002; e-i: –0.068 total: –0.066

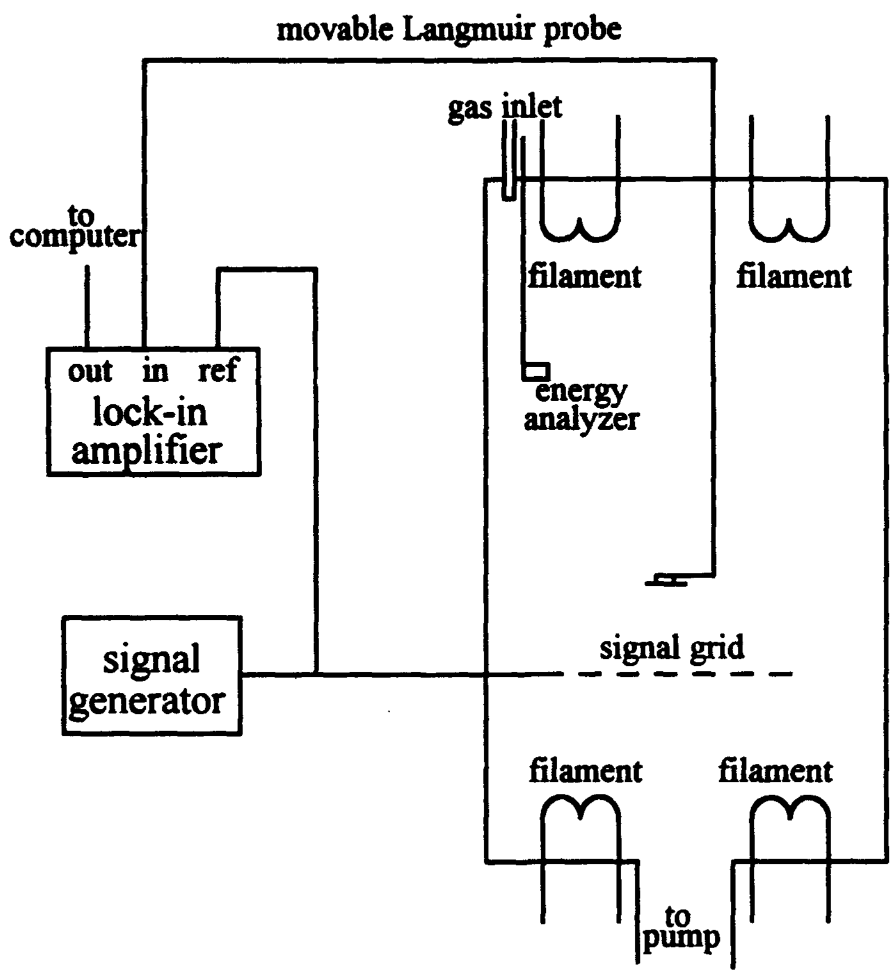


Figure 1. Schematic of the plasma chamber for measuring ion acoustic waves.

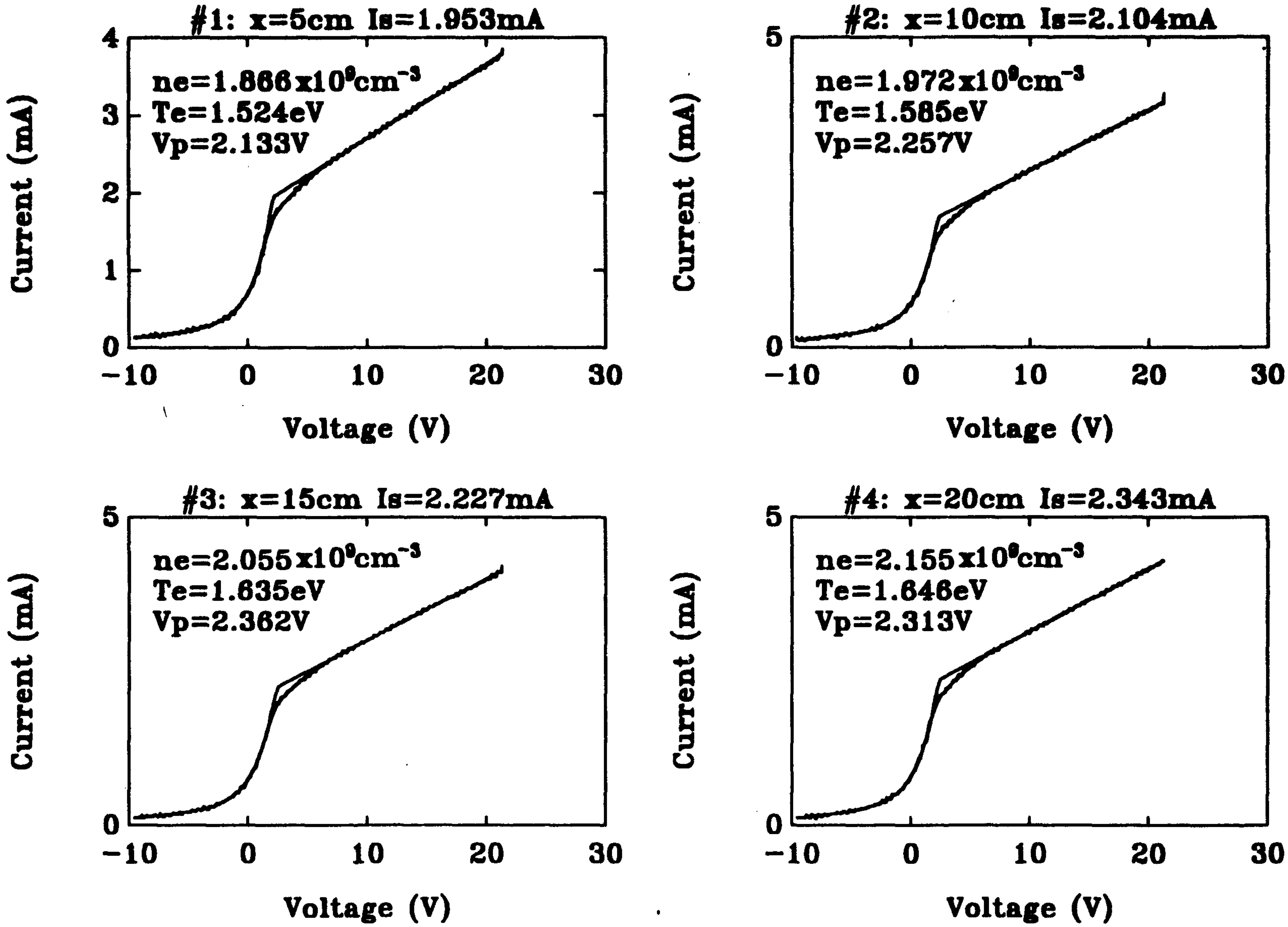


Figure 2. The I-V curve taken from Langmuir probe

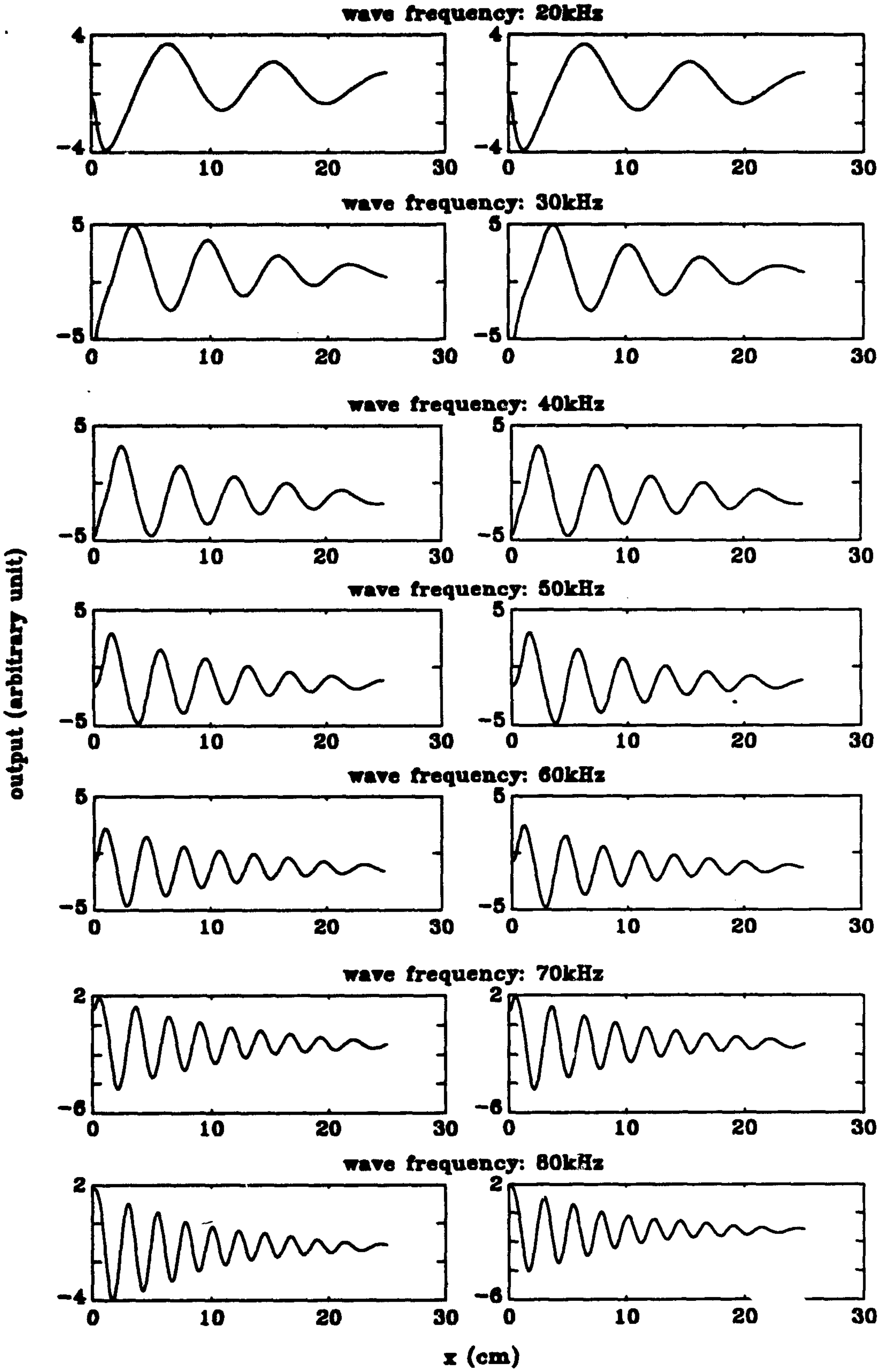


Figure 3. The waves measured in different frequencies

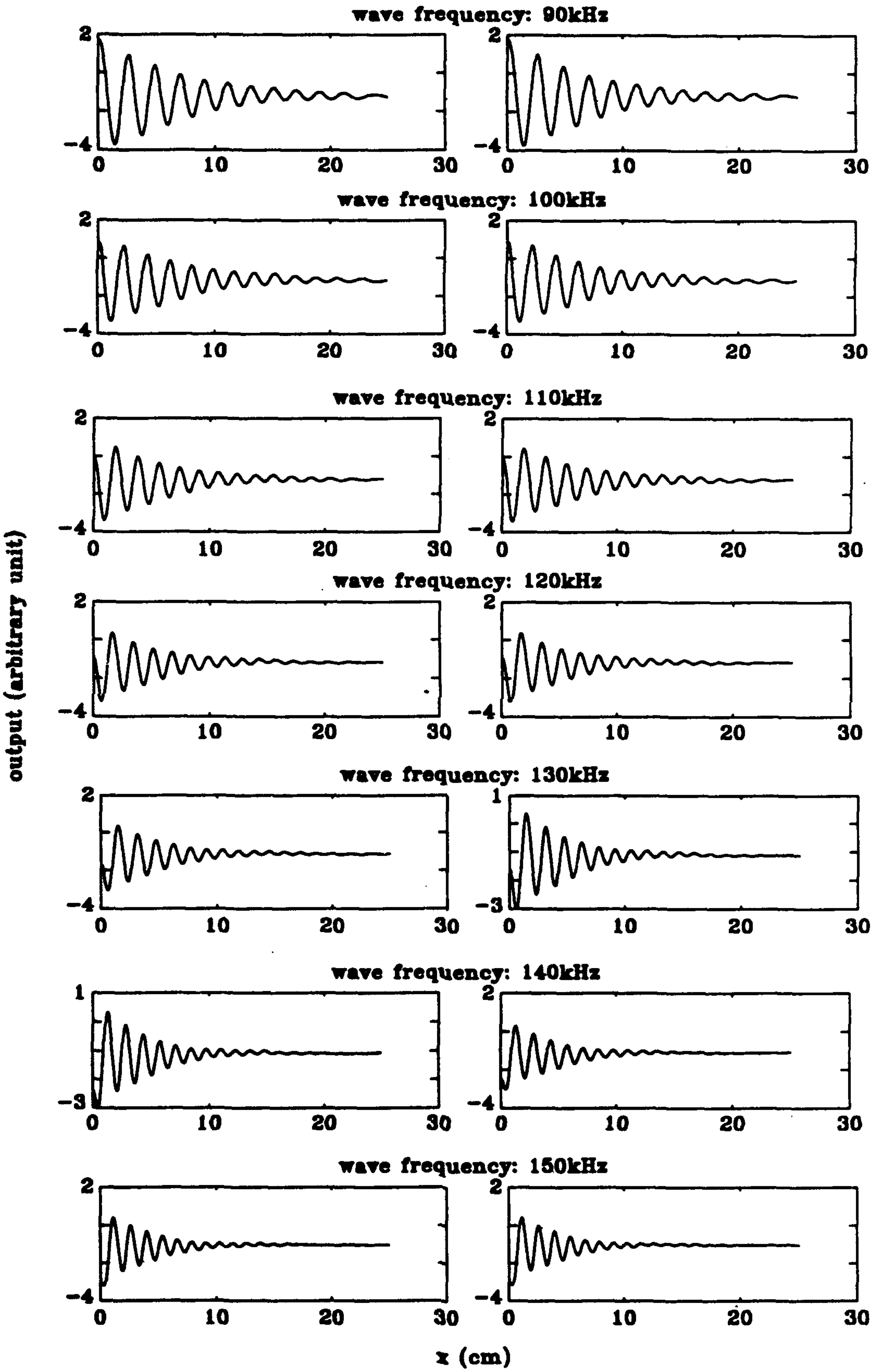


Figure 3. (cont.)

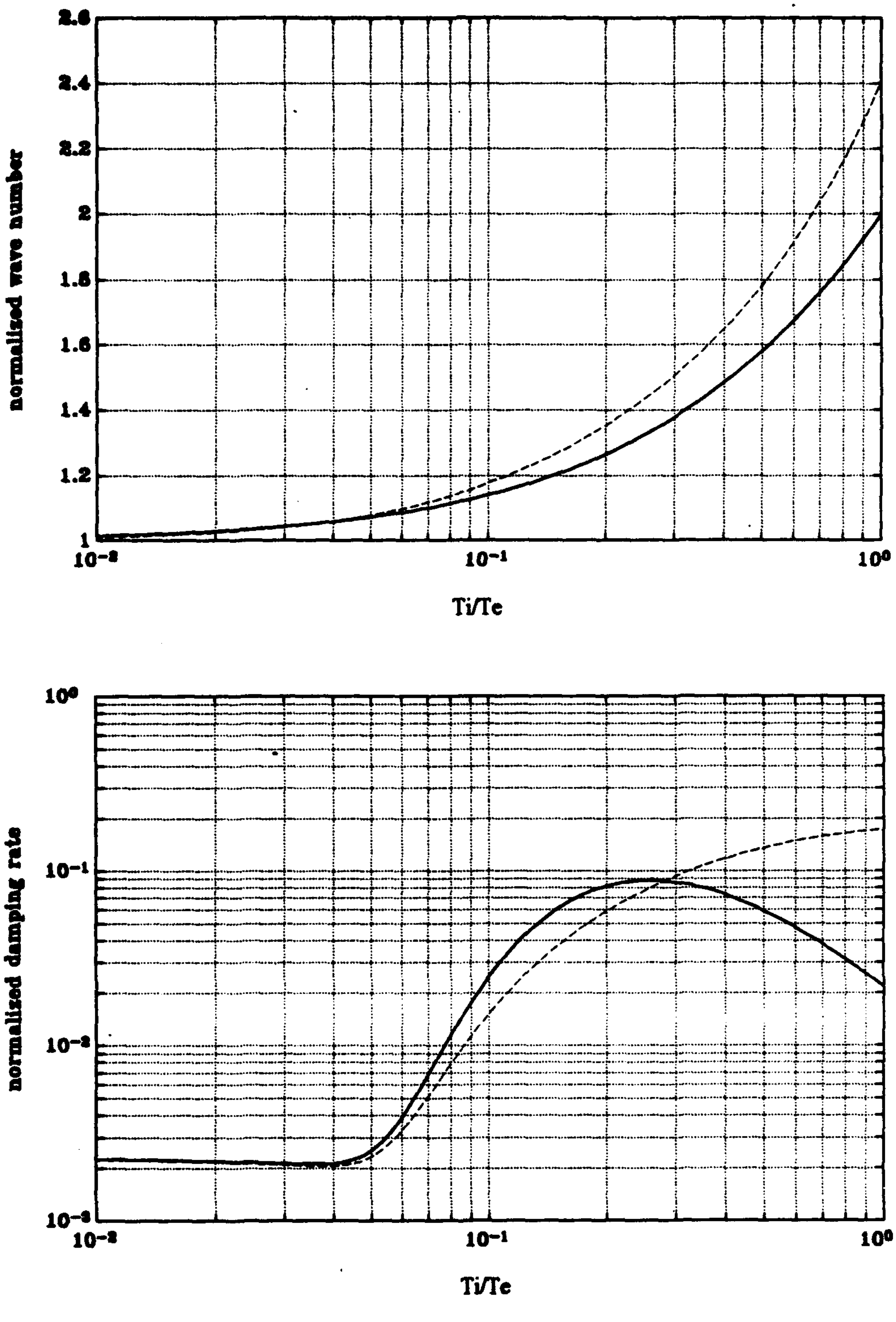


Figure 4. Normalized wave number and damping rate versus ratio of ion to electron temperatures. The solid lines are from Equation (1a) and (1b) and the dashed lines are from Equation (2) (ω/ω_{pi}=0.1).

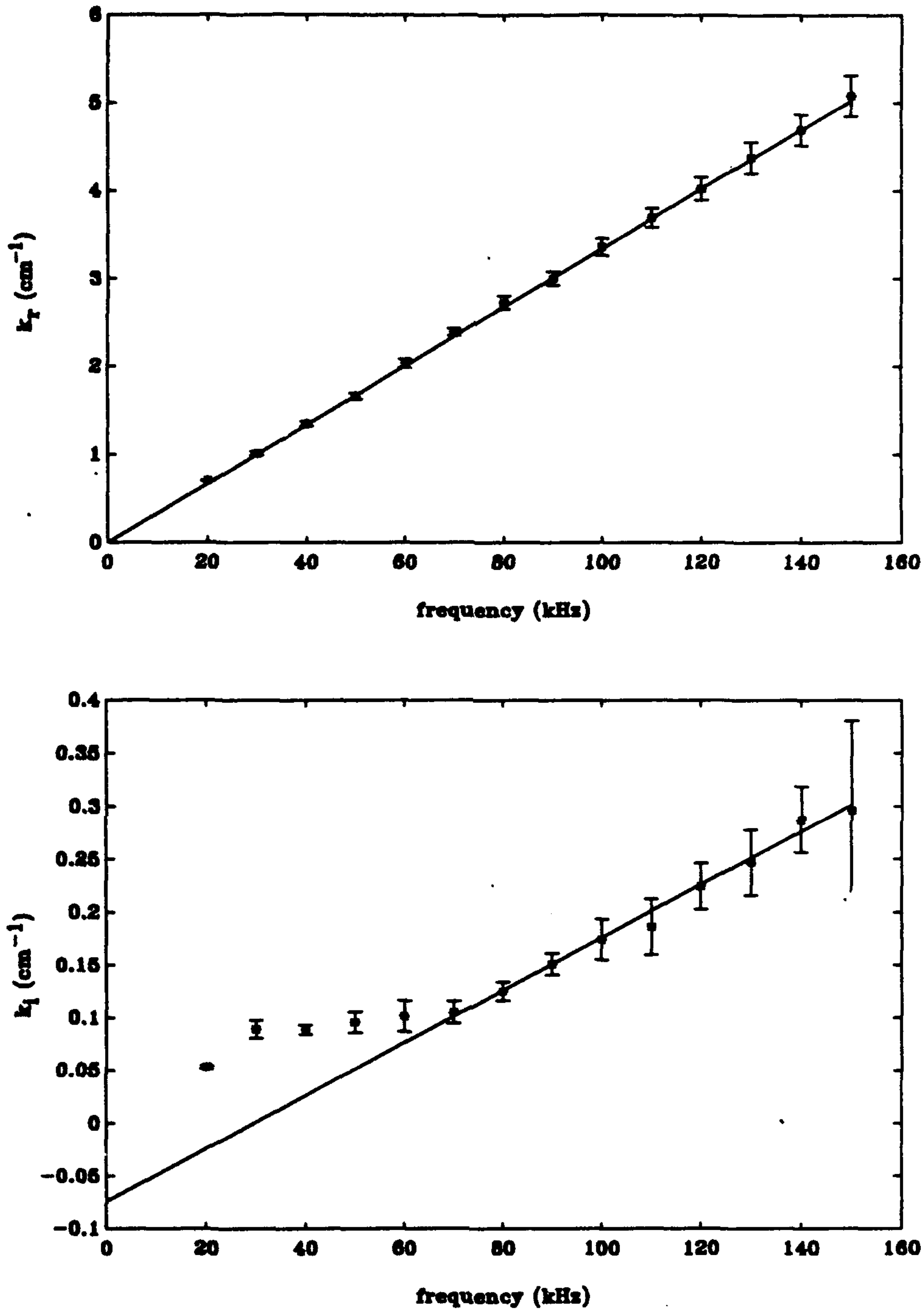
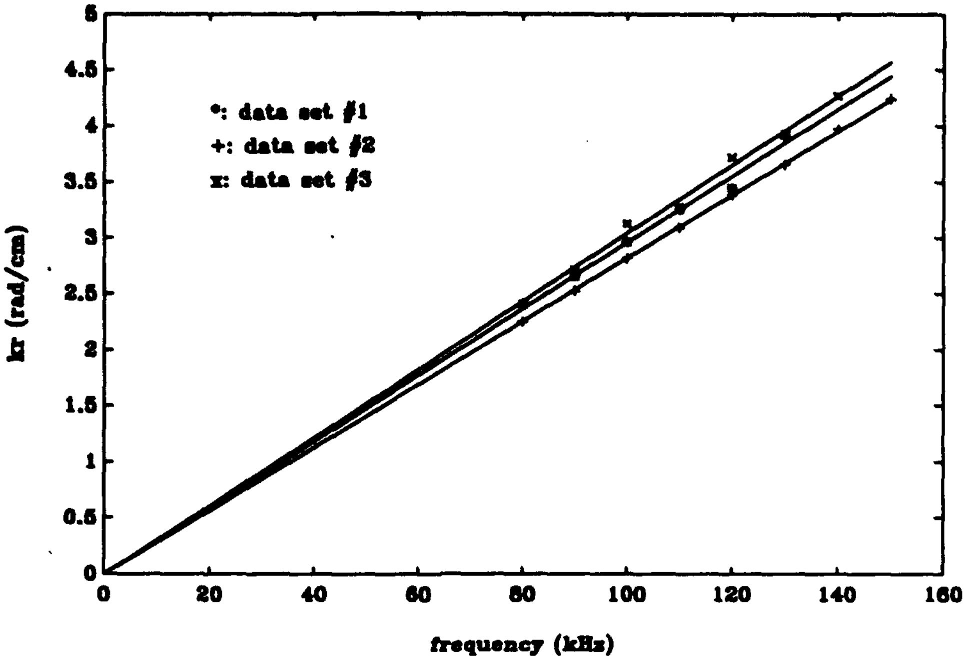
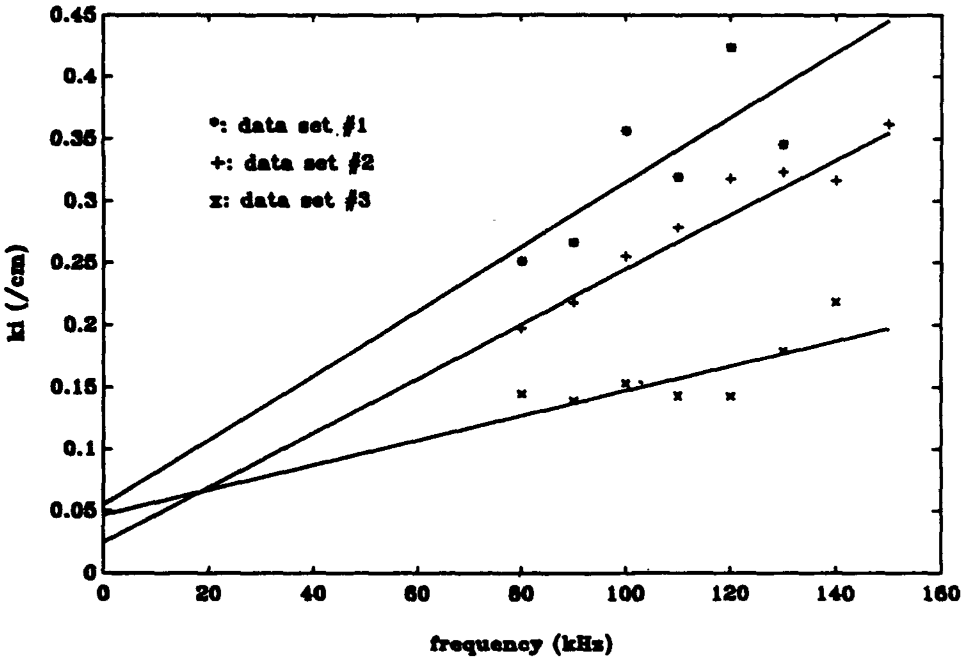


Figure 5. The wave number and damping rate versus frequency.



(a)



(b)

Figure 6. (a). Wave number versus frequency; (b). Damping rate versus frequency