Study on Wave Excitation of Low Frequency Mode in Collisionless Plasmas

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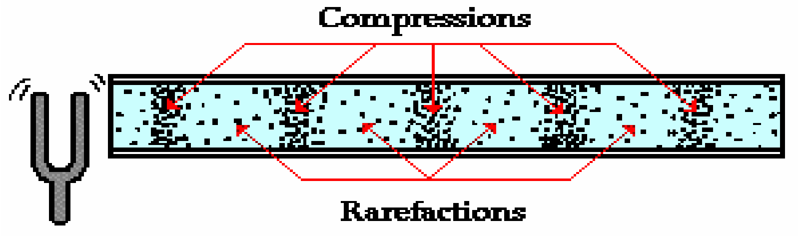
Plasma Sheath Laboratory

Theory

Sound waves in the air

Sound wave = > pressure waves, longitudinal density oscillations



$$\rho\left[\frac{\partial\vec{\upsilon}}{\partial t}+(\vec{\upsilon}\cdot\nabla)\vec{\upsilon}\right]=-\nabla p=-\frac{\gamma p}{\rho}\nabla\rho$$

where ρ : mass density, γ : compression coefficient

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho\vec{\upsilon})=0$$

$$\frac{\omega}{k}=\left(\frac{\gamma p_0}{\rho_0}\right)^{1/2}=\left(\frac{\gamma KT}{M}\right)^{1/2}\equiv c_s$$

Ion acoustic waves in the plasma

Ion acoustic wave :

Wave phenomena of low frequency mode

Longitudinal density oscillation

Collisionless effect by electric fields

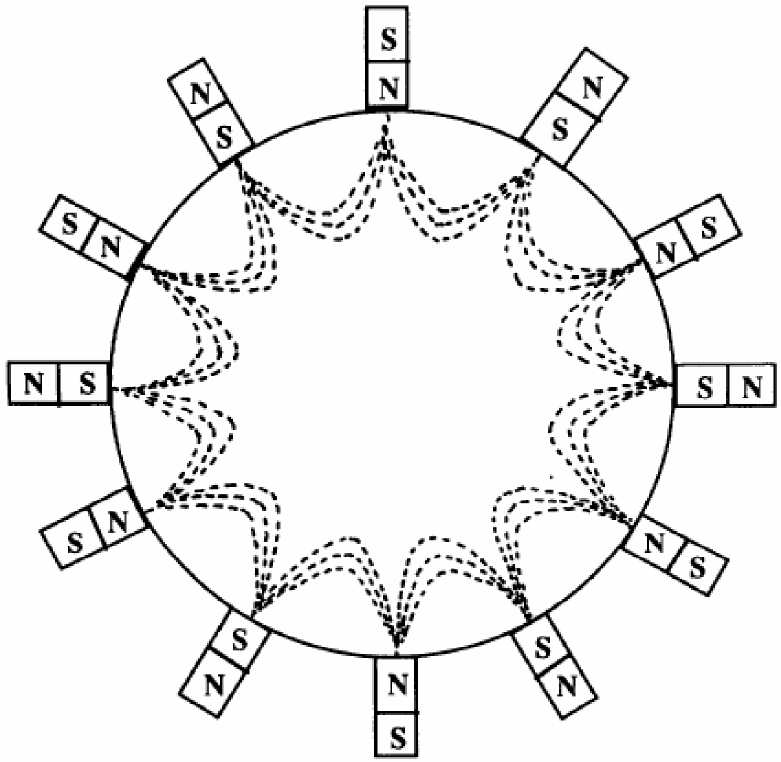
$$Mn\left[\frac{\partial\upsilon_i}{\partial t}+\left(\upsilon_i\cdot\vec{\nabla}\right)\upsilon_i\right]=enE-\nabla p=-en\nabla\phi-\gamma_i KT_i\nabla n$$

$$\frac{\omega}{k}=\left(\frac{KT_e}{M}\frac{1}{1+k^2\lambda_D^2}+\frac{\gamma_i KT_i}{M}\right)^{1/2}\equiv C_s$$

$$\frac{\omega}{k}=\left(\frac{KT_e}{M}\right)^{1/2}\equiv C_s$$

Multi-dipole Plasma System

Multi-dipole Chamber System



Magnetic Cusp Field Lines

Plasma Parameter Measurement

Gas : Ar

Base Pressure : $5\times10^{-6}\ Torr$

Gas Pressure : $2\times10^{-4}\ Torr$

$V_f = -15.61V,\ V_p = 0.83V$

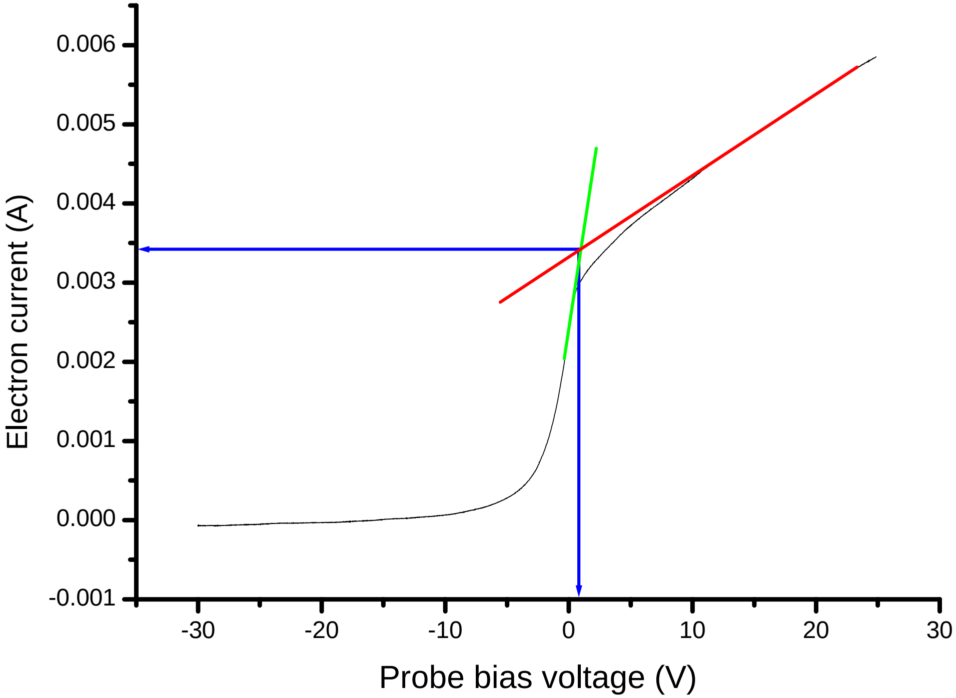
$I_e^* = 0.00348\,A$

$$I_e(V_B) = I_e^* \exp\left[\frac{-e(V_p - V_B)}{T_e}\right] \qquad ,V_B \le V_p$$

$$I_e = I_e^* \qquad ,V_B \ge V_p$$

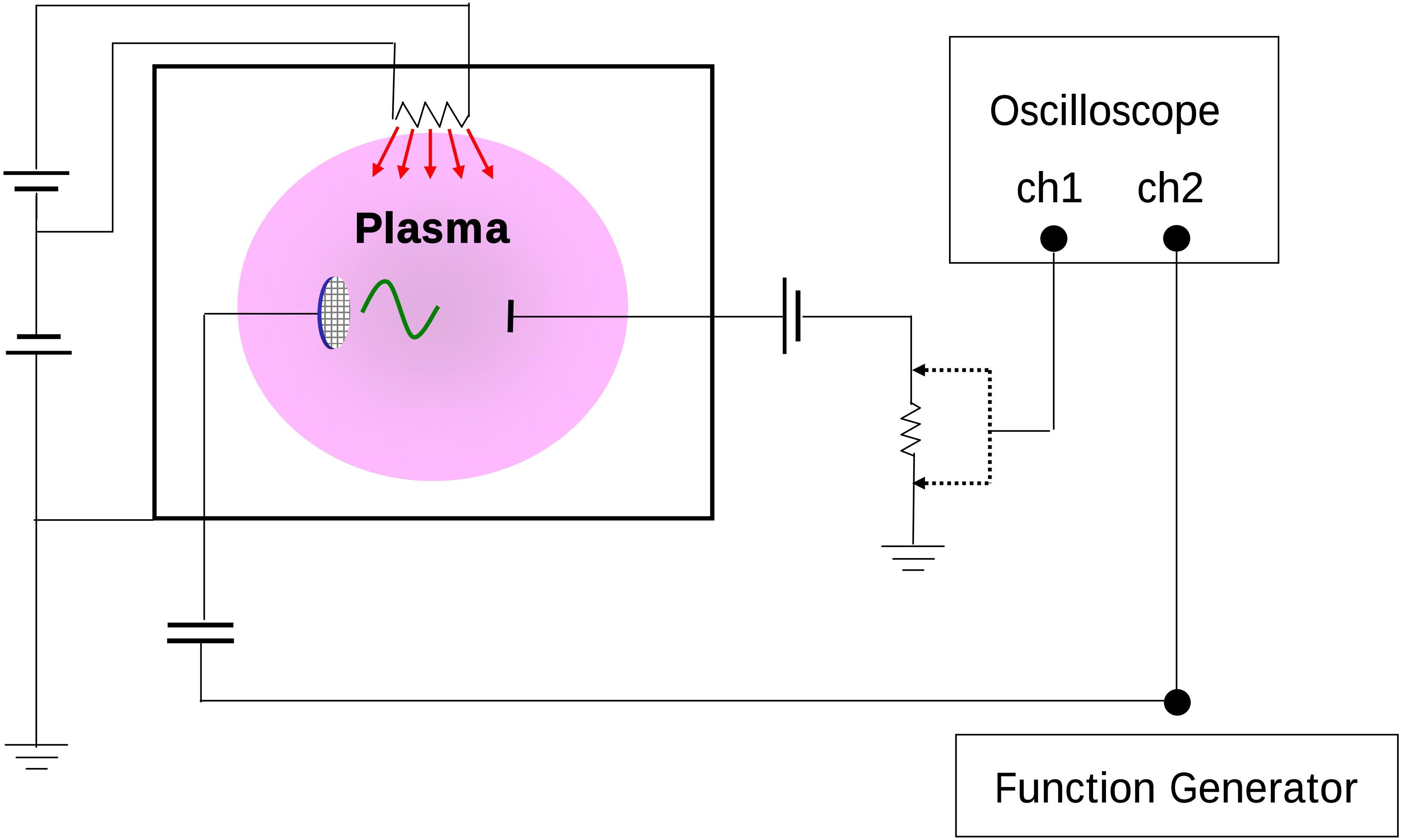
$$T_e = \frac{e(V_p - V_B)}{\ln I_e^* - \ln I_e(V_B)} \cong 2\,eV$$

$$n_e = \frac{I_e^*}{Se\overline{\upsilon}_e} = \frac{I_e^*}{Se}\frac{1}{\sqrt{T_e/2\pi m_e}} = 4.51\times10^9\ [\#/cm^3]$$



Disk Type Langmuir Probe V-I Curve

Schematic of Plasma Wave Experiment



Ion Acoustic Wave Experiment Condition

$$f_e(Hz) \approx 9000\sqrt{n_e(cm^3)} \cong 0.2\,GHz$$

$$f_i(Hz) \approx \frac{f_e}{\sqrt{40 \times 2000}} \cong 1.6\,MHz$$

$$f_{external} < f_{ion} < f_{electron}$$: Ion Acoustic Waves Condition

$$f_{ion} < f_{electron} < f_{external}$$: cf.) Electron Plasma Waves Condition

Launching Wave Condition : $20\,kHz \le f_{external} \le 2.8\,MHz$

$$V_{applied} \cong \frac{T_e}{e} \text{ or } \frac{1}{2}\frac{T_e}{e} \approx 2\,V$$

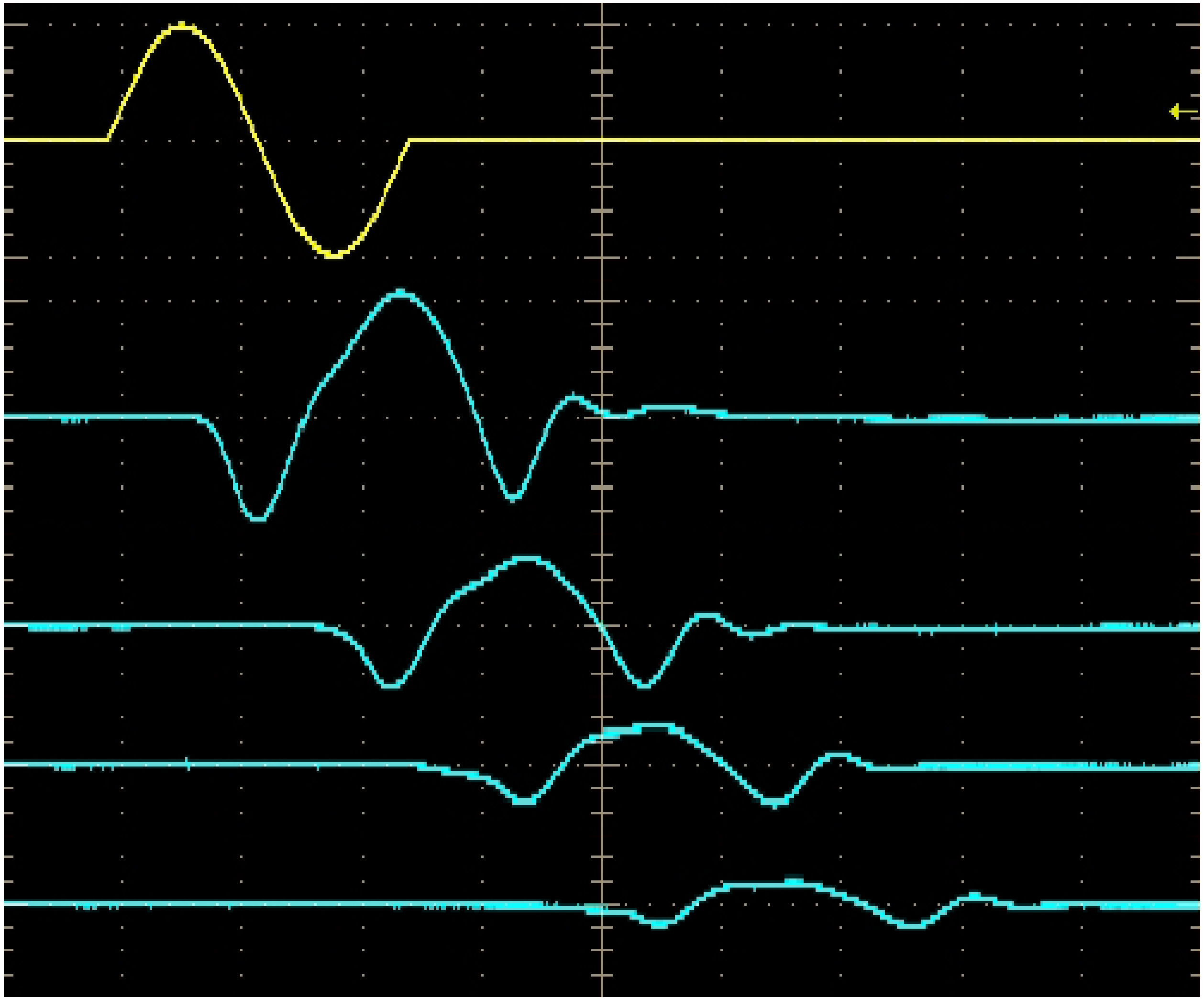
$$\frac{w}{k} \cong \left(\frac{kT_e}{M_i}\right)^{1/2} = C_s$$: The dispersion relation for ion acoustic waves

Measurement by The Time of Flight Method $\Rightarrow C_s = \dfrac{\Delta x}{\Delta t}$

Time of Flight Method

2V

100kHz



← 1cm

← 2cm

← 3cm

← 4cm

The Dispersion Relation

Launching sine wave

(20kHz ~ 3MHz)

FFT of Ion Acoustic Wave

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Frequency Measurement

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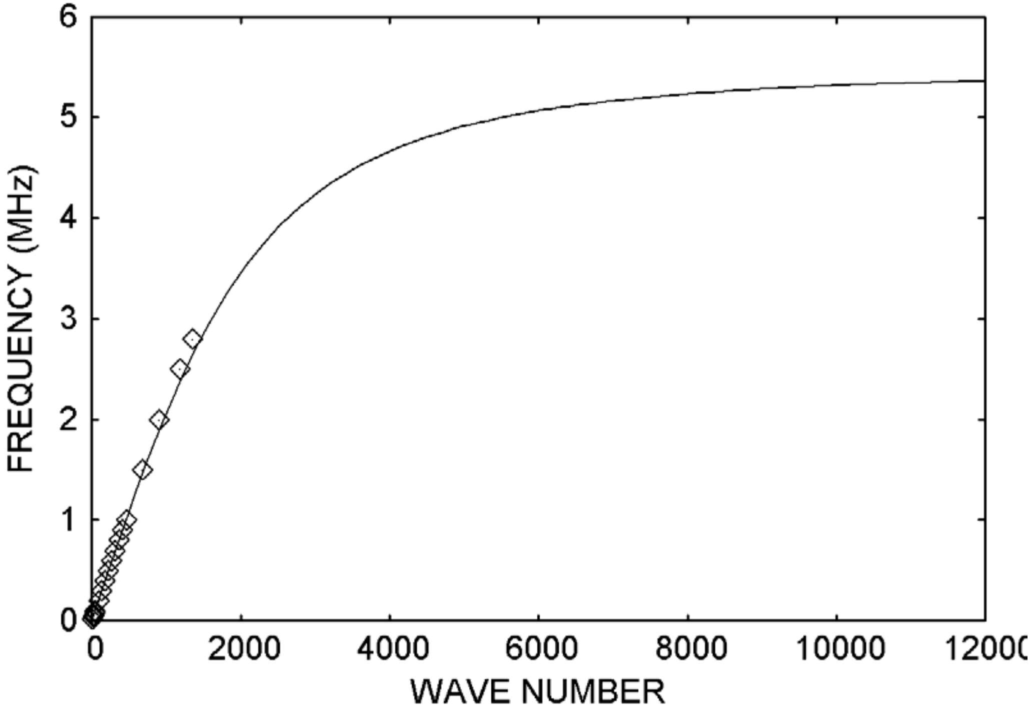
Wave Number Calculation

$$\frac{\omega}{k} = C_s$$

We know IAW velocity by time of flight method

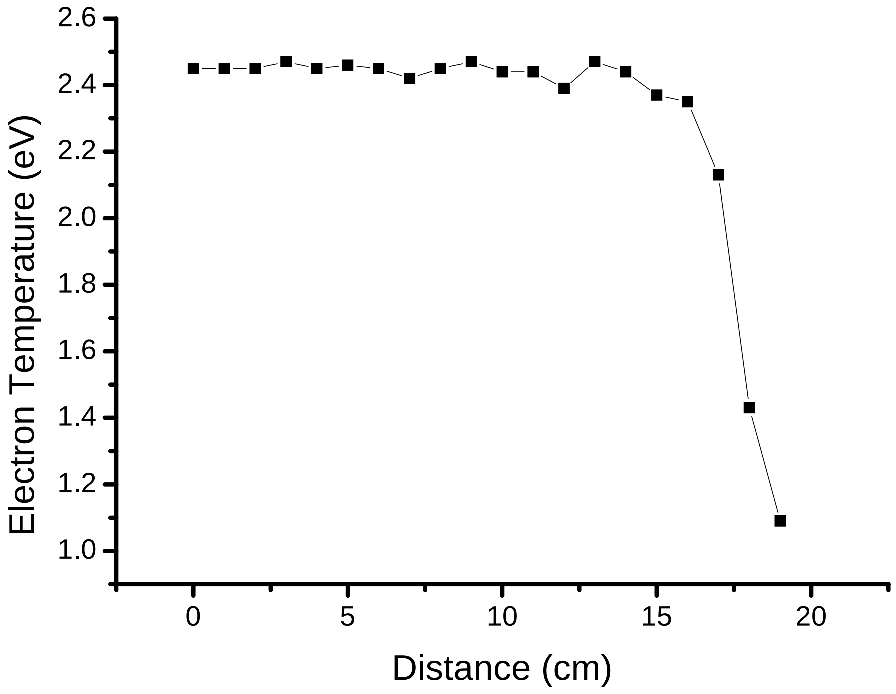


$$T_e = 2.4\ eV$$

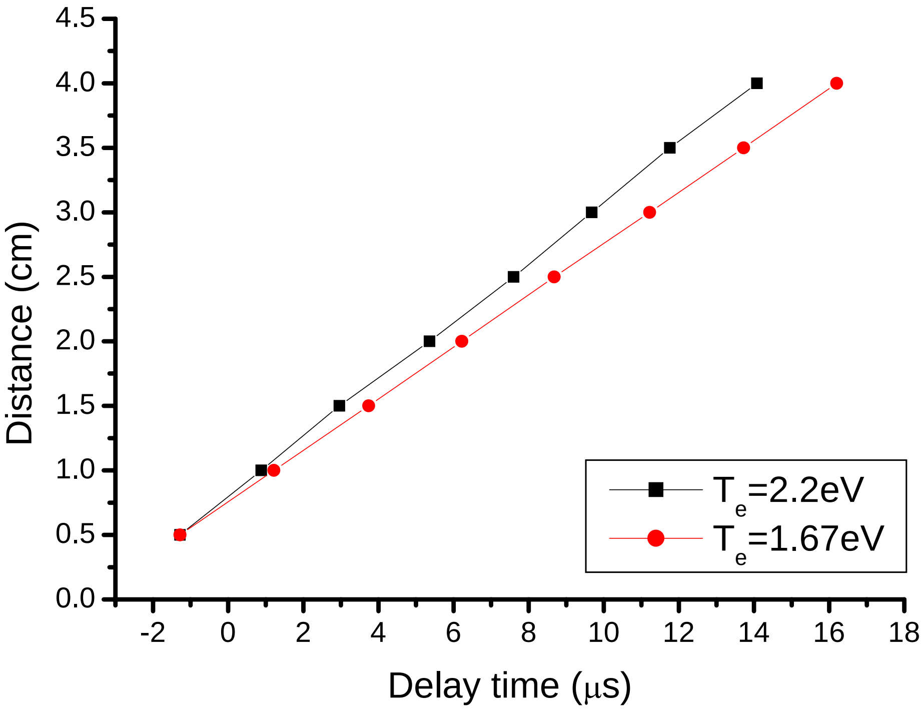
$$n_e = 8.4 \times 10^{9}\ \#/cm^{3}$$

$$\lambda_D = 743 \times \sqrt{\frac{T_e}{n}}\ cm = 3.64 \times 10^{-2}\ cm$$

Electron Temperature Measurement

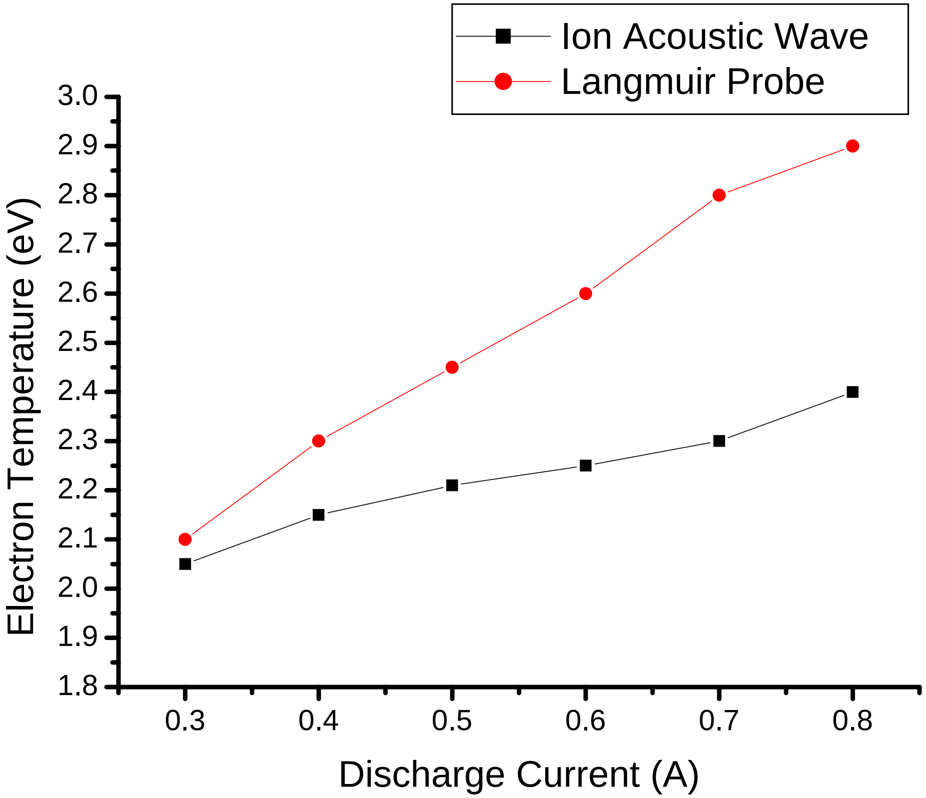


T_e distribution by radial direction



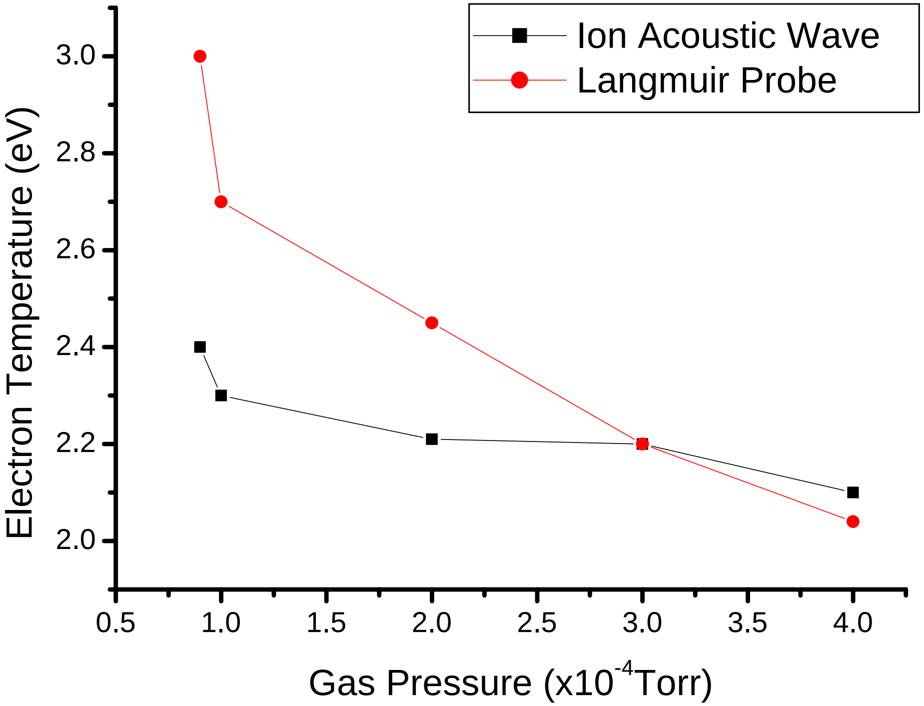
IAW velocity change by electron temperature

Electron Temperature Comparison by Two Methods



Electron temperature via. discharge current

$$\text{Gas pressure} = 2\times10^{-4}\,\text{Torr}$$



Electron temperature via. gas pressure

$$\text{Discharge current} = 0.5\text{A}$$

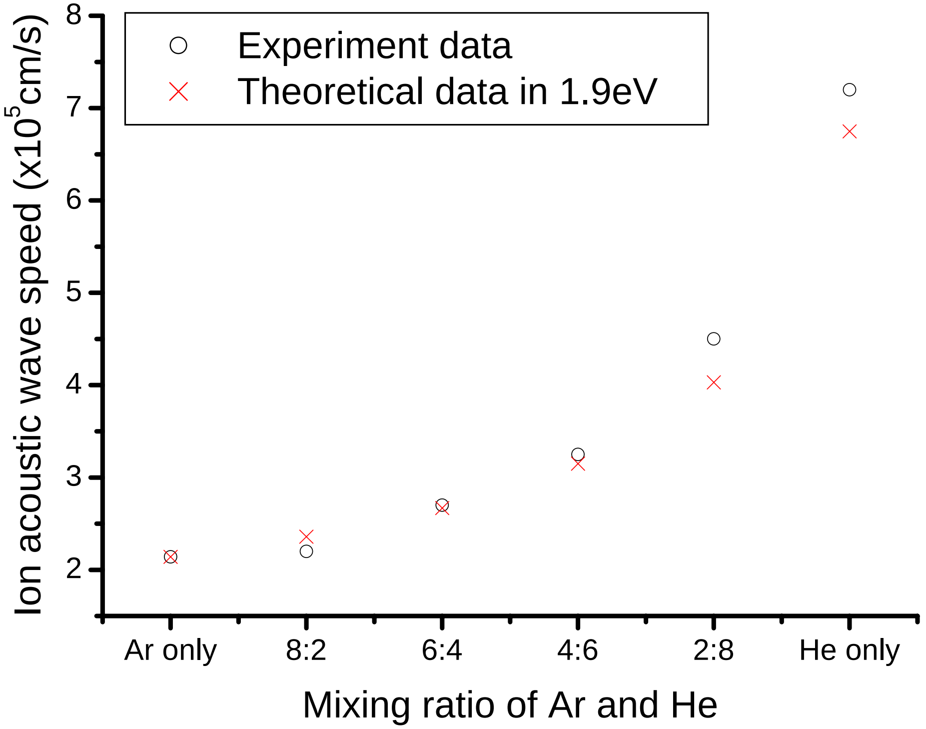
Ion Acoustic Wave for two ion species

Total gas pressure : $2 \times 10^{-4} Torr$

Gas species : Ar and He

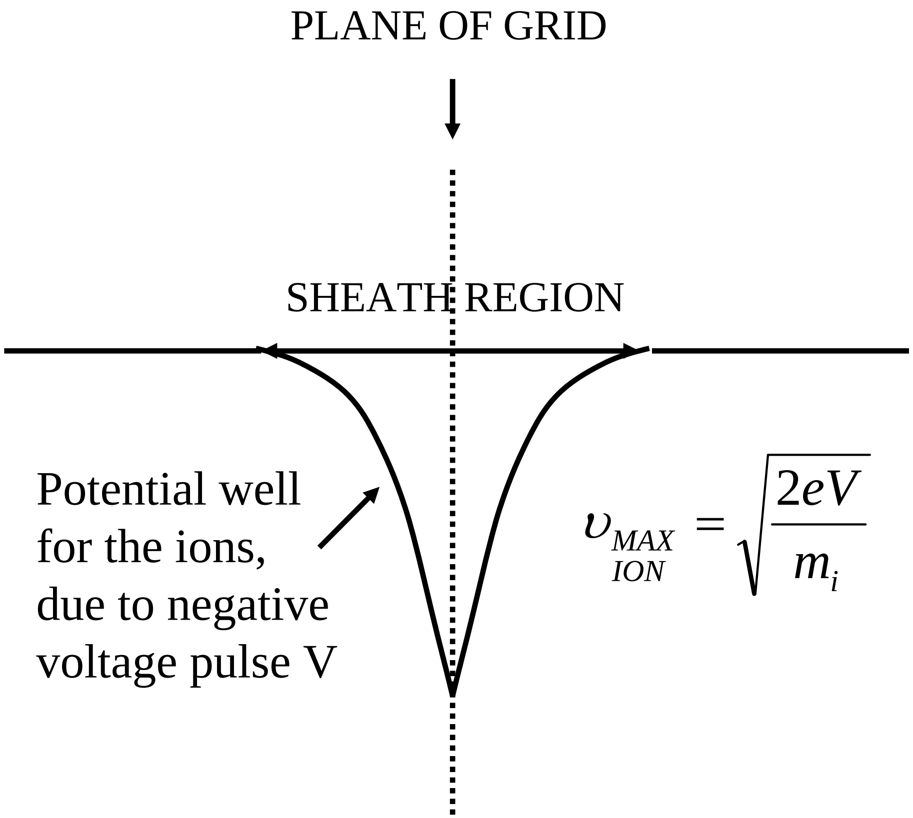
- 1.9eV at Ar only = Let the theoretical data
- Using next equation, IAW speed by density ratio of two ion species was obtained.

$$C_s = \sqrt{\frac{T_e}{\left(\frac{n_{0_1} m_1 + n_{0_2} m_2}{n_0}\right)}}$$



The speed of ion acoustic wave increased as the He gas added.

Pseudowaves Generation

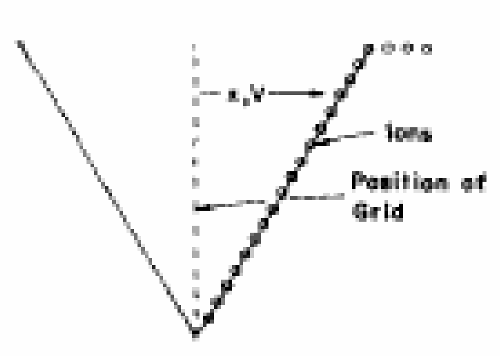


PLANE OF GRID

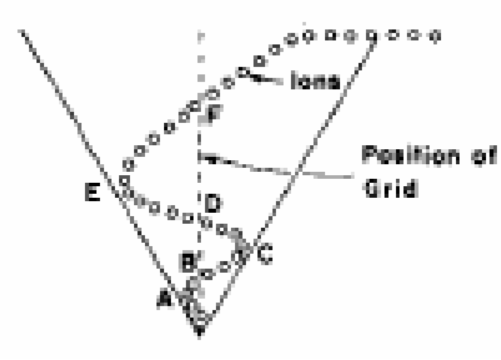
SHEATH REGION

Potential well
for the ions,
due to negative
voltage pulse V

$$\upsilon_{\substack{MAX\\ION}} = \sqrt{\frac{2eV}{m_i}}$$



Position of ions when
voltage is suddenly
applied to the grid



Trapped ions for
pulse duration

Pseudowaves is generated by negative voltage pulse.

Pseudowave Propagation

Experiment Condition

Ar gas pressure : 2×10^{-4} Torr

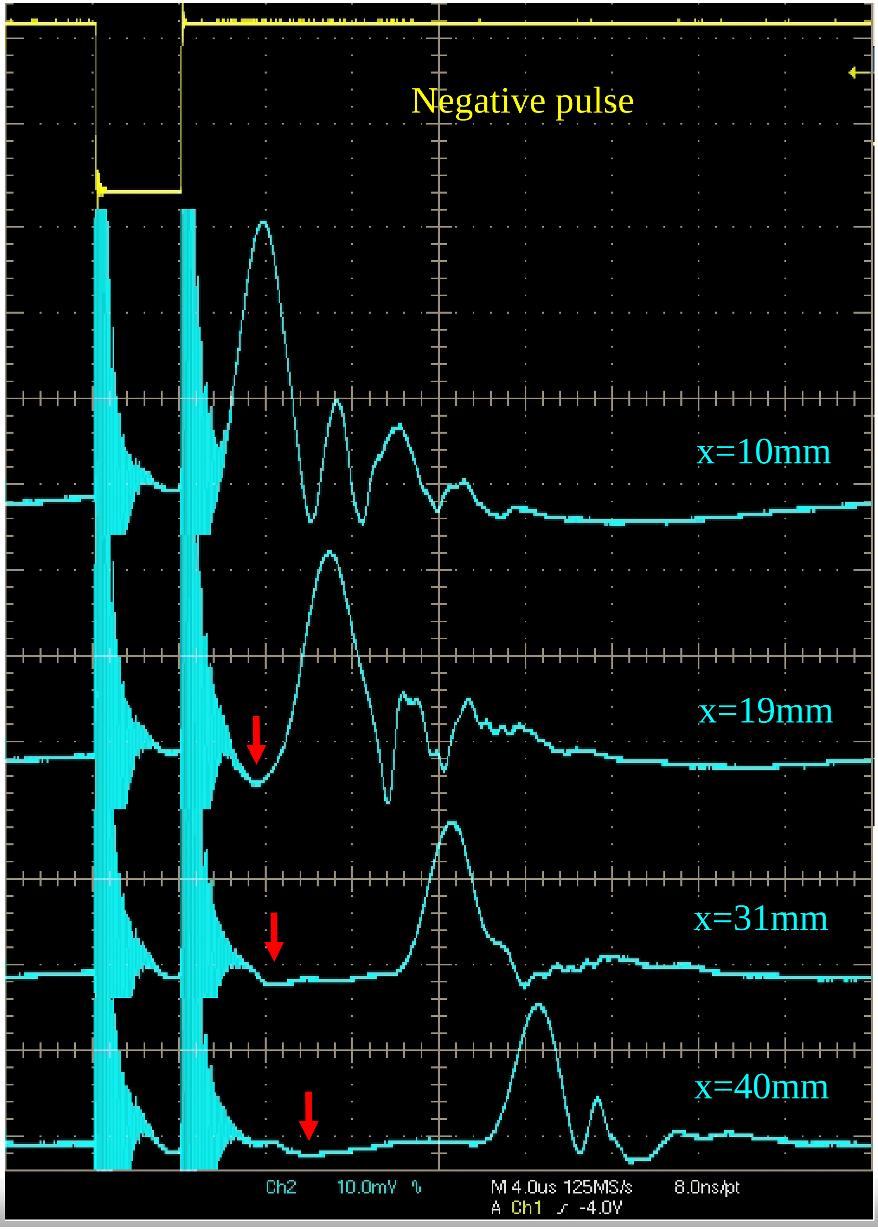
Discharge current : 0.5A

Launching wave

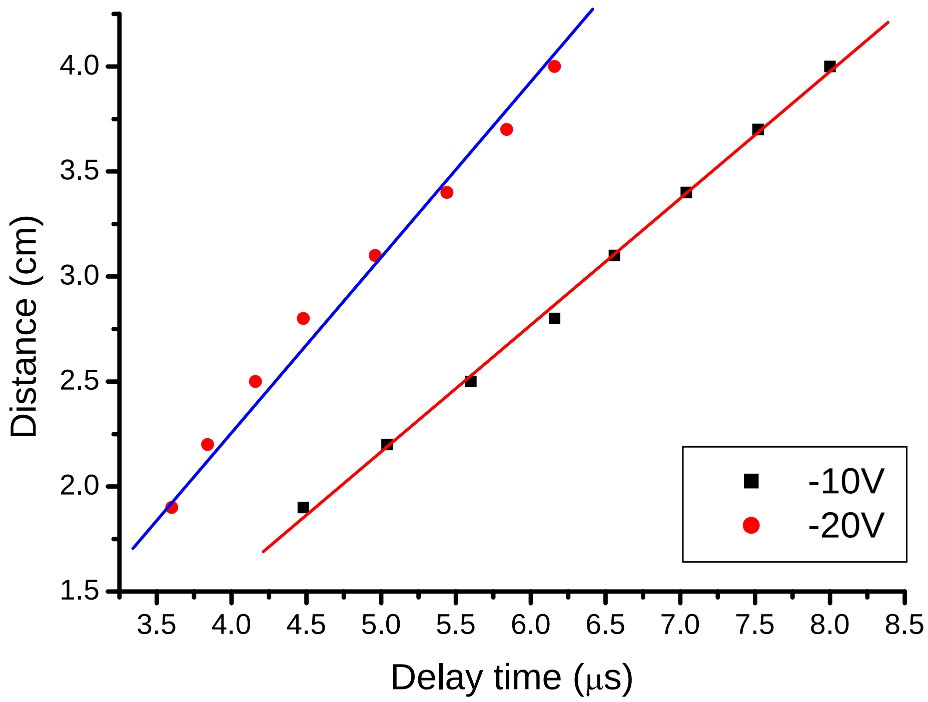
- Pulse width : $4 \mu s$
- Amplitude : -10V & -20V

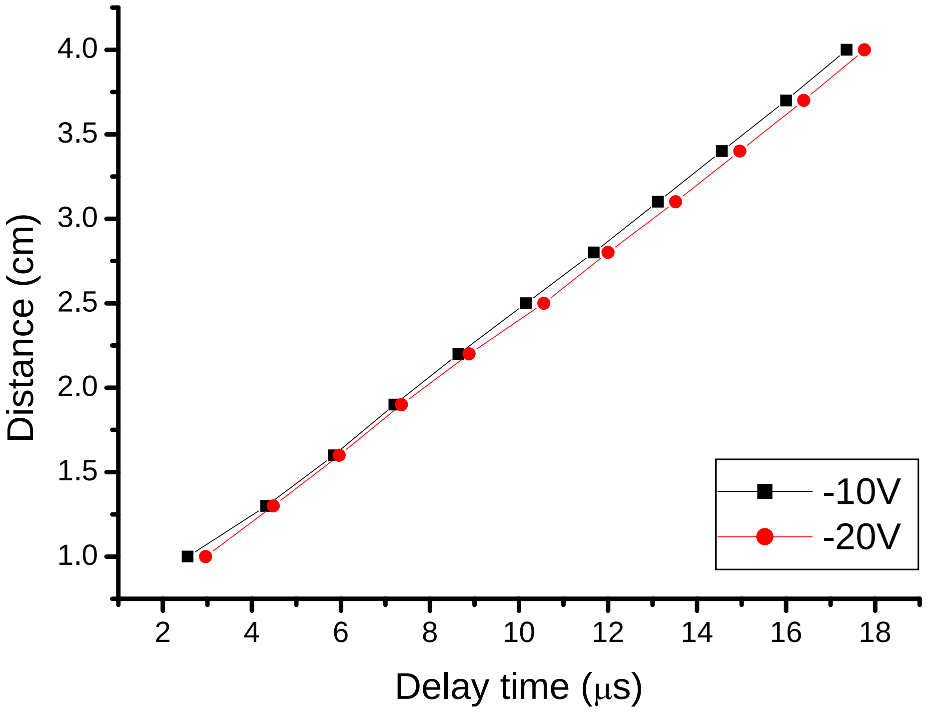
Pseudowave (indicated by the arrow)

Ion acoustic waves also propagate



Amplitude Dependence of Exciting Voltage





$$C_s = 6.02 \times 10^5 cm/s \,@\, \text{-10V}$$

$$C_s = 7.75 \times 10^5 cm/s \,@\, \text{-20V}$$

$$C_s = 2.03 \times 10^5 cm/s \,@\, \text{-10V}$$

$$C_s = 2.01 \times 10^5 cm/s \,@\, \text{-20V}$$

Pseudowaves depends upon exciting voltage

IAW are independent of exciting voltage

Summary

In plasma, electrostatic wave phenomena can be observed just like sound wave.

- Electron temperature is compared by Langmuir probe and IAW method in Argon plasma.
- Difference about Te measured by two methods presented by primary electron effect.

Electron temperature in mixed gas plasma also was obtained by measuring IAW speed.

Pseudowaves are generated by negative voltage pulse.

- The velocity of pseudowaves depend upon the amplitude of the exciting voltage.