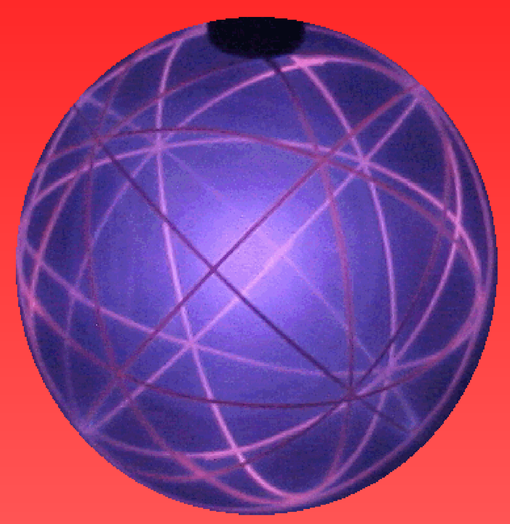
# Plasma Characteristics of the Ion Source Region in the University of Wisconsin Inertial Electrostatic Confinement Fusion Device



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## Abstract:

The ion source region of the UW-Inertial Electrostatic Confinement device consists of a filament assisted DC discharge plasma that exists between the wall of the IEC vacuum chamber and the grounded spherical steel grid that makes up the anode of the IEC device. The plasma characteristics of the source region have been investigated using a planar Langmuir probe and an antenna used for the propagation of ion acoustic waves. Using these diagnostics the average ion mass of the deuterium source plasma has been measured and is consistent with a mostly $D_3^+$ plasma. These results are consistent with a 0-D theoretical model of the source plasma. Variations in the floating potential, the plasma potential, and the plasma density have been investigated by varying the radial location of the planar probe. Variations in voltage on the IEC cathode have been shown to affect the floating potential in the source region as well as the spatial extent and density of the plasma in the source region.

## Theory

The multi-species ion-acoustic wave dispersion relation has been used to determine the concentrations of molecular ion species in the deuterium plasma used to fuel the UW-IEC device. This work was done in conjunction with the computational modeling done by Gil Emmert in which the atomic physics contributions to the fusion rate in the IEC are taken into account.

The composition of ions present in the source region of the IEC is treated using zero dimensional rate equations. The rate equations take into account the following processes:

| | |
|---|---|
| Ionization of $D_2$: | $e + D_2 \rightarrow D_2^+ + 2e$ |
| Dissociation of $D_2$: | $e + D_2 \rightarrow 2D + e$ |
| Ionization of D: | $e + D \rightarrow D^+ + 2e$ |
| Dissociation of $D_2^+$: | $e + D_2^+ \rightarrow D^+ + D + e$ |
| Dissociative ionization of $D_2$: | $e + D_2 \rightarrow D^+ + D + 2e$ |
| Dissociative recombination of $D_2^+$: | $e + D_2^+ \rightarrow 2D$ |
| Interchange reactions creating $D_3^+$: | $D_2 + D_2^+ \rightarrow D_3^+ + D$ |
| Dissociative recombination of $D_3^+$: | $e + D_3^+ \rightarrow D_2 + D$ |

Following these various reactions through to there conclusion the theoretical concentrations of deuterium ions are 85% $D_3^+$, 12% $D_2^+$, and 3% $D^+$. These concentrations can be experimentally verified using the multi-species ion acoustic wave dispersion relation

The rate equations used to calculate the concentrations of molecular ion species in the IEC source region are shown below. They illustrate the manner in which ionizations, interchange reactions and flow to the walls and grid all play a role in calculating the ion current that flows through the IEC anode.

$D^+$: $$\frac{d}{dt}(n_{11}) = n_p n_{20}\sigma_5 V_p - \frac{1}{2} n_{11} C_1 \frac{(A_g + A_w)}{Vol}$$

$D_2^+$: $$\frac{d}{dt}(n_{21}) = n_p n_{20}\sigma_1 V_p - \alpha_2 n_{21} n_{20} - \frac{1}{2} n_{21} C_2 \frac{(A_g + A_w)}{Vol}$$

$D_3^+$: $$\frac{d}{dt}(n_{31}) = \alpha_2 n_{21} n_{20} - \frac{1}{2} n_{31} C_3 \frac{(A_g + A_w)}{Vol}$$

Ionization — Interchange reactions — Flow to walls and grid

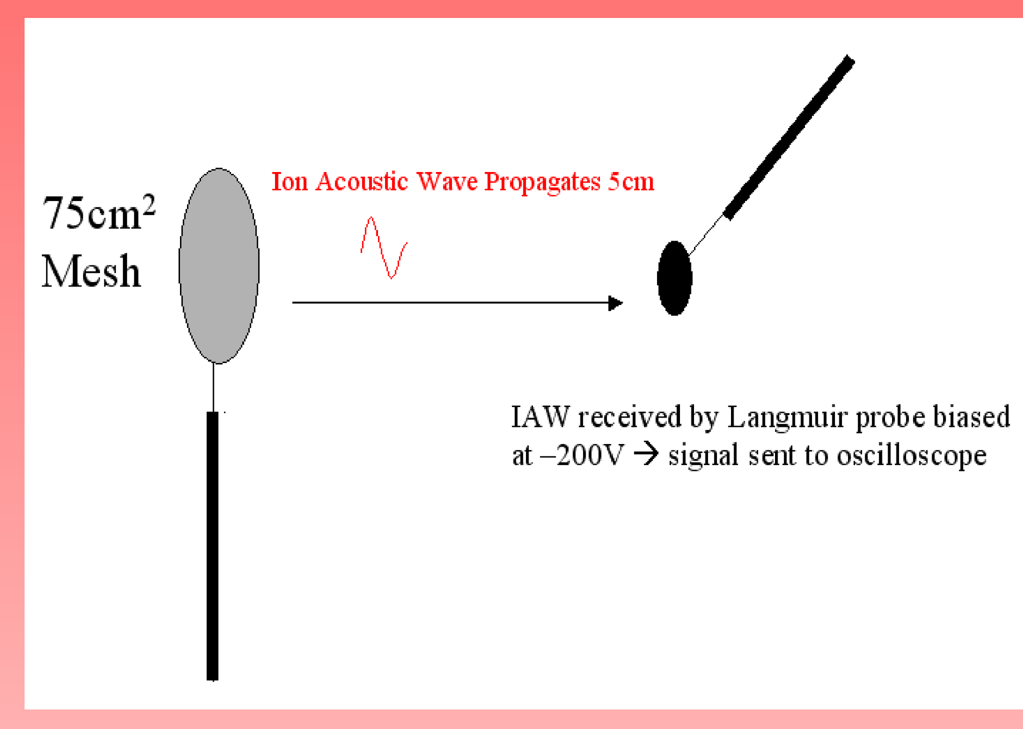
$I_{anode}$: $$e(n_{11}C_1 + n_{21}C_2 + n_{31}C_3)A_g = 2I_{ion}$$

A derivation of the multi-species ion-acoustic wave gives the following dispersion relation where $T_e$ is the electron temperature, $M_j$ is the ion mass of the jth ion species, and $c_{sj}$ is the sound speed of the jth ion species.

$$\frac{\omega}{k} = \sqrt{c_{s1}^2 + c_{s2}^2} \qquad \text{where} \qquad c_{sj} = \sqrt{\frac{n_j k T_e}{n_e M_j}}$$

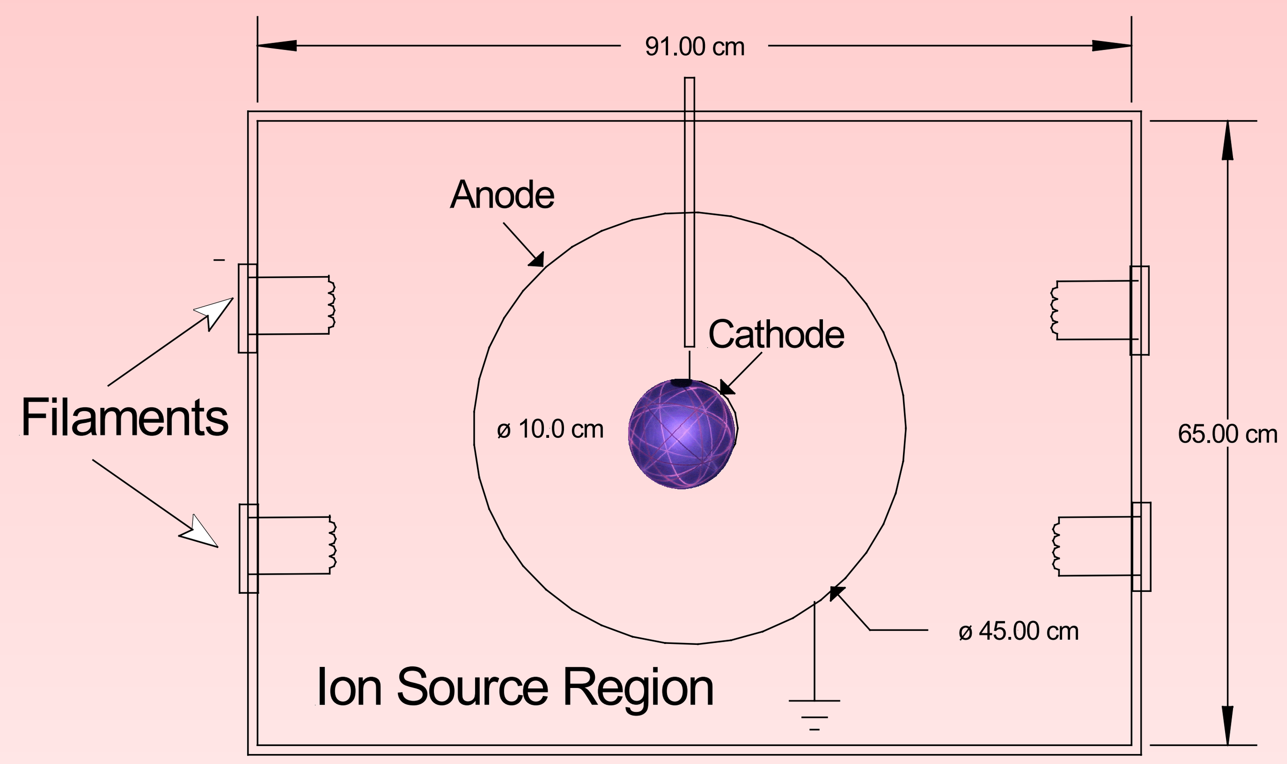
This implies: $$v_{ph}^2 = \frac{\alpha k T_e}{M_1} + \frac{(1-\alpha) k T_e}{M_2} \qquad \text{where} \qquad \alpha = n_1 / n_e$$

## Experimental Method




This figure portrays the experimental setup used to verify the molecular ion concentrations calculated to exist in the IEC source region. Excitation signals on the 75cm² mesh were kept to ~2Vpp to ensure the propagation of linear IAW waves.

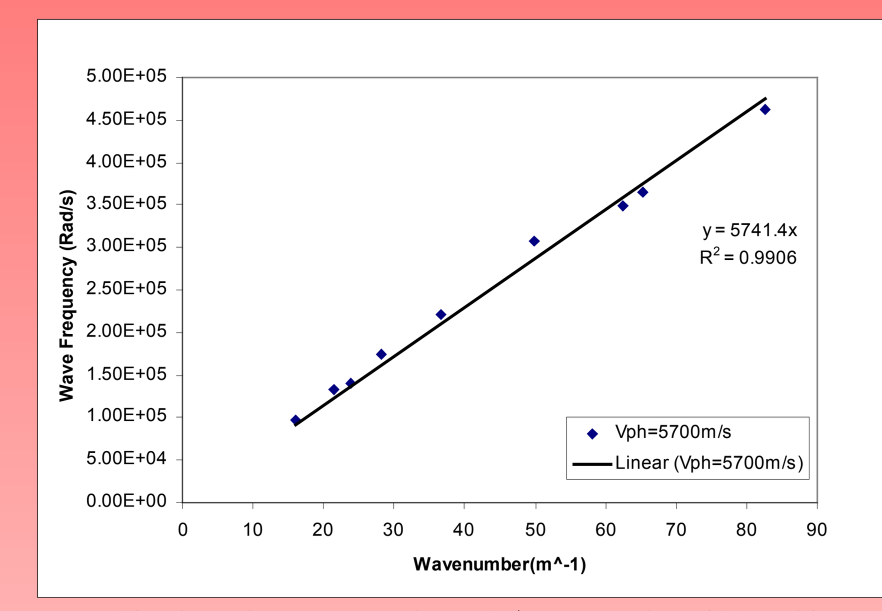
## IEC Schematic




**This schematic shows the geometry of the UW-IEC Device**

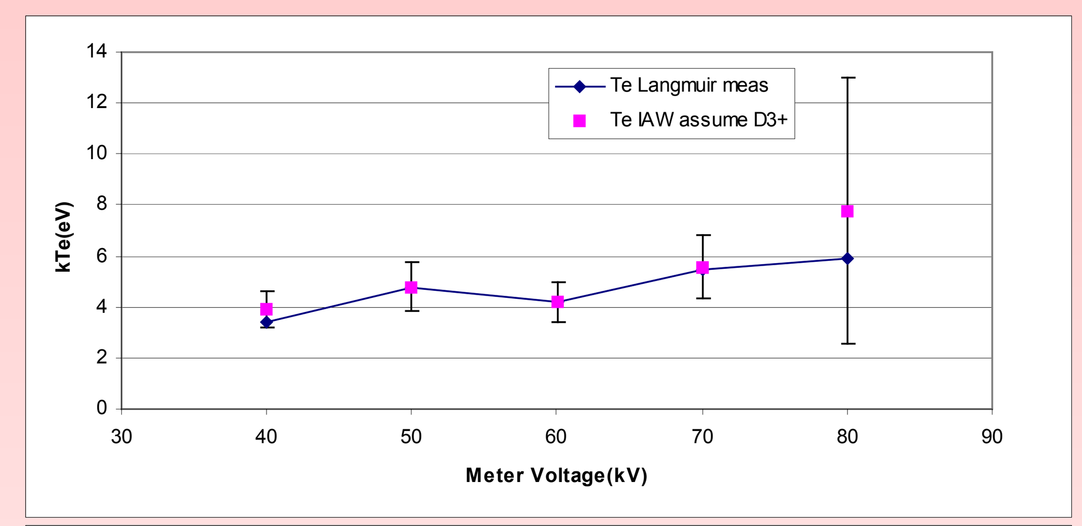
## Experimental Results

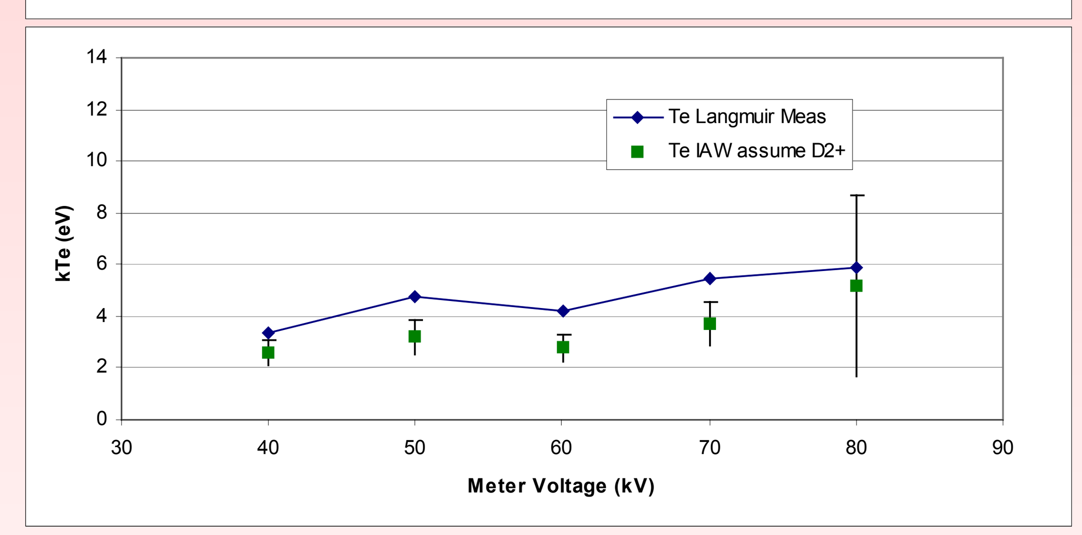
The data below illustrates the method used to obtain the phase velocity of the ion acoustic waves. The slope of the dispersion relation is the phase velocity of the wave. The data below was taken in the IEC source region with 0V of cathode potential.




The above data corresponds to a $D_3^+$ concentration of 88% with a $D_2^+$ concentration of 12%. The measured electron temperature was measured to be 1.94eV using a planar Langmuir probe. Concentrations are accurate to within 5%.

This same technique was applied with the IEC in operation at cathode voltages ranging from 40kV to 80kV. The figure below shows good agreement between measured electron temperatures and calculated electron temperatures assuming an all $D_3^+$ plasma in the IEC source region. Calculated electron temperatures assuming an all $D_2^+$ plasma are included for the sake of comparison to show the poor agreement in the $D_2^+$ case.




Comparison of IAW calculated electron temperatures assuming $D_2^+$ and $D_3^+$ plasmas (data points) with measured electron temperatures (solid lines). Indicates minimum $D_3^+$ concentrations of 60%.

## Conclusion

By examining the propagation characteristics of ion-acoustic waves in the ion source region of the UW-IEC device it has been shown the dominant ion species is $D_3^+$ accompanied by a small fraction of $D_2^+$. This has significant implications for future modeling efforts on the UW-IEC device.

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