Ion Species Measurements in the Source Region of the UW-IEC Device

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Ion Species Measurements
Motivated by Computational Work

- Computational work done by Emmert and Santarius shows atomic physics effects to dominate the behavior of IEC devices operating at high neutral gas pressures.

  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$_3^+$: $e + D_2^+ \rightarrow D^+ + D + 2e$

- A 0-D rate equation calculation based on ion source conditions, done by G.A. Emmert, shows high concentrations of molecular ions.

  Calculated Source Mixture:
  85% D$_3^+$, 12% D$_2^+$, and 3% D$^+$
  At 2 mtorr neutral gas pressure
Ion Species Measurements Motivated by Computational Work Cont.

- High concentrations of molecular ions are predicted to have a significant effect on the fusion rate

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<tbody>
<tr>
<td>Predicted neutron rate (model)</td>
<td>s⁻¹</td>
<td>0.96 x 10⁸</td>
<td>1.7 x 10⁸</td>
</tr>
<tr>
<td>Measured neutron rate (166kV, 68mA, 10cm cathode)</td>
<td>s⁻¹</td>
<td>1.8 x 10⁸</td>
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Experimental Verification of Molecular Ions in the Source Region is Desired

- Ion Acoustic Wave (IAW) velocities can determine ion mass
- IAW phase velocities ($v_{ph}$) depend on $M$, ion mass, and $T_e$, electron temperature.
- By measuring $v_{ph}$ and $T_e$ the ion mass can be calculated.
Ion Acoustic Wave Method for Determining Ion Mass Ratios

- Ion Acoustic Waves are electrostatic plasma waves that have a mass dependent phase velocity. Where \( v_{ph} = \frac{\omega}{k} \)

- The two species Ion Acoustic Wave Dispersion Relation shown below:

\[
\frac{\omega}{k} = \sqrt{c_{s1}^2 + c_{s2}^2}
\]

where

\[
c_{sj} = \sqrt{\frac{n_j k T_e}{n_e M_j}}
\]

If we define a parameter \( \alpha : \alpha = n_l/n_e \)

This implies:

\[
v_{ph}^2 = \frac{\alpha k T_e}{M_1} + \frac{(1-\alpha)k T_e}{M_2}
\]

for a two species plasma
Two Ways to Measure Ion Acoustic Wave Phase Velocity

- **Method 1: Group Velocity**
  - \( v_g = \frac{d\omega}{dk} = (c_{s1} + c_{s2})^{1/2} = v_{ph} \)
  - With this method, \( \omega \) and \( v_g \) are measured and \( k \) is calculated.

- **Sources of Error:**
  - The launch point of the wave pulse may be substantially different from the position of exciter mesh.
  - This leads to significant errors in \( v_g \) calculations based on the time of flight of the wave pulse.
Two Ways to Measure Ion Acoustic Wave Phase Velocity

- Method Two: Direct Phase Velocity Measurement:
  - By moving a negatively biased Langmuir probe through a plasma perturbed by a continuous sine wave, $\omega$ and $k$ are directly measured.
  - $v_{ph}$ can be directly calculated.
  - A high degree of accuracy can be obtained with this method.

3.0eV plasma, 0.34 Pa D$_2$ pressure, 60V bias on filaments

$v_{ph} = 7300 \text{ m/s} \Rightarrow \text{min D}_3^+ \text{ fraction } 76\% \pm 15\%$
Filament Bias Scan shows constant $D_3^+$ fraction.

Weighted Reduced Ion Mass is defined as:

$$M_R^{-1} = \frac{1}{n_e} \left( \frac{n_{D3}}{M_{D3}} + \frac{n_{D2}}{M_{D2}} + \frac{n_D}{M_D} \right)$$
IAW Experiments Using Method 1: $D_3^+$ in Source Region for Varying Conditions cont.

Pressure Scan

Weighted Reduced Ion Mass is defined as:

$$M_{R}^{-1} = \frac{1}{n_e} \left( \frac{n_{D3}}{M_{D3}} + \frac{n_{D2}}{M_{D2}} + \frac{n_D}{M_D} \right)$$
IAW Experiments Using Method 1: D$_3^+$ in Source Region for Varying Conditions cont.

Cathode Voltage Scan

Data indicates D$_3^+$ concentrations of ~80% with 25% of experimental error, across a range of source conditions.
IAW Experiments with Method 2 Show $D_3^+$ with Greater Accuracy

- For standard source plasma conditions Method 2 measures the $D_3^+$ fraction to within 15%.
- The contributions of varying ratios of $D_2^+ / D^+$ ions in the source are shown.

![Graph showing the effect of $D_3^+$ concentrations on varying ratios of $D_2^+ / D^+$](image)
Conclusions and Future Work

• Ion Acoustic Wave experiments show high concentrations of $\text{D}_3^+$ in the IEC source region for the typical operating regime of the original UW-IEC device.

• Future experiments will involve more complete parametric studies of the source plasma conditions using the method of direct phase velocity measurement.
Acknowledgements

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QUESTIONS?

Ion Acoustic Wave Response to a 130kHz Electrostatic Excitation Signal in the IEC Source Region

- Received Voltage Signal (V)
- Time (s)
- Distance from Excitation Source (cm)