Simplified Plasma Experiment for Investigation of Plasma Diffusion & Transport Mechanisms

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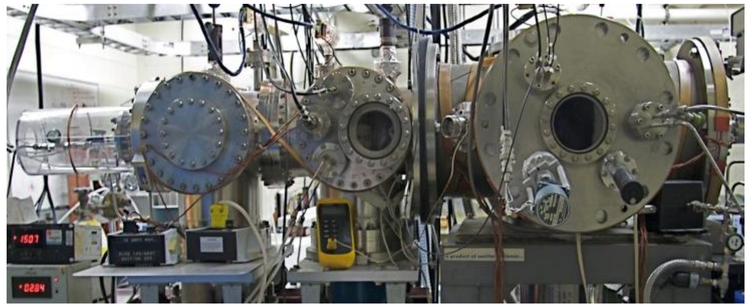
Objective

Use experimental and analytical efforts to understand the plasma dynamics of a well-characterized ion beam experiment used for validation of analytical techniques and computational codes that model plasma behavior.

Background

Ion Beam Experiment

The facility examines heavy species collisions and the transport of generated electrons with precise low-current measurements of a 1500eV xenon ion beam accelerated into a neutral xenon target gas.



Top: Ion Beam Facility with Source, Filter, & Test Chambers
Bottom: Test Cell found in Test Chamber

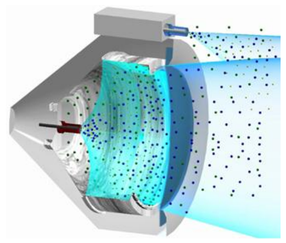
Beam ions are scattered to the walls if they experience a collision with a neutral or exit the domain unscattered. As gas is increased, more collisions occur and the electrodes measure the resulting flux of ions scattered from the centerline trajectory.

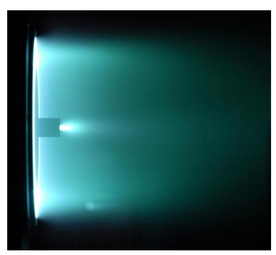
Plasma Applications

Models of intermediately-ionized plasmas – DC-ION for ion thrusters and HPHall for Hall-effect thrusters – are used to better improve plasma thrusters.

Models of collisionless electron plasmas for high-power microwave devices (e.g. ICEPIC) are being expanded to simulate heavy species collisions in intermediately-ionized plasmas.

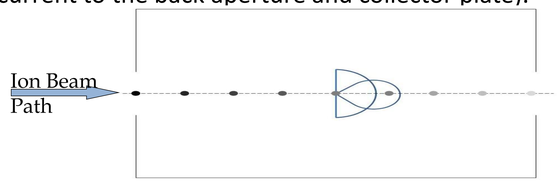
Left: Ion Thruster
Right: Hall-effect Thruster





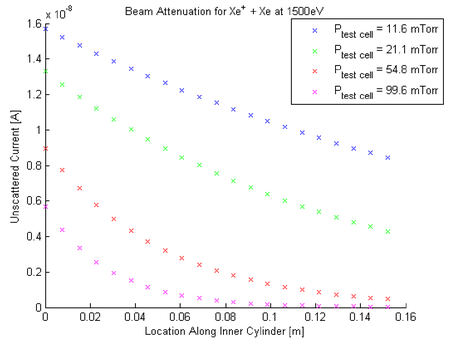
Approach

Assuming a one dimensional beam centered on the axis of the test cell, the model treats the scattered ions as discrete point sources located on the axis, where the magnitude of the source is attenuated due to charge-exchange (CEX) and elastic (MEX) collisions that occur. A MEX and CEX scattering angle distribution is introduced for the sources, and view factor are used to determine the interaction of the scattered ions with the inner cylinder, exit plate, and exit plate orifice (imaginary surface collecting current to the back aperture and collector plate).



Beam Attenuation

For given pressure, beam attenuation equations are used to calculate unscattered (and hence scattered) current at each discrete location.

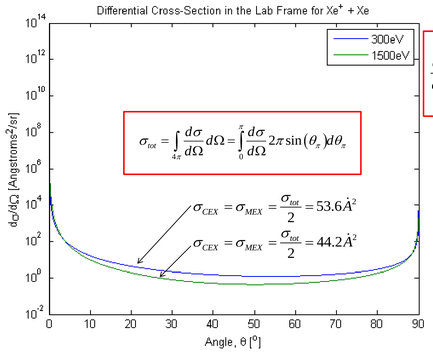


$$J(z) = J_0 \exp\left(-\frac{z}{\lambda_m}\right)$$

$$\lambda_m = \frac{1}{(\sigma_{CEX} + \sigma_{MEX})\, n_n}$$

Differential Cross-Section

A semi-empirical equation for the differential cross-section was used to calculate the current scattered in a given direction.



$$\sigma_{tot} = \int_{4\pi} \frac{d\sigma}{d\Omega} d\Omega = \int_0^{\pi} \frac{d\sigma}{d\Omega} 2\pi \sin(\theta_\pi) d\theta_\pi$$

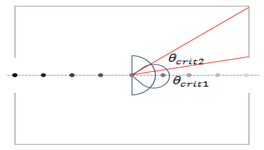
$$\sigma_{CEX} = \sigma_{MEX} = \frac{\sigma_{tot}}{2} = 53.6\text{Å}^2$$

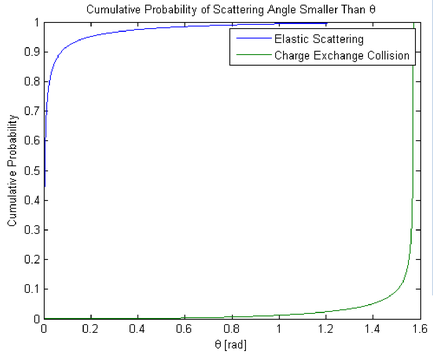
$$\sigma_{CEX} = \sigma_{MEX} = \frac{\sigma_{tot}}{2} = 44.2\text{Å}^2$$

$$\frac{d\sigma}{d\Omega} = \theta_s^{A_{MEX}} 10^{B_{MEX}} + (90 - \theta_s)^{A_{CEX}} 10^{B_{CEX}} \begin{cases} \theta_s = \theta_{MEX}, 0 \le \theta_s \le \theta_{MEX,\circ} \\ \theta_s = \theta_s, \theta_{MEX,\circ} \le \theta_s \le \theta_{CEX,\circ} \\ \theta_s = \theta_{CEX}, \theta_{CEX,\circ} \le \theta_s \le 90° \end{cases}$$

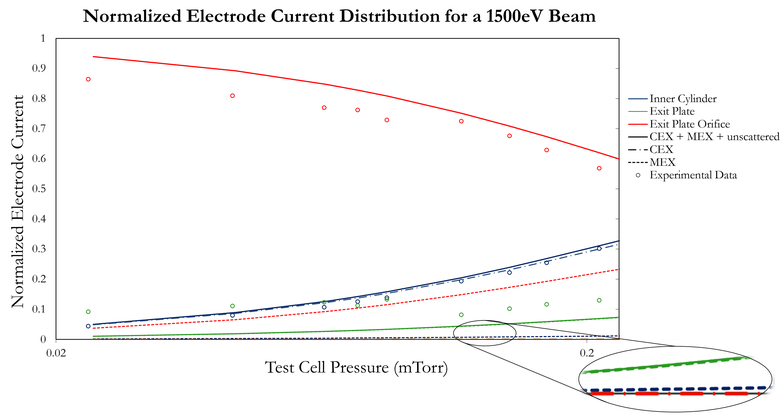
	300eV	1500eV
A_{MEX}	-2.02	-2.502
A_{CEX}	-1.098	-1.380
B_{MEX}	3.24	3.508
B_{CEX}	1.53	1.610
$\theta_{MEX,\circ}$	3.53E-5°	0.114°
$\theta_{CEX,\circ}$	89.9986°	89.939°

$$P_{cum,\theta_{crit}} = \frac{1}{\sigma} \int_0^{\theta_{crit}} \frac{d\sigma}{d\Omega} d\Omega$$





Results



Discussion

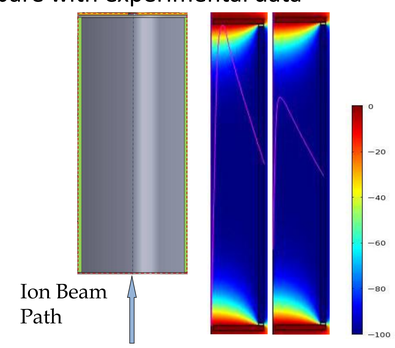
The results show that most of the current on the inner cylinder is from CEX ions that experience large angle scattering, while most of the current on the exit plate is from MEX ions that experience small angle scattering. The majority of the current on the exit plate orifice is from unscattered beam ions. In addition, the results shows that the model agree fairly well with experimental results.

Conclusion & Future Work

In conclusion, the model was able to accurately predict much of the current measured on the inner cylinder, exit plate, and exit plate orifice can be attributed to current from charge-exchange (CEX) and elastic (MEX) collisions.

Future Work

- Add the secondary electron yield (energy, angle, and material dependent) from fast ions and fast neutrals hitting the walls
- Replace the semi-empirical equation for differential cross-section, which is only available for a 300eV and 1500eV beam, with a more general equation using first-principle collision dynamics
- Using COMSOL, implement test cell electrode voltage biasing and compare with experimental data



Vic = -100V
Left: Particle injected off axis at z = 0
Right: Particle injected off axis at z = L/4

References

R. Wirz et al., *Well-Characterized Plasma Experiments for Validation of Computational Models*, 32nd International Electric Propulsion Conference, 2011.

M. Scharfe et al, *DSMC Implementation of Experimentally-Based Xe+ + XE Differential Cross Sections for Electric Propulsion Modeling*, 2010

P.N. Giuliano and I.D. Boyd, *Effects of Detailed Charge Exchange Interactions in DSMC-PIC Simulation of a Simplified Plasma Test*, 2011