On the Ar^+ and Xe^+ velocities near the presheath-sheath boundary in an Ar/Xe discharge

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Introduction

- The question of how the velocities of ions are determined at the presheath-sheath boundary in plasmas with multiple-ion species is of fundamental interest
- In a weakly collisional plasma with a single ion species a presheath develops in the plasma and ions are accelerated to the Bohm speed (ion sound speed) at the presheath-sheath edge

$$u_{\rm B} = \left(\frac{eT_{\rm e}}{M}\right)^{1/2}$$

where $T_{\rm e}$ is the electron temperature and M is the ion mass (Bohm, 1949)

- For multiple-ion species there is a generalized Bohm criterion (Riemann, 1995)

$$\sum_j \left(\frac{n_j}{n_{\rm e}}\right)\frac{u_{{\rm B}j}^2}{u_j^2} \leq 1$$

where the sum is over the number of ion species, u_j is the ion drift velocity at the presheath-sheath edge, n_j is the ion density, $n_{\rm e}$ is the electron density, and the equality is usually assumed

- However, this criterion leads to an infinite number of possible solutions
- Two simple solutions are apparent
  - All ions reach the sheath edge with the same velocity, the ion sound speed of the system.
  - Each ion species has its own Bohm speed at the sheath edge
- To model the discharge we use the object oriented plasma device 1D (oopd1) 1d-3v particle-in-cell/Monte Carlo code (PIC/MCC)

Measurements of Ar^+ and Xe^+ velocities

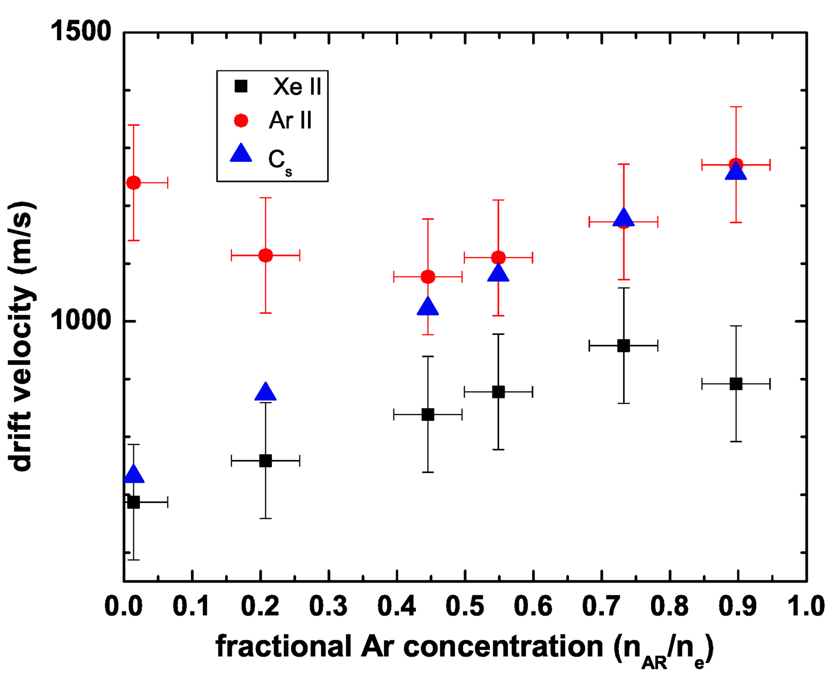


Figure 1: The measured drift velocities of Ar^+ and Xe^+-ions at the sheath edge versus the fractional Ar^+-ion concentration at 0.7 mTorr. From Yip et al. (2010).

- Measurements of Ar^+ and Xe^+ velocities indicate that the velocities approach the ion sound speed of the system near the sheath-presheath boundary for approximately equal ion concentrations
- When either ion concentration greatly differs from the other, each species leaves the plasma at its own Bohm velocity
- Recent theoretical work claims that for roughly equal densities of cold ions a collisional friction associated with ion-ion two stream instability will bring the two ion species drift velocities closer together, and each ion species leaves the plasma at the common sound speed (Baalrud et al., 2009)

Simulations to determine the Ar^+ and Xe^+ velocities

- The simulation attempts to model the multidipole experimental configuration described by Lee et al. (Lee et al., 2007, 2006) and (Yip et al., 2010)
- The simulation discharge is maintained between two equal-area electrodes (1.77×10^{-2} m^2) separated by a gap of 10 cm
- The left hand electrode is biased at -30 V to generate an ion sheath
- To model the ionization created by the energetic electrons in the multidipole chamber, we use a volume source with a uniform ionization rate of 4.3×10^{-19} $m^{-3}s^{-1}$ to maintain the steady state
- Electrons are created with electron temperature of 8.8 eV, and ions with temperature of 32 meV

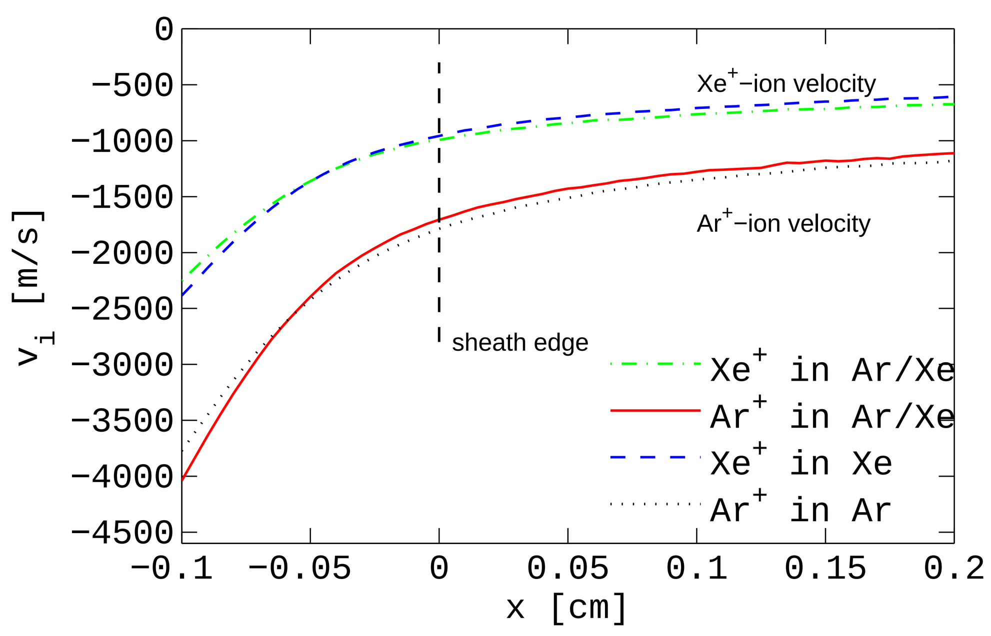
Results and discussion

- Earlier the simulations have shown that in the absence of ion-ion collisions, for a pure argon discharge the argon ion has almost the same velocity profile as it does in the mixture of argon and xenon. Similarly, for a xenon discharge the xenon ion has almost the same velocity profile as it does in the mixture of argon and xenon (Gudmundsson and Lieberman, 2011)
- Thus, each ion reaches its own Bohm speed at the presheath-sheath interface which contradicts the experimental findings of Lee et al. (2007) where the ion velocities approach the common ion sound speed for both ions in the Ar/Xe discharge
- These results have been challenged due to the lack of ion-ion Coulomb collisions in our simulations (Hershkowitz et al., 2012)
- Here we discuss the influence of adding ion-ion Coulomb interactions to the simulation as well as increased electron temperature
- We estimate the ion-ion Coulomb collision cross section by a Coulomb momentum transfer cross section and assume isotropic angular distribution of the scattered ions

$$\sigma = \pi b_0^2 \ln\Lambda$$

where $b_0 = e/(4\pi\epsilon_0\mathcal{E}_{\rm R})$ is the classical distance of closest approach and $\mathcal{E}_{\rm R}$ is the center-of-mass energy in eV and $\ln\Lambda = \ln(2\lambda_{\rm De}/b_0) \approx 13$ and $\lambda_{\rm De}$ is the Debye length for electrons.

- Figure 2 shows the velocity of argon and xenon ions versus distance from the biased plate shifted by the location presheath-sheath boundary for a pure argon discharge, an Ar/Xe discharge and a pure xenon discharge at 0.7 m Torr when ion-ion Coulomb collisions are included in the simulation.
- Each ion reaches its own Bohm speed at the presheath-sheath interface as seen in figure 3



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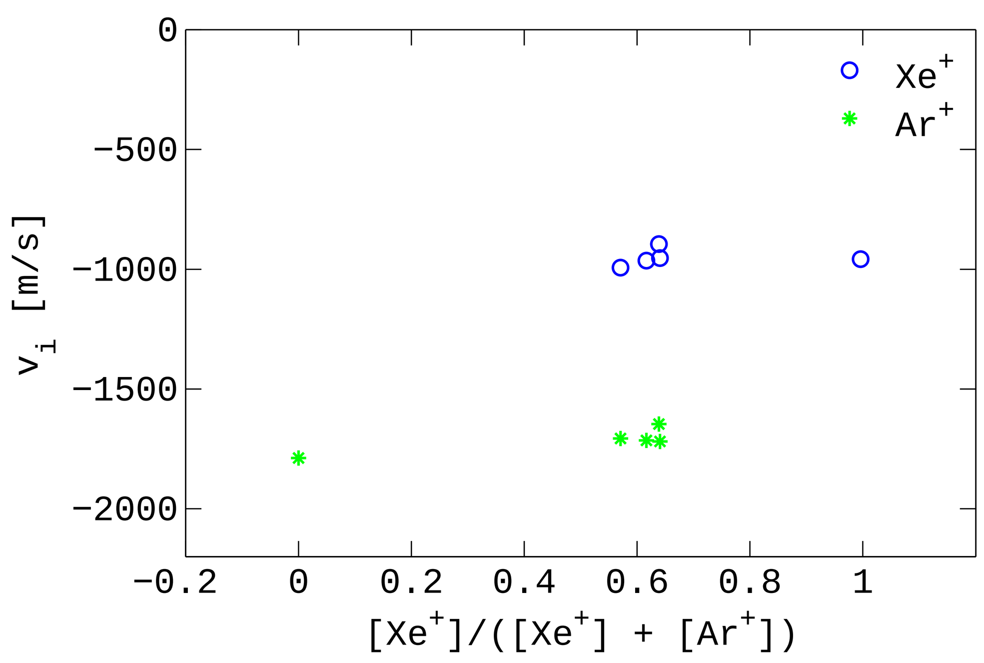
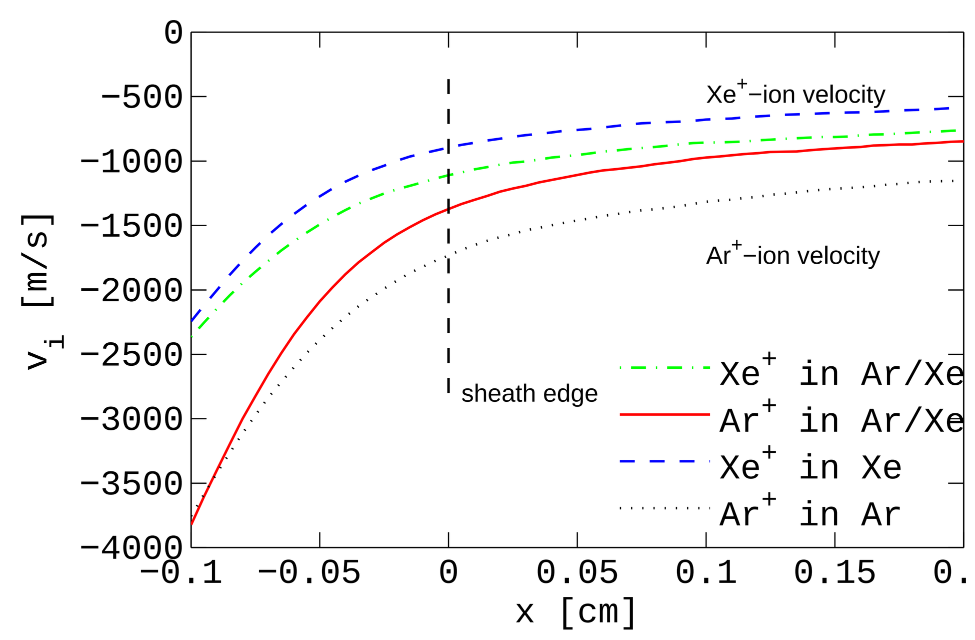


Figure 3: The velocity of argon and xenon ions at the presheath-sheath boundary versus the fractional Xe^+-ion concentration.

- Figure 4 shows the velocity of argon and xenon ions versus distance from the biased plate when ion-ion Coulomb collisions are included in the simulation and the cross section multiplied by a factor of 1000
- As the influence of the ion-ion Coulomb collisions are increased the ion velocities at the presheath-sheath interface approach each other if the ion concentration is similar but when either ion concentration greatly differs from the other, each species leaves the plasma at its own Bohm velocity as seen in figure 4



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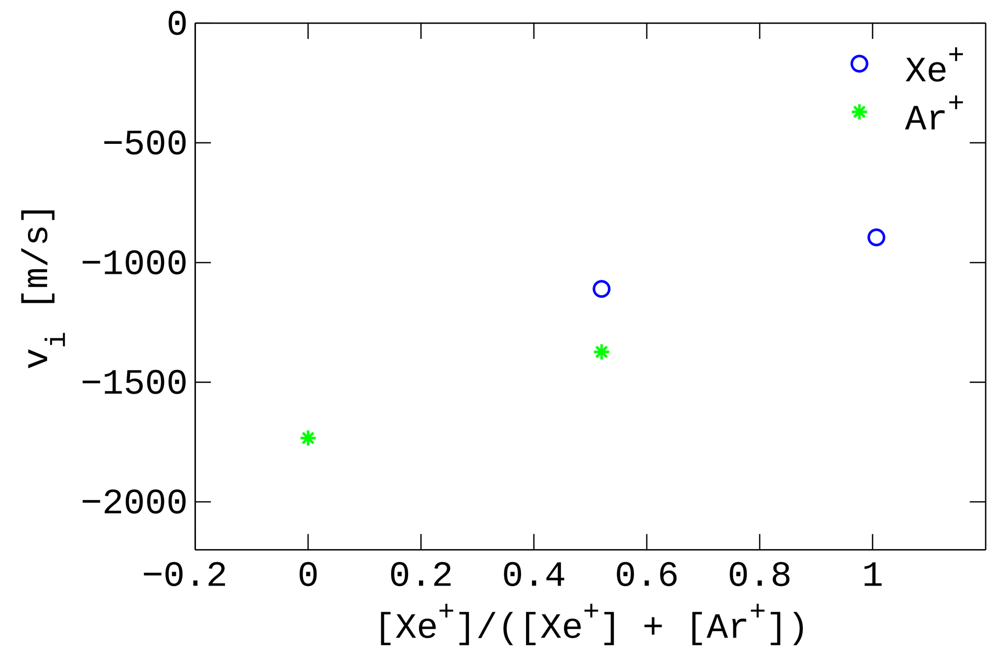

Figure 5: The velocity of argon and xenon ions at the presheath-sheath boundary versus the fractional Xe^+-ion concentration.

Conclusions

- We find that the velocity of argon and xenon ions at the presheath-sheath boundary and Ar/Xe plasma is influenced by ion-ion Coulomb collisions
- High ion-ion Coulomb collision cross section brings the two ion velocities closer together

Acknowledgments

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