Kinetic trajectory simulation method for interaction of magnetized plasma having two species of positive ions with tungsten surface

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Suresh Basnet and Raju Khanal*

Central Department of Physics, Tribhuvan University, Kirtipur, Kathmandu, Nepal

*Email: plasmanepal@hotmail.com

ABSTRACT

The kinetic trajectory simulation (KTS) method has been employed to study the plasma-wall interaction mechanism in the magnetized plasma with two species of positive ions exposed to the tungsten (W)-surface. This work is done when multi-component plasma interacts with W-surface through non-neutral plasma sheath formed near the Plasma Facing Materials (PFMs). It is assumed that two ion species have different temperatures with same degree of ionization. It is found that the ion velocity distribution functions have a cut-off Maxwellian distribution with almost equal magnitudes of cut-off and Maxwellian maximum velocities. The presheath electron temperature can significantly affect the ion velocity distribution functions, wall potential and ion flow, whose effect can be seen on the ion fluxes and current density at the wall. The wall potential is deviated from the analytical result by 1.86% in magnitude. In addition, the reflected concentration of both the ions decreases so that absorption rate increases; however, the lighter ion absorption is about 16% higher in magnitude than that of heavier ions for the W-surface (PFMs).

MODEL AND BASIC EQUATIONS

A model considered for magnetized plasma sheath that interacts with the W-surface is shown in Figure 1, where $x = D$ is the plasma injection side (sheath entrance) and $x = 0$ represents the material wall. The plasma consists of two species of singly charged positive ions (hydrogen H^+ and helium He^+) and electrons. The external magnetic field acts in the *x-y* plane, which makes an angle ψ with direction of electric field.

Vlasov equation: $\left[\vec{v}_j \cdot \nabla + \frac{e}{m_j}\left(\vec{E} + \vec{v}_j \times B_0\right)\cdot \nabla_v\right] f_j(\vec{r}, \vec{v}_j) = 0$

Poisson's equation: $\varepsilon_0 \nabla^2 \phi = -e(n_1 + n_2 - n_e)$

Electron density distribution: $n^e(\phi) = n^e_{ps} \exp\left(\frac{e\phi}{T^e}\right)\left[\frac{1 + Erf\sqrt{\frac{e(\phi-\phi_w)}{T_e}}}{1 + Erf\sqrt{\frac{-e\phi_w}{T^e}}}\right]$

Ion velocity distribution:

$$f^i_j(x, \vec{v}^i_j) = A^i_j \exp\left[-\frac{\left(v^i_{jx} - v^i_{jxm,D}\right)^2 + v^{i\,2}_{jy} + v^{i\,2}_{jz}}{v^{i\,2}_{jt}} + \frac{e\phi}{T^i_j}\right] \times \Theta\left(-v^i_{jx}\right)$$

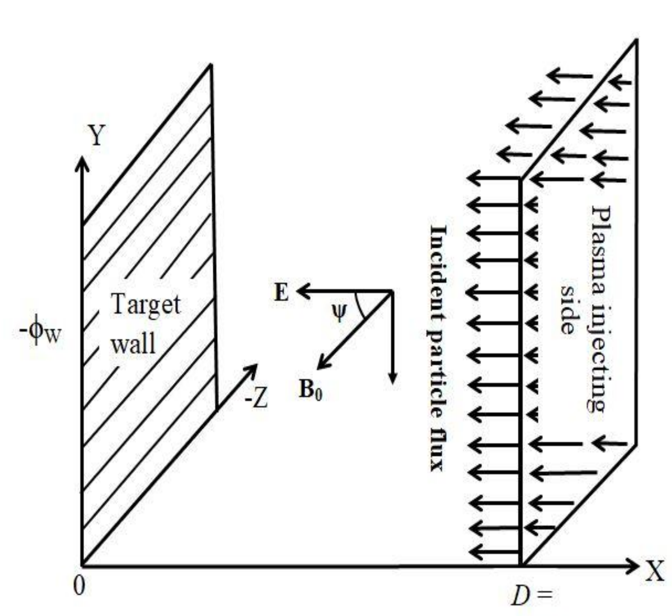

Figure 1: Schematic geometry of magnetized plasma-wall interaction.

Theoretical value of wall potential :

$$\frac{e\phi_w}{T^e} = -\ln(1+\delta_i) + \ln\left[\left(\frac{2\pi m^e}{m^i_1}\right)^{1/2}\left(\frac{T^e_{ps} + \gamma^i T^i_{1ps}}{T^e}\right)^{1/2} + \frac{\delta_i}{\sqrt{\mu_i}}\left(\frac{T^e_{ps} + \gamma^i T^i_{2ps}}{T^e}\right)^{1/2}\right]$$

Particle reflection coefficient for normal incidence:

$$R^i_{jN} = \frac{A_{j1}\ln\left(A_{j2}\,\varepsilon_{Tj} + 2.718\right)}{1 + A_{j3}(\varepsilon_{Tj})^{A_{j4}} + A_{j5}(\varepsilon_{Tj})^{A_{j6}}} \quad \text{where } \varepsilon_{Tj} = \frac{m_t}{m_t + m^i_j}\frac{E^i_j}{Z_t Z^i_j} a_L \text{ is the}$$

Thomas Fermi-reduced energy with Lindhard screening length is given by

$$a_L = \left(\frac{9\pi^2}{128}\right)^{1/3} a_0 \left(Z^{2/3}_t + Z^{2/3}_j\right)^{-1/2}$$

The reflected and absorbed ion density:

$$n^i_{jR} = R^i_{jN}\, n^i_{jw} \text{ and } n^i_{jA} = R^i_{jA}\, n^i_{jw}$$

RESULTS:

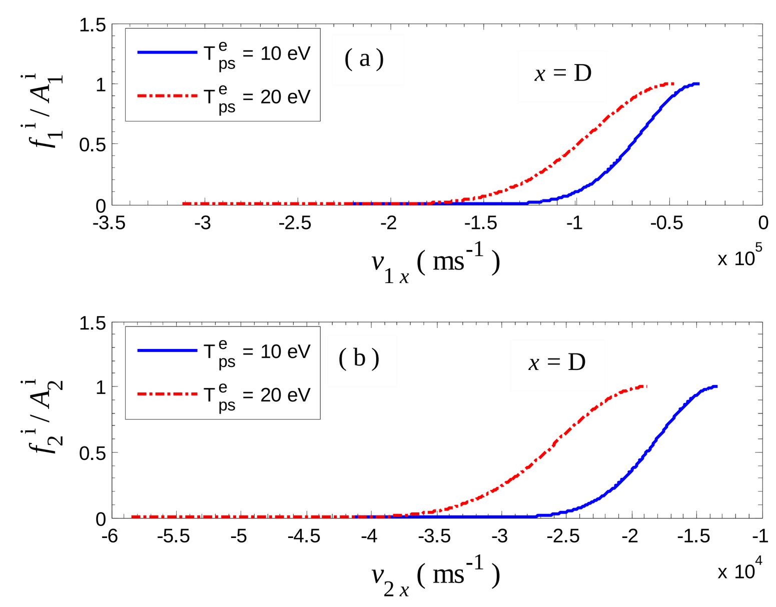

Figure 2: Ion velocity distributions at particle injection side (a) hydrogen ions (b) helium ions.

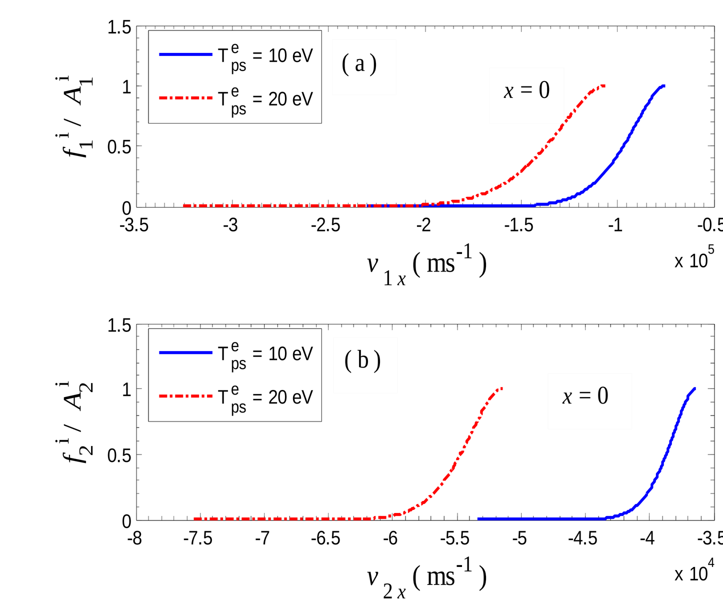

Figure 3: Ion velocity distributions at the wall (a) hydrogen ions (b) helium ions.

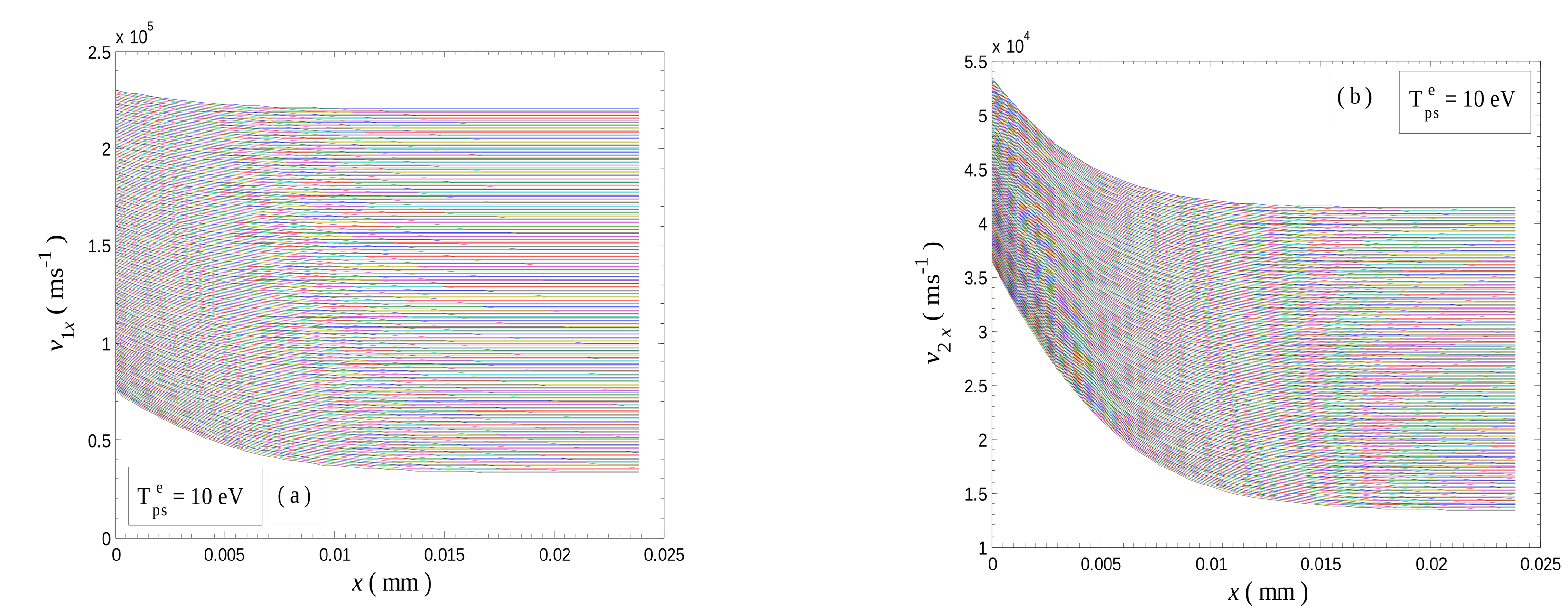

Figure 4: Phase-space ion trajectories (a) for hydrogen ions (b) for helium ions.

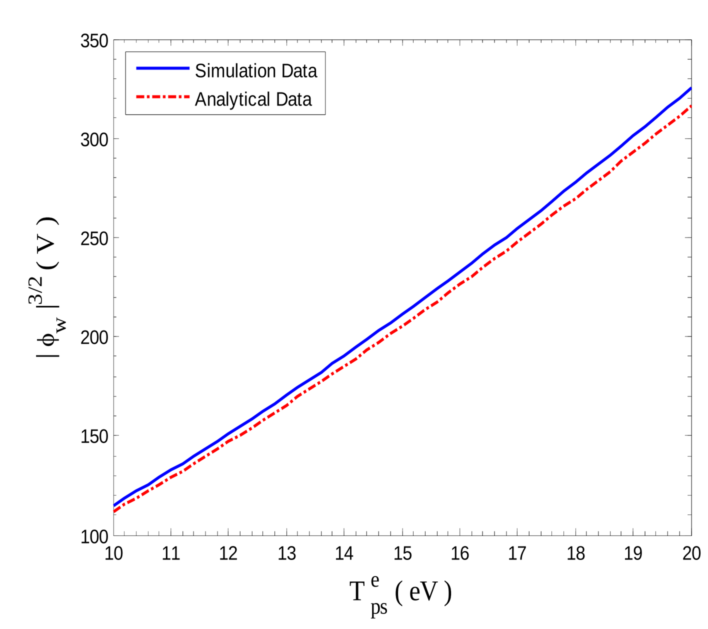

Figure 5: Variation of wall potential with presheath electron temperature.

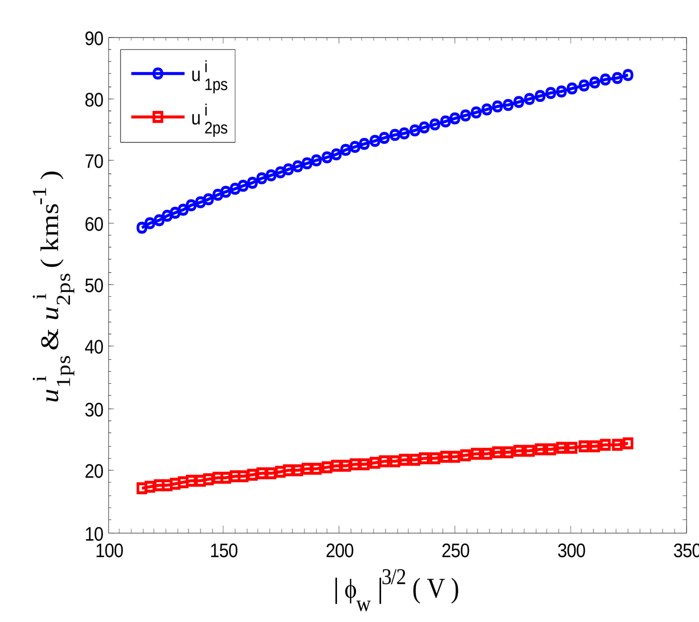

Figure 6: Variation of presheath ions velocities.

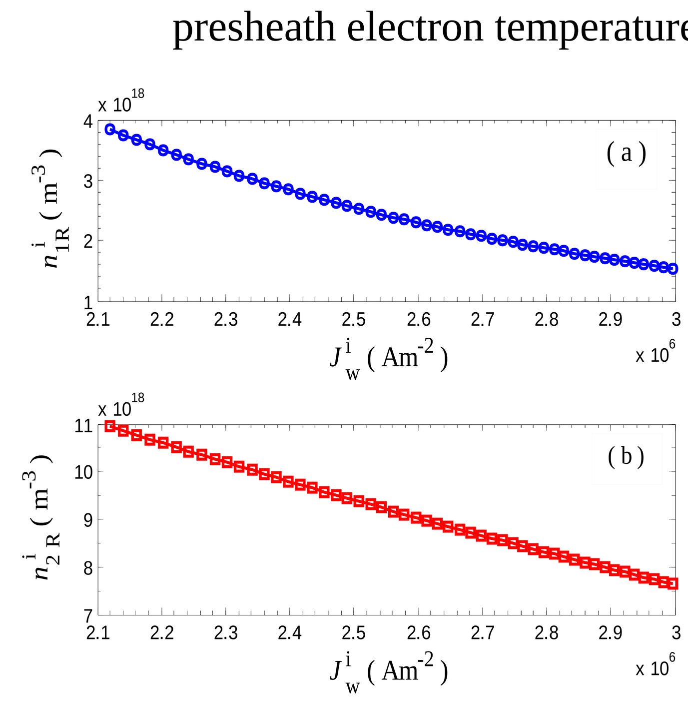

Figure 7: Reflected ion densities.

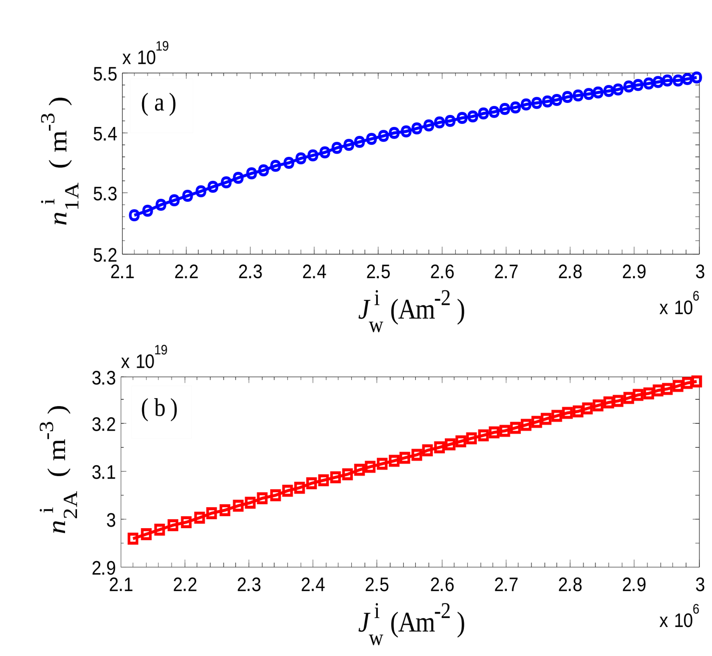

Figure 8: Absorbed ion densities.

CONCLUSIONS:

- The present work confirms that the electron temperature, wall potential, incident ion fluxes and ion current reaching the wall have considerable effects on plasma-wall transition process.
- The magnitude of wall potential increased for the increase in presheath electron temperature and it is found that the value of wall potential is higher about 1.86% in magnitude compared to the analytical result.
- The velocity of both ions at the presheath side increased for the increase in wall potential; however, the increment rate for lighter ions is higher than that of heavier ions .
- The W-surface has higher value of ion absorption coefficient for lighter ions than that for heavier ions.

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