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Effects of ion temperature on collisionless magnetized plasma Sheath structure

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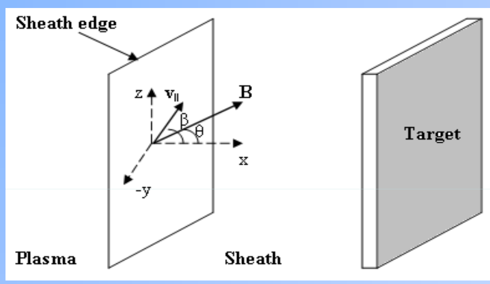
Abstract

The basic problem of plasma flowing into a wall is important in many aspects of plasma physics and understanding sheaths is of great interest to several fields ranging from material processing to magnetic confinement fusion.
It is clear that the conditions at the sheath edge can affect the characteristic of ions in a magnetized plasma sheath. By using the two-fluid model a collisionless plasma sheath is investigated in the presence of oblique external magnetic field. The ion temperature effect is considered for several ion beam divergency at the sheath edge. The initial ion velocity is chosen in order to satisfy the Bohm sheath criterion. The number and momentum equations of the ions, the Boltzmann distribution of the electrons and Poisson equation are solved numerically. It is shown that the ion temperature has significant effect on the sheath behavior when the incidence angle of the ion beam velocity at the sheath edge is great than the magnetic field angle, such as electric potential, charged particles densities and ion velocity.

The magnetized plasma sheath model

We consider a collisionless magnetized plasma sheath, which has one-dimensional space coordinate and three-dimensional speed coordinates. To consider the ion beam divergency at the sheath edge, we consider the initial ion velocity as $\mathbf{v}_{i0}=(\mathbf{v}_\perp,\mathbf{v}_\parallel)$.The external oblique magnetic field is spatially uniform, constant in time and lies in the (x, z) plane.



Geometry of the magnetic sheath

The governing equations of the model

> For the electrons in a thermal equilibrium:

$$n_e(r) = n_0 \exp\left(\frac{e\phi(r)}{kT_e}\right) \quad (1)$$

> For the ions as a fluid:

$$\vec{\nabla}(n_i\vec{v}_i) = 0 \quad (2)$$

$$m_i\vec{v}_i\vec{\nabla}\vec{v}_i = -e\vec{\nabla}\phi + e\vec{v}_i \wedge \vec{B} - \frac{\vec{\nabla}p_i}{n_i} \quad (3)$$

> The Poisson's equation:

$$\frac{\partial^2\phi}{\partial x^2} = -\frac{e}{\varepsilon_0}(n_i - n_e) \quad (4)$$

Dimensionless variables:

$$\eta = -\frac{e\phi}{T_e},\quad \xi = \frac{x}{\lambda_D},\quad \vec{u}_i = \frac{\vec{v}_i}{C_{is}},\quad N_e = \frac{n_e}{n_{e0}},\quad N_i = \frac{n_i}{n_{i0}}. \quad (5)$$

Dimensionless equations:

Using these variables, equations (1)-(4) can be reduced to the following system:

$$N_e = \exp(-\eta) \quad (6)$$

$$N_i = \frac{M}{u_{ix}} \quad (7)$$

$$u_{ix}\frac{\partial u_{ix}}{\partial \xi} = \frac{1}{1-\frac{T}{u_{ix}^2}}\left(\frac{\partial \eta}{\partial \xi} + \gamma u_{iy}\sin\theta\right) \quad (8)$$

$$u_{ix}\frac{\partial u_{iy}}{\partial \xi} = \gamma(u_{iz}\cos\theta - u_{ix}\sin\theta) \quad (9)$$

$$u_{ix}\frac{\partial u_{iz}}{\partial \xi} = -\gamma u_{iy}\cos\theta \quad (10)$$

$$\frac{\partial^2\eta}{\partial \xi^2} = \frac{M}{u_{ix}} - \exp(-\eta) \quad (11)$$

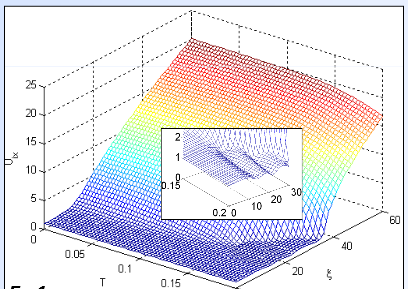
Numerical results and discussion

Eqs.(6)-(11) can be used to find the characteristics of the ions in a magnetized collisionless sheath under the effect of ion temperature. The boundary conditions and the parameters used for the numerical calculations are as follows: when $\xi\rightarrow 0$: $\eta\rightarrow 0$, $\eta'_0=0.01$; $u_{x0}=1$, $u_{y0}=-0.07$, $\beta=15°$; $\gamma=0.2$, $\theta=10°$.

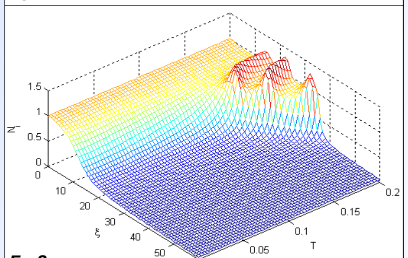
Fg.1 shows the normalized ion velocity as a functions of normalized distance ξ and ion to electron temperature ratio T, for β=15°. When β≤θ The ion velocity is weakly affected by increasing the ion temperature. But for β>θ, the ion velocity oscillates around their initial value up to ξ≈40 when the ion temperature ratio is greater than a critical thermal point, $T>T_{ic}=0.15$eV.

The normalized ion density distribution is shown in Fg.2. According to the ion continuity equation (Eq.7), the normalized ion density is inversely proportional to the ion x-component velocity in a steady state, therefore, the ion density distribution fluctuates when $T_i>T_{ic}$ up to ξ=40 then decreases along the ξ-axis direction.

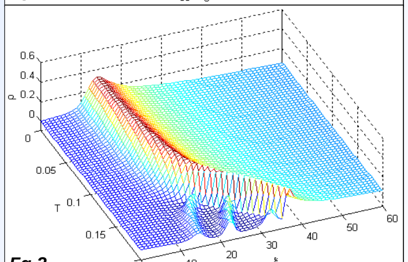
Fg.3 shows the normalized space charge density distribution as a function of ion to electron temperature ratio, and normalized distance from the plasma-sheath interface. Because of the characteristic of density distribution of ions and electrons, the space charge density distribution curve has a peak, which indicates that in this region, more positive particles gather. By increasing the ion temperature the peak approach to the wall. For $T>T_{ic}$, the ions could gather on some regions, in this area the sheath criterion is not satisfied. For these values, the electric potential oscillates around its initial value (η=0), Fig.4.



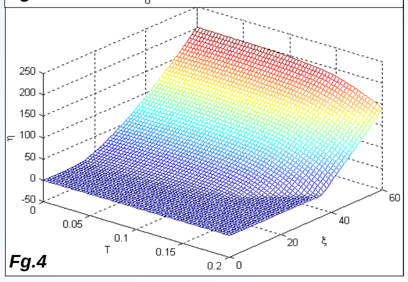
Fg.1



Fg.2



Fg.3



Fg.4

Conclusion

In this work the two- fluid model is solved numerically in the case that the ion beam has a small divergency at the plasma sheath edge and for different oblique angles of magnetic field. The dependence of the Bohm magnetized sheath criterion to ion temperature is examined. It is shown that the ion temperature has significant effects on the characteristics of the ions in the sheath. The effect depends strongly on both the magnetic field and the divergency of the ion beam at the sheath edge.