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Computational Analysis of Average Value and Amplitude in Magnetized Plasma Sheath

Bhesha Raj Adhikari*
Department of Physics, Bhaktapur Multiple Campus
Tribhuvan University, Nepal

Abstract
For different obliqueness, ion velocity has been investigated numerically. Ions which are in-streaming have to satisfy the criterion of Bohm-Chodura, to ensure the stability of plasma. Mean value as well as maximum/minimum amplitude is computed with different angles. Mean value of x-component is almost zero for all angles, whereas for y and z-component, mean value changes with different angles. On the other hand maximum amplitude almost changes for all angles. Ion velocity at presheath-sheath boundary, is affected by obliqueness of the field.

Keywords: Plasma sheath, presheath, Bohm-Chodura criterion, kinetic theory, maximum amplitude

Introduction

Analysis of mean value and maximum/minimum amplitude of velocity of ions, with different angles is recent field of research, in plasma physics [1-3]. In recent year, sheath formation between magnetic plasma and the wall, received attention for researchers [4-9]. Confining the plasma in closed surface, there is interaction of plasma with material surface.When the plasma is confined in any closed surface, it is obvious that the plasma interacts with the material surfaces, which is very important in different types of application, e.g plasma fusion, etching, material processing, medicine, agriculture and many more [13]. As the plasma–wall interaction is well understood, it will be possible to control heat loading, energy transfer and particle flow towards the wall [4, 5].

In this problem, there is shielding of a quasi-neutral plasma from negative wall by a "thin" region which is positive space charge named as sheath, whose thickness is of several electron Debye lengths, . In the usual case, <<L, where L is length of the plasma boundary layer. Sheath can only be formed, if the Bohm criterion [4-6] is fulfilled. Such sheath formation condition, demands that, the ions enter the sheath region with a high velocity [4]. In its kinetic form, for without magnetic field, this criterion may be written as.

where, $\left\langle \frac{1}{v^2} \right\rangle \le \frac{1}{{C_s}^2}$ (1)

* Correspondence: b.r.adhikari@hotmail.com

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$$C_s = \sqrt{\frac{k(\gamma^i T_B^i + \gamma^e T_B^e)}{m^i}} \tag{2}$$

is the ion-acoustic velocity, with k as Boltzmann constant, γ^i and γ^e the ion and electron polytropic constants, respectively, and T_B^i and T_B^e the ion and electron temperatures at the presheath side of the sheath edge, respectively [1, 4].

In oblique magnetic field case, above condition, is modified as Bohm-Chodura condition. [4].

$$v \geq C_s \cos\theta \tag{3}$$

This study is important, to see the change in the particle dynamics, the particle wall interaction, in magnetized case. Irrespective of this, this is significantly influencing, the charged particles, and the energy flux to the wall, which modifies the absorption, emission impurities and all other characteristics in the plasma [7]. We have used the Kinetic Trajectory Simulation (KTS) model [10, 12] to obtain solution to a non-neutral, time independent, collisionless plasma sheath.

Basic Principle of KTS Method

The fundamental equation which $f(\vec{r}, \vec{v}, t)$ has to satisfy is the Boltzmann equation [7].

$$\frac{\partial f}{\partial t} + \vec{v}.\nabla f + \frac{\vec{F}}{m}.\nabla_v f = \left(\frac{df}{dt}\right)_c \tag{4}$$

where $\vec{F}$ is the force on the particles, and $\left(\frac{df}{dt}\right)_c$ is the time rate of change of f due to collisions. The symbol ∇ stands for the gradient in (x, y, z) space. The symbol ∇_v stands for the gradient in velocity space, and $f(\vec{r}, \vec{v}, t)$ is a velocity distribution function.

In collisionsless cases the equation is [11]:

$$\frac{\partial f}{\partial t} + \vec{v}.\nabla f + \frac{q}{m}(\vec{E} + \vec{v} \times \vec{B})\nabla_v f = 0 \tag{5}$$

Plasma sheath model: The model of our work in 1d3v case is shown in Figure 1.

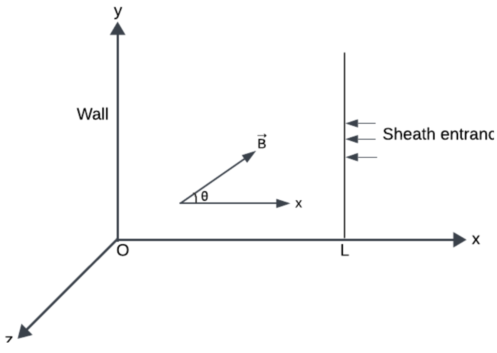

Figure 1. Diagram of the plasma sheath model

The region of simulation is bounded by two parallel planes, situated at x=0 and x=L .These planes have specified, x=L as the "plasma entrance" and an material wall is specified by x=0. The angle between the oblique magnetic field, with along the x-axis be θ. The simulation region, having two boundaries are perfectly absorbing, and does not emit any particles. Consider the plasma particles enter the simulation region from the plasma entrance wall with cut off Maxwellian velocity distribution functions.

$$f^i(L,v) = A^i exp\left[-\left(\frac{(v_x - v^i_{mL})^2 + v_y^2 + v_z^2}{v_t^{i2}}\right)\right]\Theta(v^i_{cL} - v_x) \quad (6)$$

where $v_t^s = \sqrt{\frac{2kT^s}{m^s}}$ is the species-s (ion and electron) thermal velocity,v^i_{mL} is the ion "Maxwellian-maximum" velocity at $x=L$ and v^i_{cl} ($v^i_{cl} < 0$) is the ion cut off velocity, at $x=L$.

Velocity of ions, with various components, have been computed, by Lorentz force equation [14]

$$m\frac{d\vec{v}}{dt} = q(\vec{v}\times\vec{B}) + q\vec{E} \quad (7)$$

Results and Discussion

The obliqueness dependency of velocity component of ions with mean value and maximum/ minimum amplitude have been calculated for magnetic field 3 mT. The computed results are shown in Figure 2 and Figure 3.

The overall variation of mean value of velocity components, at different obliqueness, is shown in Figure 2, which shows mean value of x-component is nearly equal to zero for all angles at magnetic field 3 mT whereas for y- component, mean value is nearly zero at an angle 0˚. Then after, it gradually increases up to 11570 ms^{-1} at obliqueness 75˚, and then it decreases monotonically up to 9794 ms^{-1} at obliqueness 90˚. On the other hand, mean value of z-component of velocity started from 9794 ms^{-1} at obliqueness 0˚. Then after, it monotonically increases up to 11800 ms^{-1} at obliqueness 25˚, and then it monotonically decreases up to zero at obliqueness 90˚. The results of our work agree with previous work and hence our espectetion provide a basis for studying ion behavior in magnetized case.

Figure 2. Variation of mean values of velocity with respect to angles at magnetic field 3 mT

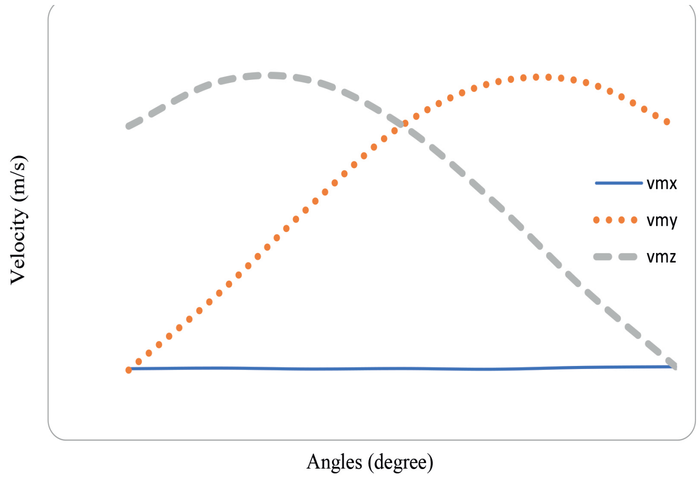

Figure 3 shows the overall variation of maximum amplitude, of different component of velocity with respect to different obliqueness, at magnetic field 3 mT. Maximum amplitude of x-component of velocity started from 13412 ms^{-1} at obliqueness 0˚. Then after, it gradually decreases until 9824 ms^{-1} at obliqueness 30˚, then remains almost constant up to obliqueness nearly 70˚, then slightly increases to 12358 ms^{-1} at obliqueness 90˚. Likewise, maximum amplitude of y-component of velocity started from 12524 ms^{-1} at angle 0˚, then it gradually decreases up to 4580 ms^{-1} at an angle 60˚, then it increases up to 14475 ms^{-1} at angle 75˚, then after again decreases up to zero at an angle 90˚. Finally, maximum amplitude of z-component of velocity started from zero at an angle 0˚, and then it increases up to 13312 ms^{-1} at obliqueness 90˚.

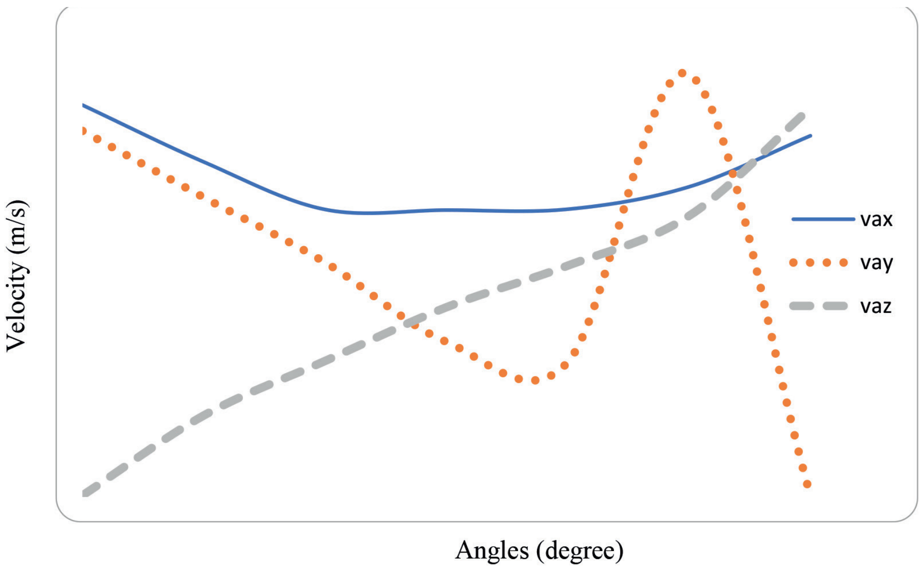

Figure 3. Variation of maximum and minimum amplitude of velocity with respect to angles at magnetic field 3 mT

Conclusion

We developed the scheme of mean value and amplitude variation for magnetized plasma sheath. It has been observed that, velocity of ions reaching the material wall can be controlled by strength of applied magnetic field. Ion velocity increases towards the wall, as obliqueness increases. At presheath-sheath boundary ion velocity is affected by obliqueness Our work is important, in different field like fusion devices, agriculture, cancer treatment, teeth treatment and many more. This study is helpful, to develop, and evaluate the solution of presheath – sheath coupling problem. Our work is helpful to extend 1d1v KTS model to 1d3v as well as 3d3v model.

References

Chodura R. Plasma-wall transition in an oblique magnetic field. The Physics of Fluids.1982; 25 (9): 1628.

Chalise R, Khanal R. A kinetic trajectory simulation model for magnetized plasma sheath. Plasma Physics and Controlled Fusion. 2012; 54 (9): 095006

Chodura R. Physics of plasma-wall transition in controlled fusion. Plenum, New York. 1986; p. 99.

Riemann KU. The Bohm criterion and sheath formation. Journal of Physics D: Applied Physics. 1991; 24 (4): 493.

Riemann KU. Theory of the plasma sheath transition. Journal of Technical Physics. 2000; 41 (1): 89.

Khanal R. A kinetic trajectory simulation (KTS) model for bounded plasmas. Na; 2002.

Chen FF. Introduction to Plasma Physics and Controlled Fusion (3rd edition), Plenum Pres, New York. 2016..

Chauhan S, Ranjan M, Bandyopadhyay M, Mukherjee S. Droplet shaped anode double layer and electron sheath formation in magnetically constricted anode. Physics of Plasmas. 2016; 23(1): 013502.

Adhikari BR, Basnet S, Lamichhane HP, Khanal R. Presheath-sheath coupling for kinetic trajectory simulation of a magnetized plasma sheath. AIP Advances. 2019; 9(5):055123.

Adhikari BR, Lamichhane HP, Khanal R. Modulation frequency and velocity variation of ions in a magnetized plasma sheath for different obliqueness of the magnetic field. BIBECHANA. 2021; 18: 147.

Adhikari BR, Basnet S, Lamichhane HP, Khanal R. Variation of velocity of ions in a magnetized plasma sheath for different magnetic field. Journal of Nepal Physical Society. 2020; 6(1): 25.

Chalise R, Khanal R. Self consistent one dimension in space and three dimension in velocity KTS model of magnetized plasma-wall transition. Physics of Plasmas. 2015; 22:1135051.

Adhikari BR, Lamichhane HP, Khanal R. Variation of mean value of velocity of ion with different obliqueness of magnetized plasma sheath. Him. Phys. 2020; 9:53.

Adhikari BR, Khanal R. Study of fitted and computed plots in magnetized plasma sheath. BMC Journal of Scientific research. 2022; 5: 11.