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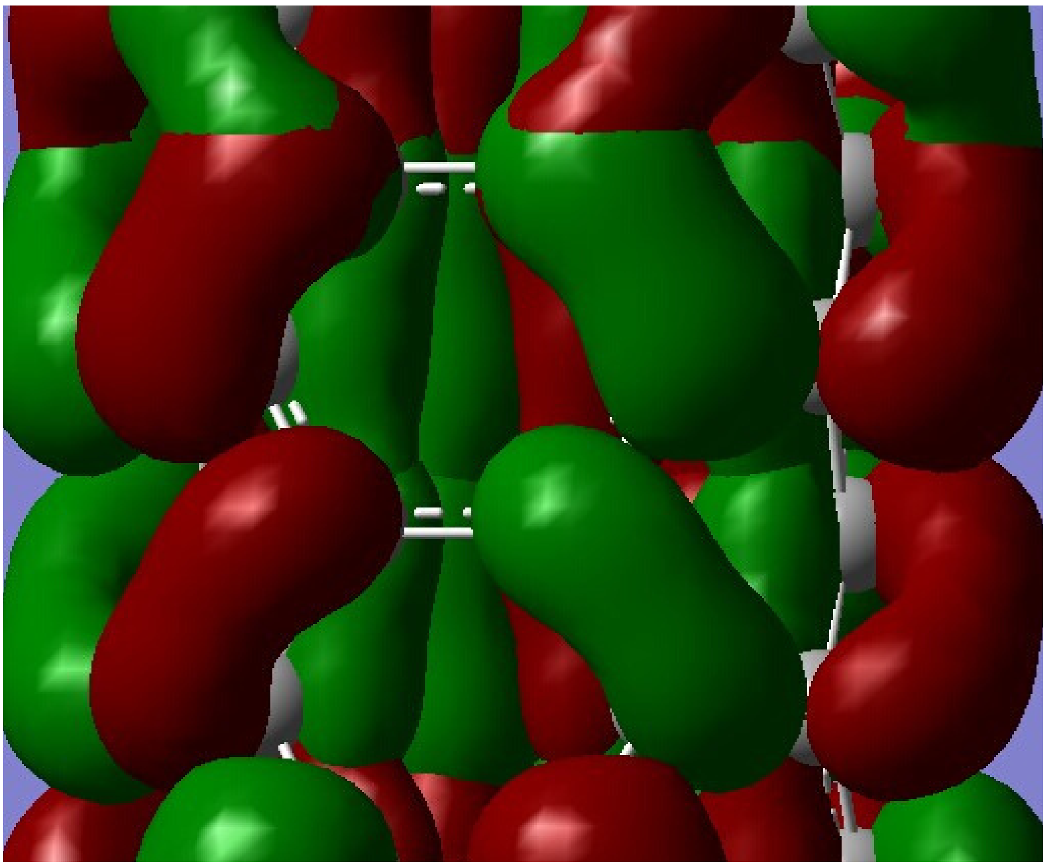

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Variation of velocity component of ions in a magnetized plasma sheath for different obliqueness of the magnetic field

Research Article

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Abstract: Frequency of oscillation and velocity variation of different component of ions in a magnetized plasma sheath has been numerically investigated by using a kinetic trajectory simulation model for varying obliqueness at constant magnetic field. By varying obliqueness average value, maximum amplitude, damping factor and frequency of oscillation of velocity components at magnetic field 8 mT have been studied. Due to the change in obliqueness of the field the average values as well as the maximum amplitude of the three components of the velocity also change but frequency of oscillation almost remains same. In this case also there is small change in damping factor as well.

Keywords: Magnetized plasma sheath • Bohm-Chodura condition • Frequency of oscillation • Kinetic theory • Mean value • Damping factor

1. Introduction

Velocity variation and frequency of oscillation of various components of ions for varying obliqueness is a new field of research [1–4]. Plasma sheath study is an old but now a days it is not a finished solved problem which is useful in different areas of plasma physics [5]. Works of both experiment and theory have been developed widely during the past several years and yet are still not fully understood [1–4, 6–10]. In recent years, the sheath formed between magnetic plasma and a particle absorbing wall has received a considerable amount of attention [6–15]. When the plasma is confined in any closed surface, it is obvious that the plasma interacts with the material surfaces so that the proper understanding of this interaction with the material surface is very important in all plasma applications (e.g. plasma confinement for fusion, sputtering, etching, surface treatment, etc) [8]. Once the plasma–wall interaction is well understood it will be possible to control heat loading, energy transfer and particle flow towards the wall and overall bulk plasma behaviour [3, 4].

To sheath, the in streaming ions at the sheath edge have to satisfy the condition called the Bohm criterion [3, 4, 6–17] . A magnetized plasma sheath is responsible for the flow of charged particles and energy towards the

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wall. In this work, we introduce and describe a new self consistent 1d3v Kinetic Trajectory Simulation (KTS) applicable for studying the magnetized PWT region.

The importance of this study is to see the change in the particle dynamics as well as the particle wall interaction in magnetized plasma sheath. Irrespective of this, plasma sheath is significantly influencing the charged particles and the energy flux to the wall, which in turn considerably modifies the absorption, emission impurities and all other characteristics in the plasma [8]. We have used the Kinetic Trajectory Simulation (KTS) model [13–17] to obtain solution to a non-neutral, time independent, collisionless plasma sheath and hence studied the ion velocities in a magnetized plasma sheath for different obliqueness of the field. This paper is organized as follows: In section 2 we discuss the basic principle of the KTS method in a simplified form. In this section we explain the distribution function in the collision less case. In section 3 we discuss about our magnetized plasma sheath model. In this section we apply Lorentz force equation which is solved by Runge-Kutta method in MATLAB using boundary condition. In section 4 we obtain the result in graphical form and we discuss about our result. Finally we summarize our work and draw conclusions.

2. Basic principle of KTS method

The fundamental equation which has to satisfy is the Boltzmann equation [8].

$$\frac{\partial f}{\partial t} + \vec{v}.\nabla f + \frac{\vec{F}}{m}.\nabla_v f = \left(\frac{df}{dt}\right)_c \tag{1}$$

where $\vec{F}$ is the force acting 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 collisionless cases the equation is called the Vlasov equation:

$$\frac{\partial f}{\partial t} + \vec{v}.\nabla f + \frac{q}{m}(\vec{E} + \vec{v} \times \vec{B}).\nabla_v f = 0 \tag{2}$$

In the KTS method we solve the kinetic equation along with other basic equations describing the plasma for given boundary and initial conditions. The distribution function at any point along the trajectory can be obtained if its value at one point (i.e., at the boundary) is known. Then density of the species ‘s’ is given by

$$n^s(\vec{x}) = \int_{-\infty}^{+\infty} d^3v f^s(\vec{x}, \vec{v}) \tag{3}$$

The space charge density is defined as

$$\rho(\vec{x}) = \sum_s q^s n^s(\vec{x}) \tag{4}$$

The electrostatic potential $\phi(x)$ is to be found from poisson’s equation

$$\frac{d^2\phi(\vec{x})}{dx^2} = -\frac{\rho(\vec{x})}{\epsilon_0}, \tag{5}$$

and the electric field is given by

$$E(\vec{x}) = -\frac{d\phi(\vec{x})}{dx} \tag{6}$$

In our simulation, we solve Eqs. 1-6 along the collisionless trajectories for given boundary conditions.

3. Plasma sheath model

The 1d3v model of magnetized plasma sheath is shown schematically in Figure 1.

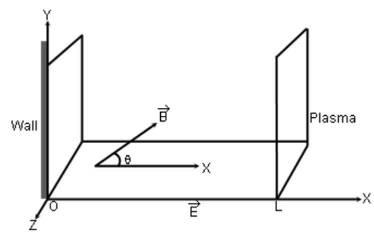

Figure 1. Schematic diagram of the plasma sheath model

The simulation region considered is bounded by two parallel planes situated at $x = 0$ and $x = L$ and the plasma consists of only electrons and singly charged ions. We have specified $x = L$ as the "sheath entrance" which separates the non-neutral, collision less sheath region ($x < L$) from the quasineutral collisional presheath region ($x > L$). Similarly, an absorbing wall is specified by $x = 0$. We assuming the angle between the oblique magnetic magnetic field with along the x-axis or electric field to be θ . The magnetic field lies in the x-y plane . We suppose the plasma particles (electrons and ions) enter the simulation region from the sheath entrance with cut off Maxwellian velocity distribution functions, the wall doesn't emit any particles and that both boundaries are perfectly absorbing. Accordingly, the electron velocity distribution function is given by

$$f^e(x,v) = A^e \exp\left[-\left(\frac{v_x^2 + V_y^2 + v_z^2}{v_{tf}^2}\right) + \frac{e\phi(\vec{x})}{kT_e}\right]\Theta\Big[v_{cL}^e(x) - v_x\Big] \tag{7}$$

where $v_c^e(x) = \sqrt{\frac{2e[\phi(x)-\phi_0]}{m^e}}$ is the electron cut off velocity at x, k is the Boltzmann constant and $\Theta(x)$ is the Heaviside function i.e.,

$$\Theta(x) = \begin{cases} 1 & \text{if} x \geq 0 \\ 0 & \text{otherwise.} \end{cases} \tag{8}$$

The ion velocity distribution function at $x = L$ is given by,

$$f^i(L,v) = A^i \exp\left[-\left(\frac{(v_x - v_{mL}^i)^2 + v_y^2 + v_z^2}{v_{tf}^{i2}}\right)\right]\Theta(v_{cL}^i - v_x) \tag{9}$$

where,$v_{tf}^{s} = \sqrt{\frac{2kT^5}{m^s}}$ is the species (ion and electron) thermal velocity, v_{ml}^{i} is the ion "Maxwellian-maximum" velocity at $x = L$ and v_{cL}^{i} ($v_{cL}^{i} < 0$) is the ion cut off velocity at $x = L$. In the core plasma the particle distribution would obviously be Maxwellian, however, in case of sheath formation the ions are accelerated towards the wall so that they become shifted Maxwellian as given by Eq. 9. In addition, for the Bohm criterion to be satisfied by the ions they must have attained certain minimum velocity (v_{cL}^{i}) at the sheath entrance. As the electrons are retracted and reflected by the negative potential wall their distribution gets cut-off at the sheath entrance as given by Eq. 7.

For the velocity distribution given by Eq. 9, we can evaluate Eq. 3 for electron density at $x = L$ as

$$n_L^e(x) = A^e \int_{-\infty}^{+\infty} dv_x \int_{-\infty}^{+\infty} dv_y \int_{-\infty}^{+\infty} dv_z \left[- \left(\frac{v_x^2 + v_y^2 + v_z^2}{v_{tf}^{e2}} \right) \right] \Theta(v_{cL}^e - v_x) \tag{10}$$

Now, from the velocity distribution function (Eqs. 9 and 3), we get ion density as

$$n_L^i = A^i \int_{-\infty}^{+\infty} dv_x \int_{-\infty}^{+\infty} dv_y \int_{-\infty}^{+\infty} dv_z \left[- \left(\frac{(v_x - v_{mL}^i)^2 + v_y^2 + v_z^2}{v_{tf}^{i2}} \right) \right] \Theta(v_{cL}^i - v_x) \tag{11}$$

In order to obtain the electron density profile, we require $\phi(x)$ to be known. In our calculation, we obtain $\phi(x)$ only at the grid points x_j so that we obtain the electron density at these points in terms of potential as

$$n^e(\phi) = n_L^e \exp\left[\frac{e\phi(x)}{kT_f^e}\right] \left[\frac{1 + erf\sqrt{\frac{e(\phi(x)-\phi_0)}{kT_f^e}}}{1 + erf\sqrt{\frac{-e\phi_0}{kT_f^e}}} \right] \tag{12}$$

Hence, one can obtain the electron density at any point if the potential profile is known. Different components of velocity of ions in the plasma sheath have been computed applying Lorentz force equation

$$\vec{F} = q(\vec{v} \times \vec{B}) + q\vec{E} \tag{13}$$

4. Results And Discussion

The time dependency of velocity component of ions have been calculated for magnetic field 8 mT at different obliqueness (30°, 60° and 75°) respectively. The results of calculation are shown Figs. 2 to 4. In Fig. 2 at angle 30° initial values of x, y, and z-component are same and started from the initial value equal to 9794 ms^{-1}. The x, y and z-component of velocity attains the average value of nearly equal to 0.0003 , 6668 and 11600 ms^{-1} respectively. Before getting the stabilized values (average values) the x-component of velocity oscillates with maximum amplitude as 2761.999 ms^{-1}. Similarly maximum amplitude of y and z-component is 3576 and 2060 ms^{-1} respectively. Each component has frequency of oscillation nearly equal to 10.5 , 10 and 10 Hz respectively. In addition, these components show damping nature of oscillation with damping factor 17.9, 18.3 and18.3 s^{-1} respectively.

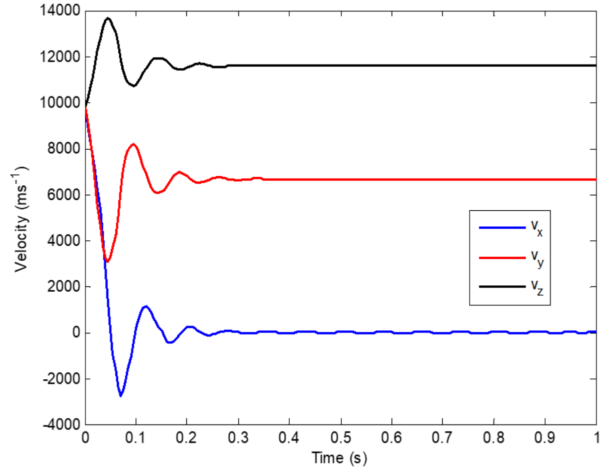

Figure 2. Variation of velocity with time at magnetic field 8mT and angle 30°

In Fig. 3 at angle 60° initial values of x, y and z-component are same and equal to 979ms^{-1}. In this figure y-component of velocity increased and the average value becomes equal to 11570ms^{-1} . But x and z-component of velocity attains the average values of -0.0008 and 6711ms^{-1} respectively. Before getting the average values each component oscillates with the maximum amplitude of 3113.99,1100 and 4619ms^{-1} respectively. Each component has frequency of oscillation nearly equal to 11.8,10 and 10.5 Hz respectively. Also,these components show damping nature of oscillation with damping factor 18.4,17 and 17.3s^{-1} respectively.

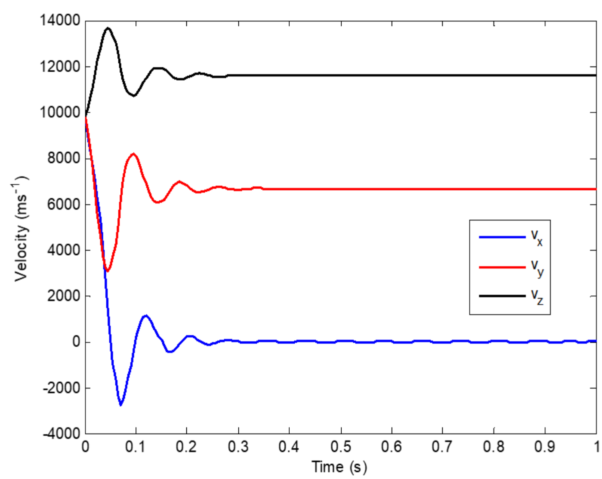

Figure 3. Variation of velocity with time at magnetic field 8 mT and angle 60°.

In Fig. 4, like previous also initial values of x, y and z-component are same and equal to 9794 ms^{-1}. The x and z-component of velocity decreases to the average values of 0.0004 and 3129 ms^{-1} respectively, whereas the the y-component of velocity increases to the average value of 11580 ms^{-1}. Before getting the average values each component oscillates with the maximum amplitude of 1605.99 , 290. and 1074 ms^{-1} respectively. Each component has frequency of oscillation nearly equal to 11.1 , 10.5 and 11.8 Hz respectively. These components also show damping nature of oscillation with damping factor 18.1, 17.6, and 17.8 s^{-1} respectively.

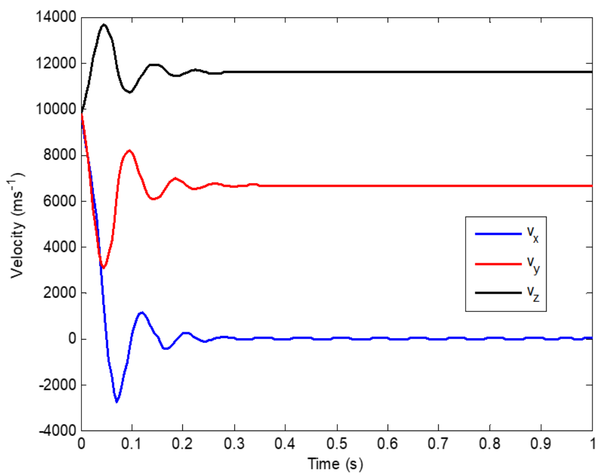

Figure 4. Variation of velocity with time at magnetic field 8 mT and angle 75°.

Table 1. The observed data of average value, amplitude, Damping constant and Frequency of oscillation at magnetic field 8 mT

Θ	Average value			Maximum amplitude			Damping factor			Frequency of oscillation		
	v_{xm}	v_{ym}	v_{zm}	v_{xz}	v_{yz}	v_{yz}	v_x	v_y	v_z	v_x	v_y	v_z
30°	0.0003	6668	11600	2761.99	3576	2060	17.9	18.3	18.3	10.5	10	10
60°	-0.0008	11570	6711	3113.999	1100	4619	18.4	17	17.3	11.8	10	10.5
75°	0.0004	11580	3129	1605.999	290	1074	18.1	17.6	17.8	11.1	10.5	11.8

Table 1 shows the summary of observed data for average value, maximum amplitude, damping factor and frequency of oscillation. Mean value (11600 ms^{-1}) is maximum on y-component at 30° with respect to other components at different angles. Also at angle 75° amplitude (290 m/s) is minimum on y-component whereas at angle 60° amplitude (4619 ms^{-1}) is maximum on z-component. At angle 60° damping factor is minimum ie 17 s^{-1} on y-component, on the other hand at 60° damping factor is maximum i.e. 18.4 s^{-1} on x-component.

5. Conclusions

It has been observed that ion velocity at presheath-sheath boundary is greatly affected by obliqueness of the field. At constant magnetic field as the obliqueness of the field changes the separation of the average values as well as the maximum amplitude of all the three component of the velocity also change but frequency of oscillation is almost constant. Angular dependence of average value, maximum amplitude, damping constant, frequency of oscillation of velocity components at magnetic field 8 mT has been observed. The study can be important in material processing, plasma etching and for confinement of plasma in fusion devices.

References

[1] Chodura R. Plasma–wall transition in an oblique magnetic field. The Physics of Fluids. 1982;25(9):1628–1633.

[2] Chodura R. Physics of Plasma-Wall Interactions in Controlled Fusion. Controlled Fusion, Plenum, New York. 1986;p. 99.

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

[4] Riemann K. Theory of the plasma-sheath transition. Journal of Technical Physics. 2000;41(1):89–121.

[5] Adhikari S, Moulick R, Goswami K. A dynamic analysis of the magnetized plasma sheath in a collisionless scenario with ion sources. Physics of Plasmas. 2017;24(8):083501.

[6] Hatami M, Niknam A, Shokri B, Ghomi H. Magnetized plasma sheath with two species of positive ions. Physics of plasmas. 2008;15(5):053508.

[7] Zou X, Qiu M, Liu H, Zhang L, Liu J, Gong Y. The ion density distribution in a magnetized plasma sheath. Vacuum. 2008;83(1):205–208.

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

[9] Khoramabadi M, Ghomi H, Shukla PK. Numerical investigation of the ion temperature effects on magnetized DC plasma sheath. Journal of Applied Physics. 2011;109(7):073307.

[10] Gyergyek T, Kovačič J. Fluid model of the sheath in front of a floating electrode immersed in a magnetized plasma with oblique magnetic field: Some comments on ion source terms and ion temperature effects. Physics of Plasmas. 2015;22(4):043502.

[11] Huang CW, Chen YC, Nishimura Y. Particle-in-cell simulation of plasma sheath dynamics with kinetic ions. IEEE Transactions on Plasma Science. 2015;43(2):675–682.

[12] Moulick R, Goswami KS. Potential around a dust grain in collisional plasma. Physics of Plasmas. 2015;22(4):043701.

[13] Chalise R, Khanal R. Self-consistent one dimension in space and three dimension in velocity kinetic trajectory

simulation model of magnetized plasma-wall transition. Physics of Plasmas. 2015;22(11):113505.

[14] Lieberman M, Lichtenberg A, Kawamura E, Chabert P. Linear electromagnetic excitation of an asymmetric low pressure capacitive discharge with unequal sheath widths. Physics of Plasmas. 2016;23(1):013501.

[15] 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.

[16] Bohm D. The characteristics of electrical discharges in magnetic fields. Qualitative Description of the Arc Plasma in a Magnetic Field. 1949;.

[17] Khanal R. A kinetic trajectory simulation (KTS) model for bounded plasmas. na; 2002.