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The dynamics of ions entering the magnetized plasma sheath obliquely – collisional and collisionless situations

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Abstract. The characteristics of ions that enter the plasma sheath with an oblique incident angle have been investigated in the presence of an external magnetic field. The ion dynamics in a collisional and collisionless magnetized plasma sheath have been numerically calculated by using a fluid model. Several values for the ion velocity at the sheath edge, orientation and strength of the magnetic field and the ion-neutral collision frequency have been considered. The results show that in a collisionless magnetized plasma sheath, the behaviour of ions that obliquely enter the sheath with some specific velocities at the sheath edge and at some specific orientations and strengths of magnetic field, is more complicated than that of ions with normal entrance angles. For the oblique entrance of ions, the weak magnetic fields cause some fluctuations in ion velocity around its boundary value, i.e. the ion velocity does not accelerate. However, the numerical calculations show that the ion dynamics in a collisional magnetized plasma sheath are the same for both normal and inclined entrance of ions into the sheath.

1 Introduction

Recently, there has been considerable interest in studying the electrodynamic properties of a plasma sheath, which is a space charged region that separates plasma from a metallic boundary [1–6]. The effects of a magnetic field and ion-neutral collisions on the dynamics of ions in a plasma sheath have been investigated in some correlative works in recent years. Most of these works have studied the dynamics of ions that perpendicularly enter the sheath through its boundary [7–22]. It is shown that the structure of a plasma sheath in an external magnetic field is different from that of a non-magnetized plasma sheath. This characteristic truly depends on the orientation and strength of the magnetic field [6,7]. The effect of collisions between ions and neutral particles are also investigated in magnetised and non-magnetised plasma sheath [10–13].

Zou et al. have shown in their new article that the effects of an external magnetic field are more complicated when the ions enter the collisionless sheath with an oblique incident angle [6]. Here, we study the dynamics of ions using a fluid model for different ion velocities at the plasma sheath edge. We also investigate the effect of ion-neutral collisions on the magnetised plasma sheath in this case.

The layout of the paper is as follows: in Section 2, we introduce the basic equations of the fluid model for ion movement in a plasma sheath by considering the electromagnetic force and ion-neutral collisions. We will also normalize the equations by using some dimensionless parameters. The normalized equations will be solved numerically in Section 3 and some characteristics of the ion will be investigated for strong and weak magnetic fields by using the numerical results.

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2 Sheath model and basic equations

Following some correlative works [6,7,9,10], we consider a plasma sheath in contact with a planar wall in the presence of an external magnetic field. We also consider the z-direction as the depth direction from the sheath boundary ($z = 0$) to the planar wall. The geometry of the magnetic sheath is illustrated in Figure 1. As presented in the figure, it is assumed that the magnetic field is embedded in the xz plane with an angle θ in the z-direction. In addition, it is assumed that the sheath characteristics change only with depth, i.e., the plasma sheath has a one-dimensional coordinate space. However, as the magnetic field changes the direction of the ion velocity, it can be considered as a plasma sheath with three-dimensional speed space.

The sheath consists of isothermal electrons, which are assumed to be in thermal equilibrium and obey the Boltzmann relation as follows:

$$n_e = n_0 \exp(e\phi/k_B T_e), \tag{1}$$

where n_e is the local electron density, ϕ is the local potential and T_e is the electron temperature. At the sheath