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The sheath criterion for a collisional plasma sheath at the presence of external magnetic field

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Abstract. The Bohm sheath criterion is modified for collisional plasma containing Boltzmann electrons and cold fluid ions at the presence of external magnetic field. Based on fluid model, the effects of the strength and the orientation of an external magnetic field on the upper and lower limits of Bohm sheath criterion have been studied by considering the collision frequency between ions and neutrals. The results show that the sheath criterion depends on the orientation and magnitude of magnetic field and the ion flow velocity at the sheath boundary.

1 Introduction

When plasma is in contact with a negative wall, a space charge region is formed in front of the wall that is called "sheath" [1]. Understanding the sheath is one of the oldest problems in plasma physics. However, this field is still one of the interests in plasma because of its practical importance in plasma dynamics [2–9]. The sheath as localized electric field confines the electrons in plasma and accelerates the ions out of the plasma. The electric field leaks out of the sheath, penetrates into plasma and forms a region in which the ions are accelerated into the plasma-sheath boundary with critical velocity. The electrodynamic properties of this boundary are of great importance since they define the dynamics of sheath. The boundary electric field should be such that it can provide enough force to accelerate the positive ions and give them the minimum velocity entering the sheath. This minimum value of ion-entering velocity is determined by Bohm criterion [10–14]. For a collisionless sheath this minimum value is the ion sound speed. In other words, the minimum value of ion entering velocity perpendicular to the sheath boundary divided by ion sound speed, that is called Mach number, is greater than unity; $M \geq 1$.

Liu et al. found an upper limit for the Bohm criterion and modified the lower limit with taking into account the ion collisions [15]. Using the fluid model, they showed that both of the upper and lower limits depend on ion collision frequency, e.g., they have indicated that the minimum value of ion Mach number decreases by increasing the ion collision frequency.

Recently, there has been considerable interest in sheath dynamics at the presence of an external magnetic field [16–19]. Zou et al. have shown that if the ion velocity at the plasma-sheath boundary has no component parallel to the boundary, the Bohm criterion makes the same condition for a collisionless plasma sheath in presence or absence of an external magnetic field [18].

Recently, we have studied the sheath dynamics in a magnetized plasma sheath for the case that ions enter the sheath obliquely [20]. The ion characteristics in this case have shown that the acceleration of ions in sheath depends strongly on the magnitude and orientation of magnetic field and the components of ion velocity parallel to the boundary at sheath edge. This dependency shows that the sheath criterion should be modified in this case. Although as a response to referee's comment to our paper (Ref. [20]) we introduced some inequalities for lower limit of Bohm criterion, complete investigation of sheath criterion needs a subsequent paper. Here we find the modified form of the upper and lower limits of Bohm criterion in a magnetized collisional plasma sheath by considering the strength and orientation of magnetic field, the ion collision frequency and the magnitude and orientation of ion velocity at plasma-sheath boundary. The layout of the paper is as follows. In Section 2, the basic equations of fluid model are defined for isothermal electrons and cold fluid ions. Then by using the normalized form of the equations, the lower and upper limits of Bohm criterion are found as a function of ion collision frequency, and the characteristics of magnetic field and ion velocity at sheath edge. In Section 3 the modified Bohm criterion is investigated by solving the basic equations numerically and studying the behavior of the electron and ion density distribution in different cases. The paper is ended by conclusion.

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