Abstract

The studies presented in this thesis analyze the issues related to the region of a magnetized plasma-wall interaction when the magnetic field is incident obliquely to the absorbing surface. Many issues exist that are crucial both theoretically as well as from the view point of modern experiments that use strong magnetic field for the purpose of better plasma confinement.

In magnetized regime, the conventional fluid treatment which uses the standard fluid equations, successfully explains the development of supersonic normal flow which is required to exceed the ion acoustic velocity c_s, at the entrance to an electrostatic *sheath* formed typically at the solid surface. However in view of this result it is difficult to find a satisfactory explanation for various observations that find the boundary value of flows (and that of the particle/energy flux) to depend strongly on the intensity of the magnetic field and its orientation with respect to solid surface. Such a relaxation in the classical sheath criterion is possible only if the strong magnetic field modifies the mechanism which ensures an equal flux of electrons and ions to the solid surface in the steady-state. In order to address this question the emphasis in the present studies is placed on the effects of magnetic field on the properties of plasma distribution functions.

In order to account for the anisotropy which is introduced by a strong magnetic field in the plasma distribution function, an alternate fluid approach is considered, based on the gyrokinetic formulation of a magnetized plasma. However, to what extent a gyrokinetic ordering is obeyed by the ions is an the issue that needs to be addressed carefully since the particle orbits show large complexities in their behavior in highly inhomogeneous presheath electric field. The validity of the gyrokinetic approximation in the region of magnetized plasma wall interaction is discussed and the motion of a charged particle is analyzed in an inhomogeneous presheath-like electric field where the magnetic field is obliquely incident. The concepts of "open" and "closed" orbits are introduced and a condition for the orbits to become "open" is obtained. A coupling between parallel motion and cross-field drift is also identified. A generalized gyrokinetic equation is prescribed in the limit of large cross-field drifts. It is concluded that the gyrokinetic approximation is a good one provided that the region of sharp variation in the potential is narrow and localized close to the solid surface. The error in the gyrokinetic based fluid treatment depends on the fraction of the ion orbits

that violate the gyrokinetic ordering and this number is small for such potential profiles.

A moment description of the generalized gyrokinetic equation is used to derive a set of fluid equations in Chapter 2. The main effect of going to a gyrokinetic formulation is that the continuity equation becomes anisotropic. As compared to standard gyrofluid treatments, a new effect included in the momentum equations relates to an enhanced cross-field drift. The quasineutral solutions of a gyrokinetics based fluid model of a magnetized presheath, show the familiar sheath singularity at the electrostatic sheath edge. However, the corresponding normal velocity approaches well below c_s, at this location. The solutions are observed to approach the ideal presheath solutions for near normal incidences. The profiles show that the angle of incidence of magnetic field strongly affects the transport characteristics across the magnetic presheath. The reduced value of normal flow indicates the need for an alternative mechanism (electrostatic fluctuation, collisional diffusion etc.) to enhance the cross-field flow of plasma to the wall for the cases of very grazing incidence of the magnetic field.

A gyrokinetics based fluid model of presheath is still a quasineutral treatment. Hence it still recovers a singularity in the profiles where quasineutral treatment fail to capture the physics. This is the location where the electrostatic (Poisson) sheath starts. Since the model used did not add in the finite gyroradius effects, non-local ion loss effects are not present here. The result is anomalously high ion densities at the electrostatic sheath edge. While the gyrokinetics based fluid treatment yields interesting and relevant results, it clearly indicates the deficiencies of a common fluid treatment in handling a magnetized plasma.

Since in most of the cases of practical interest the scaling $\rho_i \gg \lambda_{\mathrm{D}}$ is observed, the kinetic wall losses must be taken into account in order to recover the correct behavior of the flow velocity at the boundary. The issue of a correct boundary condition in a purely source-driven collisionless magnetized region of plasma-wall interaction therefore requires to be addressed by the means of a pure kinetic approach. A more important issue therefore is to first characterize these kinetic effects, especially in the oblique cases of magnetized plasma-wall interaction. With the same objective a kinetic simulation of the magnetized presheath is performed, and an attempt is made to address many of the issues related to the kinetic theory of magnetized plasma-wall interaction.

Two kinds of kinetic procedures were used in Chapter 4 and 5, to ensure the self-consistency of the simulation results. In Chapter 4, a source profile is generated to make a given potential profile self-consistent, by minimizing the errors between the input and output potential profiles. In Chapter 5, however, the self-consistent kinetic solutions were generated for a prescribed source profile using an iterative procedure. The issue of a smooth connectivity of a magnetized presheath solution to a field-free bulk plasma is addressed by using a spatially inhomogeneous source profile that vanishes in a quiescent bulk. An asymptotic relaxation of the ion distribution function to a thermal (Maxwellian) plasma is achieved by subjecting the ion distribution function the collisions with a thermal background of neutrals. Both types of treatments are carried out for bounded plasma configurations. The ion distribution and its various moments are studied to understand and interpret the kinetic results. A comparison of the kinetically obtained self-consistent plasma profiles with the fluid results is carried out. The angular dependence in the flow velocity at the entrance to the electrostatic sheath is obtained, which indicates that even for $\theta < 90^o$ the ion flow near the electrostatic sheath edge in mainly normal to the solid surface. This behavior to some extent corresponds to a relaxation in the requirement of a large ambipolar electric field as obtained commonly in a typical fluid treatment, where it is assume that both ions and electrons follow same path to reach the solid surface.

Based on the observations in the kinetic simulations, the gyrokinetics based fluid approach is revised to introduce the effects of an ion loss cone, which emerges as a result of "scraping-off" of the extended ion orbits against the absorbing wall. In a source driven presheath it is seen that the ion loss effects generate an "effective sink" of the particles. It could be shown in the present treatment that an enhanced drop in the ion density because of an enlarging loss cone is equivalent to an additional electric field which is expressible in terms of an "ion loss function", and its derivative. As an important result it is found that if the kinetic effects of ion losses are included explicitly, the singularity present at the local ion acoustic speed c_s, present in a typical fluid formation, can indeed be removed and the quasineutral solutions can be obtained right up to the solid surface. However with the electrons, that are still chosen to be infinitely mobile (Boltzmann electrons) no positively charged wall can be recovered.

As mentioned earlier, experimental findings suggest that in grazing angle configurations, the parallel ion flow remains subsonic at the sheath edge, in contradiction to existing theories. These observation are explained in Chapter 6, on the basis of enhanced cross-field drifts due to gyrokinetics. Presence of such drifts could be shown to reduce the parallel flow velocity at the solid surface, thus explaining a departure from the classical sheath criterion. The solutions indicate that a reduction observed in the existing experimental results, can be explained without invoking a secondary electric field as was required in by earlier studies.

The present study thus explores various effects of a strong magnetic field on the plasma flowing to the solid surface, by the use of both hydrodynamic and kinetic approaches. Emphasis here is placed on the dominant kinetic properties of ions, that govern the mechanism of plasma flow to an absorbing surface in a strongly magnetized regime and explains the departure from various notions of classical, unmagnetized models of plasma-wall interaction.