PLASMA TRANSPORT TO THE WALL THROUGH THE ELECTROSTATIC SHEATH

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ABSTRACT

The flow of particles and energy through the presheath and sheath region of a scrape-off plasma is calculated using a kinetic model. For a given input rate of particles and energy into the presheath and a given reflextion condition at the wall the plasma state behind the presheath and ahead of the sheath is determined. Two dimensionless quantities are characteristic for this state, i.e. the ratio of flow velocity to sound speed and the ratio of total energy flux to convected thermal energy flux. Both quantities are derived for varying angles of incidence ψ of the magnetic field. Electron reflexion by secondary emission from the wall enhances the energy flux ratio for nearly perpendicular field and leaves it unaffected for grazing incidence of the field.

1. INTRODUCTION

Plasma flow along the scrape-off layer to the absorbing wall of a limiter or divertor is adjusted to ambipolarity by an electric field. This field is relatively weak in the so-called presheath region far upstream of the wall and becomes strong in the electrostatic sheath immediately ahead of the wall. While the presheath has large dimensions, is collision-dominated and includes particle sources, for instance by ionization, the electrostatic sheath is small of the order of a Debye - or ion gyro length, and is collision- and source-free. In the latter region the velocity distribution of the plasma is strongly affected by the wall and far from being Maxwellian.

The conditions of the plasma at the transition between presheath and sheath (indicated by the index P in the following), is determined by the sources in the presheath, and by the properties of the wall: The x-component (perpendicular to the wall) of particle flux F_x and the sum of ion and electron energy flux Q_x is given by the production of particles and energy in the presheath. They both are connected (assuming cold ions) by

$$Q^{i}_{xP} + Q^{e}_{xP} = \left(\frac{m_i}{2} V_P^2 + \delta T_{eP} \right) F_x \tag{1}$$

where T_e is the electron temperature and δ a numerical factor with depends on the reflectivity of the wall. For an ion-absorbing wall the flow velocity V_P at the end of the presheath is of the order of the sound speed, i.e.

$$V_P^2 = \gamma \, T_{eP} / m_i \tag{2}$$

where γ is a numerical factor. Thus, knowing γ and δ, equs. (1) and (2) determine the electron temperature T_{ep} ahead of the sheath. Finally, the density n_p ahead of the sheath is given by

$$n_P = F_x / (V_P \cos \psi) . \tag{3}$$

In the following section a numerical model is presented which describes the particle kinetics in the presheath and sheath region, and allows to determine the numerical factors γ and δ .

2. MODEL

A 1d particle model /1/ is used which follows the collisionless particle orbits in their self-consistent electric field $\underline{E}$ and externally prescribed magnetic field $\underline{B}$ of strength such that $\omega_{ce} \approx \omega_{pe}$ and arbitrary direction ψ. (Fig. 1). Ions and electrons are borne with the same rate in a localized source to the left, electrons with temperature T_{eo}, ions with $T_{io} = 0$. Electrons reflected by the electric field and passing the plane x = 0 outward are replaced by the same number entering with temperature T_{eo}.

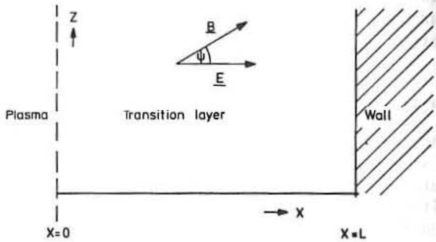

Fig. 1: Geometry of the model.

3. FLOW VELOCITY

Fig. 2a shows the x-profile of the mean flow velocity $\underline{V}$ of ions and electrons for a magnetic field angle ψ = 70°. The source to the left (which extends over about 5 Debye lengths λ_D gives rise to the presheath acceleration of the flow to a plateau value $\underline{V_p}$. The acceleration extends over about an ion gyro radius, is quasineutral and aligned with the magnetic field direction. After a plateau, the flow again becomes accelerated in the sheath. At first the flow stays quasineutral over the ion gyro scale length. Ions begin to deviate from the magnetic field lines while electrons stay tied up. Only at the last few Debye lengths also the electrons become decoupled from field lines and are strongly accelerated towards the wall. The flow becomes non-neutral. Fig. 2b gives the plateau value of the flow velocity V_p ahead of the sheath for different magnetic field angles ψ .

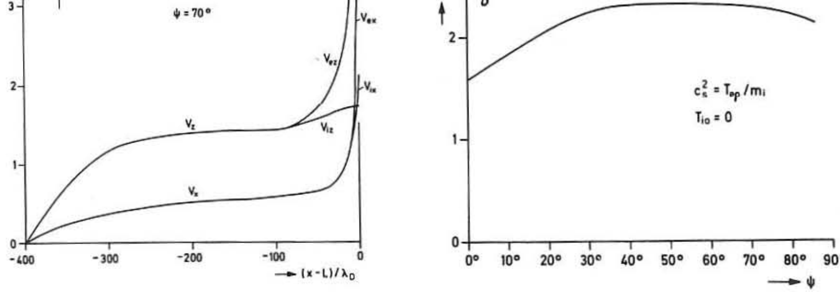

Fig. 2a,b: Flow velocity $\underline{V}(x)$ of ions and electrons and plateau velocity V_p^2 ahead of the sheath.

4. ENERGY FLOW

In Fig. 3a the energy flux profile Q(x) is plotted for ions and electrons. In the presheath as well as in the sheath electron thermal energy is transformed to ion kinetic energy. Again, the energy flux is aligned to the magnetic field except for the sheath were ion and electron energy flux deviate at the ion-gyro and Debye length respectively. The plateau value of the energy flux after the presheat and ahead of the sheath i.e. the factor δ of eq. (1) is given in Fig. 3b for different angles ψ .

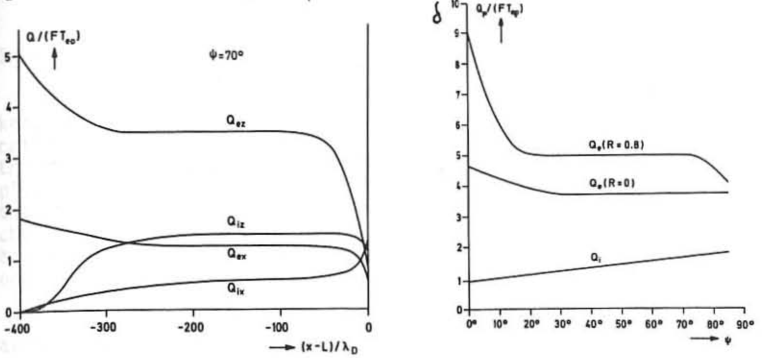

Fig. 3a,b: Energy Flux Q(x) of ions and electrons and plateau values $|Q_p|$ ahead of the sheat.

5. SECONDARY ELECTRON EMISSION

The preceding results were obtained for a completely absorbing wall. If it is assumed that the wall reemits incoming electrons above a small threshold energy as cold ones with a reflexion coefficient R the flow velocity of Fig. 2 and the ion energy flow of Fig. 3 is unchanged while the electron energy flow goes up since for the same absorbed particle flux F_x now more electron energy must be transported to the wall. Fig. 3b shows the plateau value Q_{ep} for R = 0.8. Only for nearly perpendicular magnetic field the electron energy flux is enhanced according to the considerations of /2/. For oblique angles many electrons emitted from the wall reencounter the wall by their gyro motion and are absorbed. For nearly grazing angles ψ nearly no reemitted electrons can escape the wall, therefore Q_e retruns to the value for the completely absorbing wall.

REFERENCES

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