

ON THE LOCAL TRANSPORT OF THE IONS TO A WALL AT SMALL ANGLES OF THE MAGNETIC FIELD TO THE SURFACE

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1. Introduction

Heat and particle loads are critical issues in the design efforts of fusion oriented machines. As one of the means to achieve tolerable temperatures and erosion, divertor plates and limiters are mounted at shallow pitch angles of a few degrees relative to the magnetic field. Theory predicts that at these small angles a magnetic presheath develops in front of a wall in which the ion orbits are strongly distorted so that their interaction with the wall is expected to be quite different from the case if the magnetic sheath would not exist. Results are presented which are understood as a first experimental demonstration of the existence of a magnetic presheath at small pitch angles of the magnetic field, and of the particularities of the ion orbits in a magnetic presheath. These modifications of the orbits should have significant relevance for plasma wall interactions.

2. Experimental setup

The measurements have been performed in the edge plasma of the tokamak TEXTOR-94; the separatrix is defined by the limiter ALT-II at the minor radius $r = 46$ cm. Ohmic discharges with toroidal magnetic field $B_t = 2.25$ T, the plasma current $I_p = 0.35$ MA and the mean core density $\langle n_e \rangle = 1.5 \times 10^{19} \text{ m}^{-3}$ have been investigated. The probe is mounted on the outboard side in the equatorial plane, Fig. 1 [1]. Its axis is aligned perpendicular to the magnetic field, its radial position can be changed between the discharges and it is rotated during the discharge around its axis with a frequency of 2 Hz. The "sandwich probe" head, Fig. 2, consists of two rectangular graphite plates of 30 mm length and a width of 18 mm. Probe heads with widths of 5 and 10 mm have also been applied. The plates are imbedded in a boron nitride corpus. During rotation the surface normals of the plates remain practically on the same magnetic flux surfaces.

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3. Results

In order to study the local transport to a (test)wall the probe is operated electrically floating, and no voltage is applied between the two electrodes of the probe. These plates are connected by means of an electric short circuit, and the current collected by the plates is measured potential-free by means of a current probe. In this mode the probe is suited to determine the electric current density in the plasma and due to the rotatability the direction of the current relative to the lab frame (or magnetic field). Fig. 3 shows the electrical current collected by the probe as function of the rotation angle α . The current has the same periodicity as the rotation of the probe. For larger values of the rotation angle the measured current scales as the area of the collecting plates projected parallel to the magnetic field, $\sin \alpha$, Fig. 4, but starts to deviate from this dependence for $|\alpha| \leq 30^\circ$ and becomes nearly independent of α and about zero for $|\alpha| \leq 6^\circ$. This finding is expected from theory and numerical simulation, [2] - [7]: when the ions pass across the magnetic presheath under a shallow angle their gyro-orbits are deformed into open trajectories when approaching the wall, and their gyro-energy is converted by gyro-cooling into surface-parallel drift energy in the $\vec{E} \times \vec{B}$ direction, \vec{E} being the electric field in the magnetic presheath, nearly perpendicular to the surface. Obviously the ions will not reach the target surface if their displacement in the $\vec{E} \times \vec{B}$ direction during their transit time across the magnetic presheath is larger than the corresponding dimension of the collecting probe plate. This qualitative expectation is confirmed by results of measurements with collecting probe plates of different width in the $\vec{E} \times \vec{B}$ direction: Fig. 5 shows that the rotation angle at which the collected current becomes nearly zero decreases with increasing probe width.

A more detailed description is presented in the following: For small pitch angles of the magnetic field the ions bypass the probe inside the magnetic presheath to combine with the electron current component onto the opposite probe surface. In this context one has to note the following facts:

- a) on the opposite side, after having bypassed the probe through the magnetic presheath, the ions can reach the surface,
- b) the surface parallel drift current is carried only by the ions, because the electric and $\text{grad } n$ contributions for the electrons cancel.

The relations for $j_{e,i}$ are obtained by using the dependence of the two sheath potentials on the electric currents j through the probe and by using Boltzmann's relation (simplified Ohm's law) along the magnetic field lines relating densities and potentials on both probe sides due to $\oint d\phi = 0$.

At small pitch angles the surplus of the ions j after bypassing the probe compensates the same surplus of electrons on the opposite side. Hence no electrical current can be collected by the probe.

The critical angle, below which the electric current drops nearly to zero, can be estimated from the following equations of motion (cf. Fig. 2):

$$dz/dt + \Omega_i \sin \alpha = \text{constant} \quad \text{and} \quad dz/dt \approx v_{||} \cos \alpha$$

therefore $|\Delta x| \equiv (v_{||} - v_{||0})/\Omega_i \tan \alpha$ together with $v_{||} - v_{||0} \approx c_s$ results in a value for the displacement in the $\vec{E} \times \vec{B}$ direction:

$$|\Delta x| \approx (a_i / \tan \alpha) \quad \text{with } a_i = c_s / \Omega_s, \quad c_s = \sqrt{k(T_e + T_i)/m_i} \quad \text{and } \Omega_i = eB/m_i$$

For the experimental values of the ion and electron temperature $kT_i = 100$ eV and $kT_e = 20$ eV the estimated values of the thus related probe width Δx and of the rotation angle α are compared in Fig. 5 with the experimental ones. The trend of the two curve is similar but the absolute values differ by up to a factor of two. Modeling of the transport across the magnetic presheath including the electric field selfconsistently and including edge effects may bring the theoretical and experimental results closer together.

These findings are understood as a first experimental verification of the existence of a magnetic presheath in front of a wall in a magnetized plasma. Moreover it is concluded that plasma wall interactions such as sputtering, generation of secondary electrons and the concomitant change of the electric field in the sheath in front of a wall, as well as the initiation of unipolar arcs are significantly different as if the ions would continue their gyration undisturbed down to the wall. It seems to be mandatory that these boundary conditions have to be taken into account in future simulations of the edge plasma in fusion devices.

References

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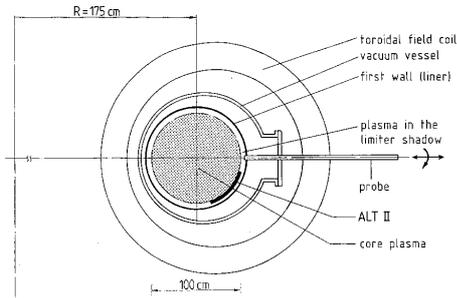


Fig. 1 Rotating probe on TEXTOR-94

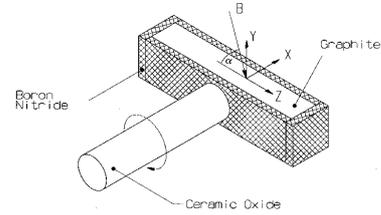


Fig. 2 Geometry of the Sandwich Probe

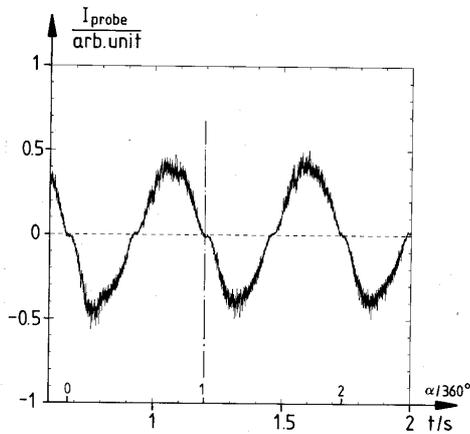


Fig. 3 Electric current collected by the probe as function of the rotation angle

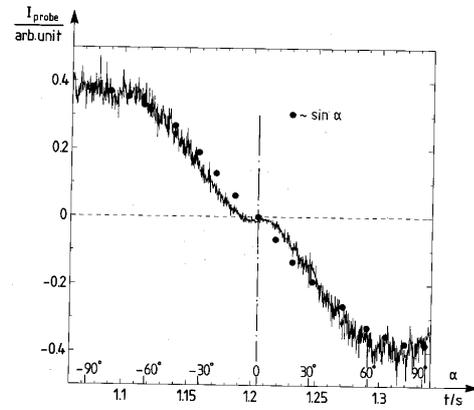


Fig. 4 Collected electric current compared with $\sin \alpha$

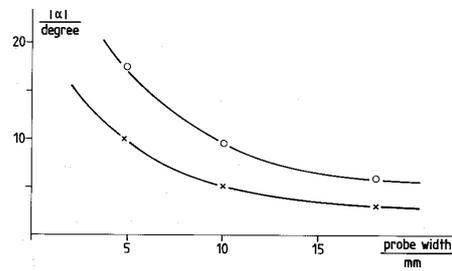


Fig. 5 Rotation angle at which the collected current becomes zero as function of the electrode plate width, o exeriment, x theory