Kinetic solution of a collisionless magnetic presheath

A. Geraldini[1,2], F. I. Parra[1,2], and F. Militello[2]

[1]*Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford, OX1 3NP, UK*
[2]*Culham Centre for Fusion Energy, Abingdon, OX14 3DB, UK*

Magnetic presheaths, first studied by Chodura [1] are boundary layers present in the edge region of a tokamak, where the Scrape-Off Layer (SOL) plasma reaches the divertor or limiter target. They are present if the magnetic field impinges with an oblique angle a on the target surface. In that case, there is a small region of size a typical ion Larmor orbit ρ_i in which ions may intersect the wall during an orbit. The physics of this region is crucial for determining boundary conditions to impose on SOL plasmas at the wall [2].

We develop a gyrokinetic model of the magnetic presheath of a typical magnetic fusion device, in which the magnetic field is at grazing incidence with the wall, $a \sim 0.1 << 1$ [3]. Across the magnetic presheath, the electrostatic potential drop is so large that ion orbits are distorted. In addition to large gradients normal to the wall, our ordering allows weak turbulent gradients parallel to the wall. These gradients are due to the presence in the SOL of turbulent structures, which are elongated along the magnetic field and have a characteristic size across the field $l = \rho_i / d \sim 10$ mm $>> \rho_i \sim 1$ mm, where $d \sim 0.1 << 1$ is another small parameter. We use $a \sim d << 1$ to solve the ion equations of motion perturbatively. Exploiting the solutions to the phase space trajectories of the ions [4], we find that the ion distribution function is independent of the gyrophase angle of the orbit and we derive the lowest order ion gyrokinetic equation, which has a simple solution in a collisionless magnetic presheath. The density of ions in closed orbits is obtained by numerically integrating the ion distribution function in velocity space.

We further demonstrate that an additional piece of the ion density is required in order to solve correctly for the magnetic presheath potential and density profiles. This piece is the density of ion orbits whose trajectory intersects the wall over a gyroperiod. We derive an equation for the lowest order density of such open orbits. Assuming adiabatic electrons, which is justified provided $a >> \sqrt{m_e/m_i} \sim 0.02$ radians, the electron density is known. Because the Debye length is small, $\lambda_D \sim 0.02$ mm $<< \rho_i$, the quasineutrality equation can be used to solve for the electrostatic potential. Using our model, we obtain numerical results for the density and electrostatic potential profiles in a collisionless magnetic presheath with no turbulent gradients parallel to the wall. The results obtained from our model provide boundary conditions for gyrokinetic codes of the SOL.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053 and from the RCUK Energy Programme [grant number EP/I501045]. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] R. Chodura, Phys. Fluids 25, 1628 (1982)
[2] J. Loizu et al, Phys. Plasmas 19, 122307 (2012)
[3] A. Geraldini, F.I. Parra and F. Militello, arXiv: 1608.02002 (accepted for publication in Plasma Phys. Control. Fusion on 24 November 2016)
[4] R.H. Cohen and D.D. Ryutov, Phys. Plasmas 5, 808 (1998)