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# Direct steady-state solutions of kinetic magnetised plasma sheaths at shallow magnetic field angles

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Most kinetic simulations of turbulence in fusion plasmas employ a gyrokinetic and quasineutral description, exploiting the fact that the Larmor frequency and plasma frequency are both much faster than the turbulent timescale. In the magnetised sheaths forming next to divertor/limiter targets, these approximations become however invalid because very strong electric fields arise on the length scales of the ion gyroradius $\rho_i$ and Debye length $\lambda_D$. These fields usually reflect electrons and reduce the electron flux so that ambipolar conditions can be achieved. Time-dependent kinetic simulations that resolve the magnetised sheath dynamics require significant computational effort, yet the steady state is reached on smaller timescales than those governed by turbulence. We thus developed an approach that directly calculates the steady state in the collisionless limit, furthermore taking advantage of two small parameters: the magnetic field angle $\alpha$ at the target [1] and the ratio $\lambda_D/\rho_i$. The small angle enables one to analytically derive expressions for the ion and electron density [2, 3] in terms of a given electrostatic field (retaining the strong deformation of non-circular gyro-orbits). The scale separation is used to solve two separate equations for each of the scale lengths of interest: $\rho_i$ and $\lambda_D$. Coupled iteration schemes are used to find the steady-state electrostatic potential solution on both length scales, with an extra optional iteration to impose ambipolarity. The time taken on a single CPU core ranges from a few seconds to a few minutes, depending on parameters, though it could be further reduced by parallelising the density calculation. Using this approach, the sheath electrostatic potential profiles and the strongly distorted ion distribution functions reaching the target can be calculated. We show that kinetic electron physics, including finite gyro-orbit size via the parameter $\rho_e/\lambda_D$, can cause a monotonic electrostatic potential profile to be inconsistent at fusion-relevant angles. We also characterise the evolution of 1-dimensional cross-field spatial structures (e.g. due to turbulence) as they traverse the magnetised sheath, and provide conditions under which a steady state becomes inconsistent with such structures. We discuss possible implications for sheath boundary conditions.

References

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