Quasineutral kinetic simulation of a collisionless scrape-off layer

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It has been suspected for some time that ion and electron velocity distributions in the tokamak scrape-off layer (SOL) may depart significantly from thermal conditions in low or intermediate collisionality regimes. In detached plasmas, for example, Langmuir probes are often accused of measuring electron temperatures that are "too high" with respect to the predictions of fluid models, or with other measurements such as spectroscopic line ratios. Probes are sensitive to energetic electrons, so it may be that such discrepancies indicate the existence of a non-thermal tail. Violent transient events such as edge localized modes (ELMs) can also lead to rapidly evolving non-thermal distributions that can only be modelled correctly by a kinetic approach.

We apply a novel simulation technique [1] to the 1D SOL problem. It is a particle-in-cell (PIC) approach that is in most respects identical to standard techniques except for the way in which the electric field is calculated. Usually in PIC codes the electric field is obtained from the charge density using Poisson's equation. This leads to two problems. The first is related to constraints required to guarantee numerical stability. The spatial grid must be fine enough to resolve the Debye length and the time step small enough to resolve the electron plasma period. With 100-1000 simulation particles per grid cell, this limits the maximum system length to the order of a centimeter, whereas real connection lengths in tokamaks are in the range of tens of meters. The second problem is due to the coarse resolution of the charge density. In a real quasineutral SOL such as in the Tore Supra tokamak, relative charge densities of the order 10^{-14} must be resolved. Using a small number of discrete simulation particles, only 10^{-1}-10^{-2} can be resolved. The instantaneous electric potential is therefore dominated by statistical shot noise. PIC codes are well suited for simulating the non-neutral sheath, but it is not evident that they can correctly simulate quasineutral plasma.

Rather than solving Poisson's equation, the quasineutral particle-in-cell (QPIC) approach uses the electron fluid momentum equation to calculate the electric field. At each time step the electron fluid pressure is calculated at all points on the spatial grid. The ion density replaces the electron density in the fluid equation; this trick sets up an artificial restoring force that acts to maintain quasineutrality. QPIC can simulate arbitrary time and spatial scales. For example, a realistic SOL can be simulated with cell size of 1 m and a time step proportional to the electron transit time across a cell. The steady state kinetic solution can be obtained with reasonable resolution in a few minutes on a personal computer. The code has been benchmarked against kinetic problems from the literature with known solutions. In particular we have reproduced exactly the kinetic solution of the Mach probe problem [2]. In this contribution we will show new results including the effect of a two-temperature electron distribution on Mach probe measurements, and the propagation of heat and particles along a field line to a divertor target following an ELM burst.

References

[1] W. M. Manheimer, M. Lampe, G. Joyce, J. Comput. Phys. **138** (1997), 563.
[2] K. -S. Chung, I. H. Hutchinson, Phys. Rev. A **38** (1988) 4721.