Kinetic Calculation of Neoclassical Transport Including Self-Consistent Electron and Impurity Dynamics

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Abstract

Numerical studies of neoclassical transport, beginning with the fundamental drift-kinetic equation, have been extended to include the self-consistent coupling of electrons and multiple ion species. The code, NEO, provides a first-principles based calculation of the neoclassical transport coefficients directly from solution of the distribution function by solving a hierarchy of equations derived by expanding the drift-kinetic equation in powers of ρ_{*i}, the ratio of the ion gyroradius to system size. This includes the calculation of the first-order electrostatic potential via the Poisson equation, although this potential has exactly no effect on the steady-state transport. Systematic calculations of second-order particle and energy fluxes, plasma flows and bootstrap current, and comparison with existing theories, are given for multispecies plasmas. The ambipolar relation $\sum_a z_a \Gamma_a = 0$, which can only be maintained with complete cross-species collisional coupling, is confirmed, and finite mass-ratio corrections due to the collisional coupling are identified. We also explore the effects of plasma shaping and discuss how analytic formulae obtained for circular plasmas (i.e., Chang-Hinton) should be applied to shaped cases. Finite orbit width effects are studied via solution of the higher-order drift kinetic equations, and the implications of non-local transport on the validity of the δf formulations are discussed.

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