Multi-Species Kinetic Simulations of Neoclassical Transport in Tokamak Plasmas

E.A. Belli

General Atomics, P.O. Box 85608, San Diego, California 92186-5608 USA

Neoclassical dynamics are believed to be important in explaining enhanced edge flows, current, and confinement phenomena in tokamaks. Recent drift-kinetic codes, such as NEO, provide a practical predictive tool for high-accuracy neoclassical calculations. Advanced simulation requires inclusion of impurities, general flux surface geometry, and sophisticated collision models. Implementation of the full linearized Fokker-Planck collision operator is non-trivial due to the complexity of the operator and the need for implicit evaluation, yet is essential for studies of neoclassical transport, particularly in the highly collisional plasma edge. Thus, novel numerical algorithms to treat the disparate velocity scales that arise in the case of multi-species plasmas must be used. In this talk, these methods will be described and analysis of the limitations of more commonly used model collision operators and theories will be explored. Applications to integrated modeling of transport which couples drift-kinetic calculations with gyrokinetic simulations, using the neoclassical particle and energy fluxes along with the complementary turbulent fluxes to evolve the density and temperature profiles, will also be presented, including comparisons with experimental measurements. Integration of the calculation of the neoclassical bootstrap current into experimental analysis tools for MHD equilibrium reconstruction and the implications for stability calculations in the edge will also be explored.

Extensions of neoclassical theory and simulations to include advanced physics effects, such as toroidal non-axisymmetries and strong toroidal rotation, will also be presented. Toroidal non-axisymmetries are always present in tokamaks due to magnetic field ripple and may arise due to imposed resonant magnetic perturbations (for the purpose of mitigating ELMs), or other MHD activity. Intrinsic toroidal plasma rotation due to the neoclassical toroidal viscosity (NTV) which is induced by 3D magnetic perturbations may be important for confinement in reactors like ITER, where the momentum input is small. In this talk, analysis of the NTV torque with full kinetic corrections and non-ambipolar transport will be explored. Inclusion of poloidal asymmetries in the density distribution, which are induced by strong toroidal rotation from neutral beam injection via the centrifugal force and by anisotropic RF minorities via the mirror force, will also be described. Implications for studies of the transport of heavy impurities, for which accumulation can lead to radiation losses and fuel dilution in a reactor, will be discussed.