Neoclassical effects in electromagnetic gyrokinetic theory for the tokamak pedestal

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The conventional gyrokinetic theory that adopts a Maxwellian equilibrium is not sufficient to reconstruct the full spectrum of ideal MHD physics, including the physics of kink modes. The latter, being associated with the current density gradient, is usually neglected in a core plasma when the toroidal mode number $n \gg 1$, however, can grow fast in the pedestal region due to the high plasma pressure gradient and associated current there.

The electromagnetic gyrokinetic theory has been extended to capture these effects. The particle distribution function is of the form: $f = F + \delta f$, where F describes the equilibrium (in gyrokinetic ordering) and δf is associated with fluctuations: $\nabla_{\parallel} \delta f \sim \delta f / L$ along and $\boldsymbol{\nabla}_{\perp} \delta f \sim \delta f / \rho$ across equilibrium magnetic field lines, where L is the characteristic size of the system and ρ is the Larmor radius of a species. To recover ideal MHD, one needs to retain a current density in the equilibrium distribution function, such as neoclassical currents, and hence solve the drift kinetic equation for F perturbatively, expanding it in powers of $\delta = \rho_{\vartheta}/L \ll 1$, where ρ_{ϑ} is the poloidal Larmor radius. The leading order in F is the Maxwellian, employed in conventional gyrokinetics. The following order provides neoclassical flows, including the bootstrap current associated with the pressure gradient and required to capture features of the kink mode physics in the pedestal and corresponding terms in ideal MHD. The gyro-angle dependent part of the second order correction in a δ expansion has to be retained in F as well to keep the ordering consistent. F is then used to derive the gyrokinetic equations to describe fluctuations. To obtain δf, the second small parameter is introduced, $\Delta = \rho / L \ll 1$, and the corresponding expansion is applied.

Integrating the extended electromagnetic gyrokinetic equations over velocity space with corresponding weight functions recovers full ideal MHD.