Axisymmetric Neoclassical Theory for Low-Collisionality Ions to their Second Larmor-Radius Order*

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The neoclassical solution for an axisymmetric equilibrium ion distribution function is extended to the low-collisionality regime characterized by $\nu_i L/v_{thi} \sim \rho_i/L \equiv \delta \ll 1$. No geometrical approximations are made, the poloidal and toroidal components of the magnetic field being assumed comparable, so the dimensionless collisionality parameter is $\nu_* \sim \nu_i L/v_{thi}$. The conventional banana regime solution is based on a first Larmor-radius order drift-kinetic equation and applies to $\delta \ll \nu_* \ll 1$. The ordering $\delta \sim \nu_* \ll 1$ is more appropriate for fusion-grade plasmas, but requires a drift-kinetic solution to the second Larmor-radius order. In this case, besides the conventional $O(\delta)$ contributions to the non-Maxwellian perturbation of the distribution function relative to the Maxwellian and to the poloidal flow velocity relative to the thermal velocity, new and comparable $O(\delta^2\nu_*^{-1})$ contributions arise. In addition, and for the ordering of the flow velocity $u_i \sim \delta v_{thi}$, comparable contributions related to flow effects might be expected as $O(\delta u_i v_{thi}^{-1}\nu_*^{-1})$. The solution of this second Larmor-radius order, low-collisionality neoclassical equilibrium problem is obtained, with the new effects represented by a new source in the generalized Spitzer problem for the odd part of the distribution function. This new source does not contain any net $O(\delta u_i v_{thi}^{-1}\nu_*^{-1})$ term and its only $O(\delta^2\nu_*^{-1})$ term vanishes if the equilibrium is up-down symmetric. An explicit geometrical factor quantifies such novel second Larmor-radius order, low-collisionality effect in equilibria that lack up-down symmetry. For this $\delta \sim \nu_* \ll 1$ neoclassical solution, the pressure anisotropy part of the Chew-Goldberger-Low stress tensor is comparable to the gyroviscosity and their contributions to the flux-surface-averaged parallel momentum equation balance exactly.

*Work supported by the U.S. Department of Energy.