§16. Three-Dimentional Reduced Drift Kinetic Equation for Neoclassical Transport of Helical Plasmas in the Ultralow Collisionality Regime

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In the reactor-relevant helical plasmas, an important component will be the fast ions produced by either neutral beam injection or thermonuclear fusion reactions. Understanding the influence of these fast ions on the plasma behavior is one of the major issues in fusion plasma physics research. Recently, confinement of fast ions has attracted more attention in the helical confinement research.

Based on the original five-dimentional drift kinetic equation, we have established the following three-dimentional reduced drift kinetic equation

$$\partial_t f_c + \frac{1}{J_c}\frac{\partial}{\partial c^i}\left[J_c\left(\langle A_c^{\ i}\rangle_{\eta,\varphi,\vartheta} - \frac{1}{2}\langle D_c^{\ ij}\rangle_{\eta,\varphi,\vartheta}\frac{\partial}{\partial c^j}\right)f_c\right] = 0,$$

for neoclassical transport of helical plasmas in ultralow collisionality regime; the derivation of the reduced drift kinetic equation is based on a plausible assumption that we can find an approximate constant of motion, in addition to the energy and magnetic moment. The reduced drift kinetic equation is a continuity equation governing the distribution function of confined particles in the three-dimentional phase space of constants of motion. It is clear that the effect of finite supperbanana width and finite aspect ratio have been included in this equation. Note that this three-dimentional reduced drift kinetic equation includes collisional slowing down and energy-scattering terms in addition to the pitch-angle-scattering term. Therefore, the reduced drift kinetic equation developed in the present study is especially suitable for studying transport of fast ions in helical magnetic confinement systems.

Although the reduced drift kinetic equation derived here is independent of the specific choice of the three constants of motion, we have discussed a convenient choice of the three constants of motion for the potential application of the reduced drift kinetic equation. And we have presented the necessary formulas for calculating the dynamic coefficients used in the reduced drift kinetic equation.

One of the potential applications of the reduced drift kinetic equation is that it may provide an alternative way to perform numerical simulation of the neoclassical transport of helical plasmas in the ultralow collisionality regime, especially the neoclassical transport of fast ions in helical systems. As we have discussed, the neoclassical transport of helical plasmas was originally described by the four-dimentional drift kinetic equation. It is difficult to solve this four-dimentional equation in terms of the four independent variables, $(\psi, \vartheta, E, \mu)$, even if to numerically solve it. Conventionally, two necessary approximations have to be made to reduce this four-dimentional problem. (I) By assuming that the supperbanana width is much smaller than the equilibrium scale length of the plasmas, ψ may be treated as a parameter. (II) By assuming that the distribution function only slightly deviates from the local Maxwellian distribution, E may be treated as a parameter.

Since the reduced drift kinetic equation is a three-dimentional continuity equation, it will not be difficult to numerically solve it. It is under construction to solve a computer code to numerically solve this reduced drift kinetic equation.