§28. Connection Formula for the Neoclassical Radial Transport Coefficients in the Ultra Low Collision Frequency Regimes in Heliotron/Torsatron

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It is well-known that the neoclassical ambipolar condition in a non-symmetric torus has only ion root in the high collisionality limit, only electron root in the low collisionality limit, and both roots in intermediate regimes. To consider this dependence of the roots on the collisionality, the existence of the super banana regimes is indispensable. In some numerical calculation methods developed for the neoclassical transports in non-symmetric tori[1],however, ∇B and curvature drifts are not included in the linearized Vlasov operator (collisionless orbit propagator) $v_D \cdot \nabla f_1$ in the drift kinetic equations following the conventional gyro-radius expansion method. This is because the motivation of these methods is mainly the study of the $1/\nu$ and collisionless detrapping (with $E_r \neq 0$) regimes. Neglecting these magnetic drifts disables these methods from treating super banana, transit banana and direct loss orbits and thus the radial diffusion in low collision frequency regimes with weak radial electric fields will be overestimated. This overestimation should be corrected based on other analytical theories (or scaling laws) and/or numerical calculations including the magnetic drifts since especially the overestimation of the ion diffusion precludes the study of ambipolar condition mentioned above. Although the conventional theory based on the gyro-radius expansion of velocity distribution function is not justified when the direct loss occurs or the deviation of the collisionless orbits from the magnetic surface becomes comparable to the plasma dimension on the thermal velocity range[2], the conventional method (based on the paradigm of local transports) is still useful when the particles forming these collisionless orbits exist only on the tail of the distribution. The neoclassical treatment of the loss cone in low aspect ratio configurations is discussed in Ref.[3]. An empirical scaling for the super banana regimes in large aspect ratio configurations is presented in Ref.[4]. Although it depends on the configurations(inward shifted or outward shifted), the bounce averaged magnetic drifts of ripple trapped particles in heliotron/torsatron type tori with relatively low aspect ratios such as LHD and CHS are caused comparably by both of minor and major radial gradients of the adiabatic invariant J and thus it is not clear which scaling is suitable. However, here we show that the scaling in Ref.[4], which is tuned for a torsatron with a relatively high aspect ratio[5], is still useful in CHS and gives convenience in treating the super banana regimes.

Figure 1 shows the mono-energetic diffusion coefficients before the energy integration in the connection formula in Ref.[4] with replacing the $1/\nu$ regime and the collisionless detrapping regime terms by the DKES (Drift Kinetic Equation Solver) results (for R_{ax}=92.1cm, B=1.5T, r/a=0.5, $T_e=T_i$=(2/3)keV). The effective values for the parameters ε_t and ε_h in the super banana ν regime term and the super banana plateau regime term are determined by the DKES results for the $1/\nu$ and the collisionless detrapping regimes to make the effective fraction of ripple trapped particles[1] reflected in the calculation. Since the dependence of the diffusion coefficient in the super banana ν regime on magnetic configurations is smaller than that in the $1/\nu$ regime and the collisionless detrapping regime ($1/\nu$:$\varepsilon_t^2\varepsilon_h^{3/2}$, collisionless detrapping: $\varepsilon_t^{3/2}$, super banana plateau: $\varepsilon_t^2\varepsilon_h^{-1/2}$, super banana ν : $\varepsilon_t^{1/2}\varepsilon_h^{-1}$), this simplified treatment of the super banana regimes is still useful for a practical use, in contrast to the other regimes where the numerical results of DKES are used. As shown in the figure, both of the connection formula for electrons and the DCOM (Diffusion COefficient calculator by Monte carlo method)[6] result for the electron with the energy of 1keV shows the $1/\nu$ to super banana ν transition at CMUL$\equiv \nu/v \sim 10^{-4}$m^{-1}. The mono-energetic diffusion coefficients $D_{11}/[v_T(Bv_T/\Omega)^2]$ as the function of CMUL and EFIELD$\equiv E_r/v$[T] in $1/\nu$ and collisionless detrapping regimes do not depend on the particle energy and the particle species and thus can be commonly used for general particle species with arbitrary plasma parameters while those in the super banana regimes depend on the energy and species. Therefore it is convenient for a practical purpose to remove the ∇B and curvature drifts from the linearized Vlasov operator in the mono-energetic calculation and to correct the overestimation in the super banana regimes in the step of energy integration using this connection formula.

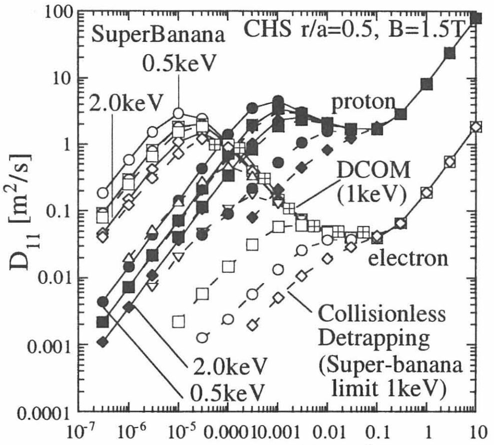

Fig.1 The mono-energetic radial diffusion coefficients D_{11} in CHS given by connecting the DKES results and the empirical scaling for super banana regimes. The closed and open symbols denote the coefficients of proton and electron, respectively. Solid and dotted curves are the cases without and with(collisionless detrapping) radial electric fields, respectively.

References

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