§18. Mirror Particle Loss in a Field-Reversed Configuration

Takahashi,T.(Grad.Univ.for Advanced Studies)
Tomita,Y.,Momota,H.

Stochastic particle motion at X-points and its properties in a Field-Reversed Configuration (FRC) have been reported in [1]. Ion motion at X-points is understood as nonadiabatic phenomena. Without the electrostatic potential, ions near the separatrix are considered to be suffered the rapid loss compared with electrons due to this phenomena. Electrons outside and away from the separatrix, on the other hand, are lost faster because of the high collision frequency and the high thermal speed. The ambipolar potential, however, controls to keep an equality between the charge and loss flux of electrons and ions. This particle loss process have studied insufficiently as yet.

To understand the particle mirror loss process in an FRC, we have developed the kinetic model as,

$$D_\psi \frac{\partial^2 f}{\partial \psi^2} + D_J \frac{\partial^2 f}{\partial J^2} + \frac{\partial}{\partial H} D_H \left(\frac{\partial f}{\partial H} + \frac{f}{T}\right) = 0 \qquad \text{for } J \geq J_c,$$

where H, ψ and J denote the Hamiltonian, the magnetic flux function and the radial action integral, respectively. The critical value of the radial action J_c represents that the particle with the radial action smaller than J_c is not able to travel the mirror points. The diffusion coefficients D_ψ and D_J due to collisions are obtained from the fluctuation-dissipation theorem in our model. The diffusion coefficient due to the collisionless stochastic scattering is obtained numerically as

$$D_J = 18.3 \exp\left[\frac{|q|\psi}{2.06\frac{H-q\phi}{\Omega} + 2.07\times 10^{-5}|q| r_s^2 B_s}\right] \times \exp\left(-0.26\frac{J}{J_{max}}\right)\frac{(H-q\phi)^2}{\Omega^2 \tau_{bounce}}.$$

After solving the equation above, we have found the two kinds of the distribution function. One is for the particles which never suffer the mirror loss because of the larger electrostatic potential at the mirror points than the one at the midplane. The other is for the particles with the loss cone in J-space. The obtained distribution functions are

$$f(H,\psi,J) = a(\psi)\frac{1}{T}e^{-\frac{H}{T}},$$

$$f(H,\psi,J) = a(\psi)\frac{1}{T}e^{-\frac{H}{T}}\sin\left(\frac{\pi}{2}\frac{J-J_c}{J_{max}-J_c}\right).$$

The radial profile $a(\psi)$ is determined to satisfy the charge nutrality and the equality of the loss flux for electrons and ions. Figure 1 shows the ambipolar potential at the mirror points and at the midplane near the separatrix as a function of the mirror ratio in a case that the potential at the midplane away from the separatrix are standarized as 0. The potential gap between at the midplane and at the mirror point (A) is found to be 0, when we consider the stochastic pitch angle scattering at X-points. This result is attributed to the fact that the collisionless pitch angle scattering ions at the separatrix is large enough to enhance ion loss upto the mirror loss of electrons without any electrostatic potential. The consequent density gradient considering the stochastic scattering of ions becomes large, which is presented in Fig.2. The overall particle confinement time is predicted from the continuity of the radial density profile near the separatrix. It appears that the confinement time for a high temperature plasma (10 keV) is proportional to the square of both the separatrix radius and the separatrix magnetic field.

We have employed the classical transverse transport alone in our model. The anormalies should be discussed as cross-field diffusion. And the collision term in our model should be also modified for the further discussion.

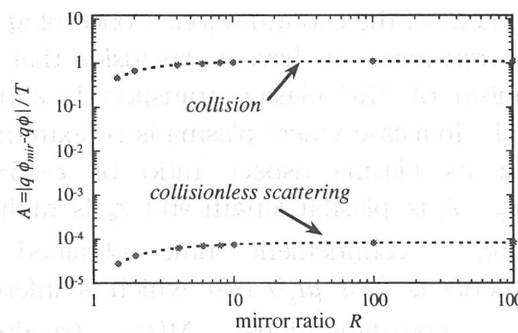

Fig. 1: The ambipolar potentials versus the mirror ratio R. The diffusion coefficient in J-space due to collisionless stochastic pitch angle scattering is employed for the curve indicated as "collisionless scattering".

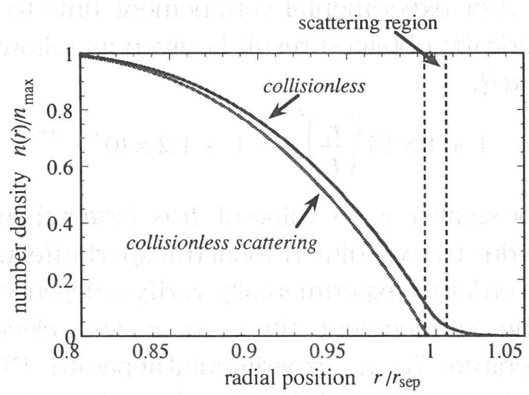

Fig. 2: The number density in terms of the radial position r, which is normalized the one at O-point. The plasma temperature is chosen as 10 keV in this figure. Due to the large diffusion coefficient D_J for the collisionless pitch angle scattering, the large density gradient is observed for this case.

Reference

[1] T. Takahashi, Y. Tomita, H. Momota, and N. V. Shabrov, Plasma Phys. 4, (1997) 4301