§17. Enhanced Loss of Plasma Particles in a Field-Reversed Configuration Attributed to Stochastic Pitch Angle Scattering

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The Collisionless stochastic pitch angle scattering[1] of a charged particle in a field-reversed configuration has been reported already. Since particles located around certain closed magnetic surface if they located deep inside the separatrix, the pitch angle scattering of plasma particles gives no enhancement of direct loss of particles. Outside the separatrix, however, certain magnetic surfaces extend toward the open space or wall of a vacuum vessel. As is well known for the case of magnetic mirror trap of plasmas, the loss property of plasma particles depends in this case on the pitch. Consequently, we will have a loss process attributed to the collisionless stochastic scattering additional to the collisional particle loss.

In an axially symmetric and steady field-reversed configuration, the energy W and the canonical angular momentum P_θ are conserved. We have another constant of motion: J defined by $(1/2\pi)\oint v_\perp^{\,2} dr$, except for the domain closed to the field-null x-point. Therefore, the distribution function of plasma particles of j species can be expressed, $f_j(J, W, P_\theta, \psi, \chi)$. Here, we have applied the cylindrical coordinates system. The spatial coordinates r *and* z have been transformed to the flux function $\psi(r,z)$ and the stream function $\chi(r,z)$. The equation for the distribution function takes the form, in the zero-th order collisionless regime:

$$\frac{d\psi}{dt}\frac{\partial f}{\partial \psi} + \frac{d\chi}{dt}\frac{\partial f}{\partial \chi} = 0$$

Other terms disappear because time derivatives of J, W, and P_q vanish. We are interested to a time averaged distribution function. For this case, the first term on the left-hand side of this equation vanishes too. Thus the distribution function keeps constant along a line of force between field-null x-points. For a gyrating particle, the time-averaged value of P_q is $q\psi$. Thus, the consequent distribution function can be expressed as $f_j(J, W, \psi)$.

The distribution function $f_j(J, W, \psi)$ can be obtained as a

$$D_\psi \frac{\partial^2 f_j}{\partial \psi^2} + D_j \frac{\partial^2 f_j}{\partial J^2} + \frac{\partial}{\partial W} D_W \left(\frac{\partial f_j}{\partial W} + \frac{f_j}{T}\right) = 0$$

solution to the next order Fokker-Planck equation:

Collisionless stochastic pitch angle scattering gives no change in values of ψ and W. Therefore, we apply the values of D_ψ and D_w derived from particle collision.

The diffusion coefficient D_J includes collisional effects as well as the collisionless stochastic change that is given by the empirical formula:

$$D_J = \frac{18\, W^2}{\Omega_{cj}^2 \tau_{bounce}} \exp\left[\frac{|q_j \psi|}{2W/\Omega_j + 10^{-5}|q_j B_s| r_s^2} - \frac{J}{4J_{\max}}\right]$$

The boundary condition for the differential equation is determined from the loss criteria of a particle in a magnetic mirror: $J<J_c$. The quantity J_c is the ratio of the kinetic energy divided by the gyro-frequency at the mirror point. The distribution function f vanishes at $J=J_c$.

The solution to the Fokker-Planck equation can be obtained approximately by assuming a form:

$$a_j(\psi)\frac{1}{T} e^{-(W+q_j\varphi)/T}\, \Im(J)$$

Giving:

$$f_j(W, J, \psi) = \frac{a_j(\psi)}{T} e^{-(W+q_j\varphi)/T} \quad \text{for} \quad W < \varphi(\psi)$$

and for $\quad W > \varphi(\psi)$

$$f_j(W, J, \psi) = \frac{a_j(\psi)}{T} e^{-(W+q_j\varphi)/T} \sin\left(\frac{\pi}{2}\frac{J - J_c}{J_{\max} - J_c}\right)$$

Coefficients $a_j(\psi)$'s are obtained, and consequently the loss flux $\lambda_j(\psi, \phi)$ of respective species of particles, by the charge neutrality condition and vanishing its time derivative, both of which are the function of the scalar potential ϕ at the mirror point.

Consequently, the Fokker-Planck equation takes the form in terms of the particle density n:

$$D_\psi \frac{\partial^2 n(\psi)}{\partial \psi^2} + \lambda(\psi) = 0$$

The value $\lambda(\psi)$ takes a large value near the separatrix if the ion temperature is much larger than 400eV. This means that the enhancement]of particle loss in a field-reversed configuration attributed to the collosionless stochastic scattering of pitch angle appears if ion temperature is much higher than 400eV. Detailed discussions and results will be presented in a journal.