§33. Magnetic Turbulence and Anomalous Transport

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Self-sustained theory of plasma transport has provided an analysis of the anomalous transport due to magnetic braiding [1]. Self-consistent determination of magnetic turbulence and anomalous transport is performed [2].

The factors M and M_s are introduced to denote the enhancement of transport due to magnetic braiding. The coefficient $\sqrt{m_i / m_e}\,M$ is introduced as the ratio between $\hat{\chi}_e^M$ and $\hat{\chi}_i^M$ [1]. We here assume that the collisionality is low, i.e., $\nu << \tau_t$ and $\nu << \tau_{dec}$, (τ_t : transit time of particles, L_{ac}/v_{th}, L_{ac} : auto-correlation length of magnetic filed line in the presence of stochasticity, τ_{dec} : decorrelation time of plasma due to the cross field diffusion). The transport coefficient due to the magnetic stochasticity is given as $\chi \simeq (v_{th}D_M)\tau_{dec}/\tau_t$ if $\tau_{dec} \le \tau_t$ and $\chi \simeq v_{th}D_M$ if $\tau_{dec} > \tau_t$, where D_M is the diffusion coefficient of the magnetic field line. The suppression factor M_S is the ratio τ_t/τ_{dec}. The decorrelation time is given by $\hat{\tau}_{dec}^j = 1 / \hat{\chi}_j^M \hat{k}_r^2$.

The auto-correlation length of the magnetic field line is given by $\tilde{B}_r / B \simeq L_{ac}^{-1} k_r^{-1}$ and has the relation $D_M = (\tilde{B}_r/B)^2 L_{ac}$. Using these relations, one has $\hat{\chi}_e^M \sim (\tau_{dec}^e v_{the} / \tau_t^e v_{Ap})\hat{k}_r^{-2}\hat{L}_{ac}^{-1}$ and $\hat{\chi}_e^M \equiv 1 / \hat{\tau}_{dec}^e \hat{k}_r^2$. We have

$$\tau_{dec}^e \sim \tau_t^e \tag{1}$$

In another word, $M_S \simeq 1$ holds for electrons. For ions the decorrelation time is given by $\tau_{dec}^i = \sqrt{\frac{T_e m_i}{T_i m_e}}\frac{1}{M}\tau_{dec}^e$ for $\hat{\tau}_{dec}^i = 1/\hat{\chi}_i^M \hat{k}_r^2$. The ratio is found to be given by the suppression factor M,

$$\tau_{dec}^i / \tau_t^i = M. \tag{2}$$

The factor M and the diffusion coefficient D_M are not independent and they should be determined consistent with the M-mode turbulence. The renormalization of turbulence gives the relations for electrons, $\hat{\chi}_e^M \simeq \frac{\tau_{dec}^e}{\tau_t^e}\frac{v_{the}}{v_A}\frac{1}{\hat{k}_r}\hat{B}_r$ and $\hat{\chi}_i^M \simeq \hat{\phi}$ for ions. Notice the relations $\hat{B}_r = (\hat{k}_\theta / \hat{k}_\perp)^4 s \hat{k}_r \hat{k}_\theta^{-2} (\hat{\phi}/\hat{\lambda})$ and $\sqrt{m_i / m_e}\,M = \hat{\chi}_e^M / \hat{\chi}_i^M$. After some algebra, the suppression factor M and thermal transport coefficients in case of the braided magnetic field are obtained as

$$M \simeq \sqrt{\alpha\beta_i} \tag{3}$$

$$\chi_i \sim g^{-1}(1 + G\omega_{E1}^2)^{-1}\alpha^2\delta^2\frac{v_{the}}{qR} \tag{4}$$

$$\chi_e \sim \chi_i \cdot \sqrt{\alpha\beta_i m_i / m_e} \tag{5}$$

which shows an order-of-magnitude enhancement compared to the electrostatic limit. The factor M turns out to be much smaller than unity for the parameter of experimental interest.

This result could be compared to the theory based on the scale-invariance method , in which the relation $\chi \propto \alpha^2\delta^2(v_{the}/qR)$ was derived for the case of braided magnetic field [3]. It agrees with Eq.(4).

1) S.-I. Itoh, et al., Phys. Rev. Lett. 76 (1996) 920.
2) S.-I. Itoh, et al., Research Report FURKU 95-13 (1995).
3) J. W. Connor, Plasma Phys. Contr. Fusion 35 (1993) 757.