§28. Subcritical Excitation of Plasma Turbulence

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The subcritical nature of the turbulence is explicitly obtained in this research. Our method resolve difficulties in the conventional methods like amplitude expansion [1]. Critical pressure gradient at which the transition from collisional transport to the turbulent one is to occur is predicted. This provides a prototype of the theory for nonlinear-non-equilibrium systems.

The reduced set of equations for the electrostatic potential ϕ, pressure p, and current J are employed (See [2] for the details.) The Lagrangian nonlinearity is renormalized [2] as the nonlinear diffusion coefficients $\{\mu_{\perp N}, \lambda_N, \chi_N\}$.

The stationary solution is studied. We have the relation as $\mu_N(\mu_N + \mu_c) = \hat{\phi}^2$, $\mu_{e\,N}(\mu_{e\,N} + \mu_{e\,c}) = P^2\hat{\phi}^2, \chi_N(\chi_N + \chi_c) = Q^2\hat{\phi}^2$, where $\hat{\phi}$ is the normalized fluctuation amplitude. In the strong turbulent limit, ratios $\mu_{e\,N}/\mu_N = P$ and $\chi_N/\mu_N = Q$ are found to be close to unity. ($\mu_{\perp c}, \lambda_c, \chi_c$ are the contributions from collisional diffusion). The marginal stability condition was derived as

$$\frac{G_0^{3/2}}{s^2}\frac{(\lambda_N + \lambda_c)}{(\chi_N + \chi_c)^{1.5}(\mu_N + \mu_c)^{0.5}} = \Im_c \quad (1)$$

where $\Im_c$ is a critical Itoh-number and is of the order of unity and G_0 is the normalized pressure gradient, $G_0 = \Omega' \frac{dp_0}{dr}$.

Equation (1) shows the backward-bifurcation. The transition from collisional transport to the strong turbulence takes place at the gradient $G_0 = G_* \cong \Im_c^{2/3}(2sa\omega_p/c)^{4/3}\chi_c^{2/3}$. Figure 1 illustrates the theoretical prediction of the fluctuation level as a function of the pressure gradient, G_0. Explicit multifold forms of $\hat{\phi}(G_0)$ and $\chi(G_0)$ are seen. The lower-amplitude branch is thermodynamically unstable. Anomalous transport is predicted to occur due to the subcritical excitation, if G_0 exceeds the critical value G_*, which is much smaller than the linear stability boundary G_c.

In summary, the nonlinear theory of the current-diffusive interchange mode turbulence in confined plasmas was developed. A nature of the subcritical turbulence was shown from the theoretical formula. Comparison study with the result from the direct nonlinear simulation was made.

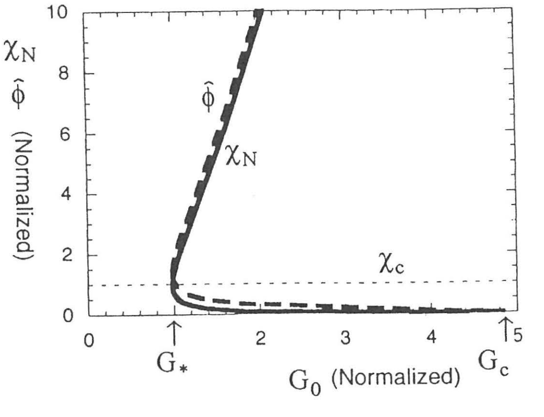

Fig.1 Transport coefficient (solid line) and fluctuation level (dashed line) vs the pressure gradient G_0 (normalized to $(sa\omega_p/c)^{4/3}\chi_c^{2/3}$.) Thin dotted line shows the level of collisional transport. χ_N and $\hat{\phi}$ are normalized to χ_c. ($\mu_c = \chi_c = \sqrt{m_i/m_e}\,\mu_{e,\,c}$ and $m_i/m_e = 1836$. $\Im_c \simeq 0.25$)

1) T. Herbert: *AIAA J.* 18 243 (1980).
2) K. Itoh, et al.: *Plasma Phys. Cont. Fusion* 36 279 (1994).