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Theory of Anomalous Transport in Toroidal Helical Plasmas

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Abstract

Theoretical model of the anomalous transport in Torsatron/Heliotron plasmas is developed, based on the current-diffusive interchange instability which is destabilized due to the averaged magnetic hill near edge. Analytic formula of transport coefficient is derived. This model explains the high edge transport, the power degradation and energy confinement scaling law and the enhanced heat-pulse thermal conduction.

keywords: anomalous transport, interchange instability, magnetic hill, current diffusivity, torsatron/heliotron.

1. Introduction

Much work has recently been done on the plasma transport across the magnetic surface in toroidal plasmas. This is the case for stellarators with the shear and magnetic hill such as Torsatron/Heliotron devices[1-3]. This plasma, in which the pressure gradient rather than the toroidal current plays the dominant role in instabilities, may yield a knowledge on anomalous transport complementary to tokamaks. Experiments have shown that (I)the energy confinement time τ_E degrades with power[4-7]. By the comparison within different devices, a scaling law of τ_E has been proposed[5]. Detailed studies have shown that (II) the effective thermal conductivity χ_{eff} increases with temperature for given minor radius, r[8], (III) the profile of χ_{eff} for a given heating power, however, is an increasing function of r[7,8], and a simple form like $\chi_{eff} \propto T_e^{1.5}/B^2$ is not valid. It is also known that (IV) the thermal transport coefficient that is determined by the heat pulse propagation, χ_{HP}, is larger than χ_{eff}[9]. These results have similarities and differences with tokamaks, and the explanation of these will provide a key to understand the anomalous transport in toroidal plasmas.

The interchange mode[10] has been thought to be a candidate to explain the anomalous transport in Torsatron/Heliotron. This mode can be destabilized, for instance in the presence of finite resistivity, η. Much efforts has been done on the anomalous transport driven by the registive interchange mode[11-14]. Theoretical method is either mixing length model[15], scale invariance method[16] or one/two point renormalization technique[17]. The different methods have given the same result on χ_{eff} from the physics point of view (the difference appears only for a numerical constant)[18]. In spite of these intensive studies, the anomalous transport, characterized by (I)-(IV), remains unexplained.

We have recently investigated the effects of transport coefficients on the interchange instability, such as thermal diffusivity, χ, viscosity, ν, and especially, the current diffusivity, λ[19]. The important role of the current diffusivity was found; Below the critical beta value against global MHD mode, the microscopic interchange mode is destabilized through current-diffusivity, not by the resistivity.

In this article we derive the anomalous transport coefficient based on the microscopic current-diffusive interchange mode (abbreviated by 'λ-mode'). We found $\chi_{eff} \propto (d\beta/d\rho)^{3/2} \delta_s^2 v_A/R$ (β: ratio of plasma pressure to magnetic pressure, ρ: normalized minor radius r/a, a:plasma minor radius, δ_s: collisionless skin depth, v_A: Alfven velocity, R:major radius). This result is consistent with the experimental knowledge (I)-(IV).

We use a model equation based on the reduced set of equations for stellarators[20]. The cylindrical model [coordinates (r, θ, z)] is employed in order to look for the analytical insight. We also consider the case of zero equilibrium current. The model equations consist of the Ohm's law, equation of motion and the energy balance equation, as is explicitly given in Refs.[19,21]. (The term $\lambda\nabla^2 j$ is added to the Ohm's law as $E+v\times B=\eta j-\lambda\nabla^2 j$.) We use the picture of the mean field theory; we analyze the growth rate and mode structure of the λ-mode by keeping χ, ν, λ, η. The instability driven transport coefficient (derived by the mixing length theory) is equal to the one which is used for stability analysis.

We solve the eigen value equation by the Fourier transform. The parallel derivative is approximated by $k_{/\!/} = k_\theta s x$ ($k_\theta = m/\rho_1$, $x = \rho - \rho_1$, m poloidal mode number, ρ_1: rational surface, $s = \rho_1 \iota'(\rho_1)$, ι: rotational transform), since we study the microscopic mode which is localized to the rational surface. The variable is changed from x to k as $u(x) = \exp[\gamma t + im\theta - inz/R] \int u(k)\exp(ikx)dk$, where u is the perturbing stream function, γ is the growth rate, and n is the toroidal mode number. Eliminating the current and pressure perturbations from set equations, and assuming the electrostatic perturbation, we have the eigenvalue equation for γ in the k space as[19]

$$\frac{1}{L^2}\frac{\partial}{\partial k}\frac{1}{\bar{\eta}+\bar{\lambda}k_\perp^2}\frac{\partial}{\partial k}u + \frac{D_0 k_\theta^2}{\bar{\gamma}+\bar{\chi}k_\perp^2}u - (\bar{\gamma}k_\perp^2+\bar{\nu}k_\perp^4)u = 0, \qquad (1)$$

where $k_\perp^2 = k_\theta^2 + k^2$, $1/L = k_\theta s$, $D_0 = -\beta_0 \Omega' p_{eq}'/2\varepsilon^2$, $p_{eq} = p_0(\rho)/p_0(0)$ (p_0 being the equilibrium pressure), $\varepsilon = a/R$ and Ω' is approximately given as $\Omega' = \varepsilon^2 (N/\ell)\rho^{-2}(\iota\rho^4)'$. (N is the toroidal pitch number and ℓ is the multiporarity.) The term D_0 denotes the drive by the pressure gradient with the bad curvature. The transport coefficients are normalized as $\bar{\chi} = \chi\tau_{Ap}/a^2$, $\bar{\eta} = \eta\tau_{Ap}/\mu_0 a^2$, $\bar{\nu} = \nu\tau_{Ap}/a^2$, $\bar{\lambda} = \lambda\tau_{Ap}/\mu_0 a^4$, and the time is normalized as $\bar{\gamma} = \gamma\tau_{Ap}$, where $\tau_{Ap} = R\sqrt{\mu_0 m_i n_i}/B_0$, n_i is the ion density, m_i is the ion mass and B_0 is the equilibrium magnetic field.

Equation (1) is solved by Rayleigh-Ritz method. Writing Eq.(1) as $\mathcal{L}u=0$, and the functional $\mathcal{R}[u]$ is defined as $\mathcal{R}[u]=\int_{-\infty}^{\infty} u\mathcal{L}u dk / \int_{-\infty}^{\infty} u^2\, dk$. Test function of $u=\exp(-\alpha^2 k^2/2)$ is employed. Equations $\mathcal{R}[u]=0$ and $\partial\mathcal{R}[u]/\partial\alpha=0$ determines the growth rate τ and α. The value α is the typical radial extent of the mode. Apart from a numerical coefficient of order unity, the transport coefficient χ is given as[15]

$$\bar{\chi} = \bar{\tau}\,\alpha^2. \tag{2}$$

The Rayleigh quotient $\mathcal{R}$ is obtained as

$$\mathcal{R} = -s^2\bar{\lambda}^{-1}\alpha^2\{y^2-2y^3\exp(y^2)\mathrm{Erfc}(y)\} + 2D_0 k_\theta^2 \zeta\exp(\zeta^2)\mathrm{Erfc}(\zeta)$$

$$-\bar{\tau}k_\theta^2\{1+1/2y^2\} - \bar{\nu}k_\theta^4\{1+1/y^2+3/4y^4\} \tag{3}$$

where $y=\alpha^2 k_\theta^2$, $\zeta=\alpha^2(\bar{\tau}/\bar{\chi}+k_\theta^2)$, and $\mathrm{Erfc}(y)=\int_y^\infty \exp(-v^2)dv$. [Resistivity contribution is small if $\bar{\eta}<\bar{\lambda}k_\theta^2$. This condition is satisfied, as shown a posteriori, and η is neglected.] In order to obtain the physics insight, we obtain the analytic expression. In the following, we assume that $\bar{\chi}\simeq\bar{\nu}$, since the electrostatic E×B transport is studied. (It is straightforward to study the general case of arbitrary ratio of $\bar{\chi}/\bar{\nu}$, but this does not change the result qualitatively.)

In the large αk_θ limit, the asymptotic limit of the function Erfc is used. Taking the leading term in αk_θ (note $\bar{\chi}=\bar{\nu}=\bar{\tau}\alpha^2$), the eigenvalue equation $R[u]=\partial R[u]/\partial\alpha=0$ gives the growth rate and the radial extent α of the fast interchange mode[22] as $\bar{\gamma}=\sqrt{D_0}/(\alpha k_\theta)^2$ and $\alpha^2=\sqrt{\bar{\lambda}(\bar{\gamma}+2\bar{\nu}k_\theta{}^2)}/s$. For the small αk_θ limit, the Taylor expansion of R is used. The first order term is written as $\bar{\gamma}\simeq(\sqrt{8}/5)\alpha k_\theta\sqrt{D_0}$. From these results, the largest growth rate is given for the poloidal mode number satisfying $k_\theta\alpha\sim 1$. For such mode, we have the stimate

$$\bar{\gamma} \simeq \sqrt{D_0} \tag{4-1}$$

$$\alpha^2 \simeq s^{-1}\sqrt{3\bar{\lambda}\sqrt{D_0}}. \tag{4-2}$$

Substituting Eq.(4) into Eq.(2), we have

$$\bar{\chi} = \frac{3}{s^2}\frac{\bar{\lambda}}{\bar{\chi}}D_0{}^{3/2} \tag{5}$$

We use the relation[23] $\bar{\lambda}/\bar{\chi}\sim(\delta_s/a)^2$. Noting the normalization, the explicit form of χ is finally given as,

$$\chi = F(\rho)\ \{d\beta/d\rho\}^{3/2}\delta_s{}^2 v_A R^{-1} \tag{6-1}$$

where $F(\rho)$ is the geometry-dependent numerical coefficient

$$F(\rho) = \frac{3}{s^2}\left\{\frac{N}{2\ell}\frac{1}{\rho^2}\frac{d}{d\rho}(\chi\rho^4)\right\}^{3/2}. \tag{6-2}$$

The ratio between the relative amplitudes of density and potential fluctuations, $\tilde{n}/n$ and $e\tilde{\Phi}/T$, can be derived from Eq.(4). Since the convective change dominates in n, we have the relation $\tilde{n}/n=(\omega_*/\tau)e\tilde{\Phi}/T$, where ω_* is the drift frequency, $Tk_\theta\kappa/eB$ ($\kappa=|\nabla n/n|$ and we assume that $T_e=T_i$). Using the condition $k_\theta\alpha\simeq 1$ and the expressions for τ and α, we have

$$\tilde{n}/n \simeq [3.1 s D_0^{-1}\kappa R\ \beta(a)]\ e\tilde{\Phi}/T. \quad (7)$$

This result gives that the density fluctuation is usually smaller than the potential fluctuation.

We study what is predicted from this model, comparing to the experimental results (I)-(IV).

Firstly, the dimensional dependence of χ is such that $[\chi]\propto[T]^{1.5}/RB^2$ and is independent of that of density. Equation(6) predicts χ of the experimental range (see Fig.1). Second, the point model analysis gives the energy transport scaling law as

$$\tau_E = A^{0.2}B^{0.8}n^{0.6}a^2RP^{-0.6}\langle F\rangle^{0.4} \quad (8)$$

where A is the ion mass ratio, P is the heating power and $\langle F\rangle$ is the average of F near the boundary[24]. The weak but positive dependence on the mass ratio is obtained. We also find that the improvement of the confinement by increasing the shear (s^{-2} term in F) is almost offset by the increment of the magnetic hill ($\{N(\rho^4\chi)'\}^{3/2}\rho^{-3}$ term in F). This result explains the fact that, from the comparison between different devices, τ_E seems to weakly depend on the rotational transform/ shear. $\langle F\rangle^{0.4}$ weakly depnds on geometrical parameters. The predicted indices to B, n, a, R, and P, as a whole, agrees to the scaling law[5].

Third, the formula χ includes the radial dependence $(\beta'/n)^{3/2}$, not $T^{3/2}$, and predicts a large transport near edge. Since the pressure gradient is substantial near the edge (even though the pressure itself must be small) and n(r)/n(0) is decreasing towards the edge, the anomalous transport can be large near edge. With this radial dependence and that of $F(\rho)$, χ is larger near the edge, as is shown in Fig.1.

Forth, the heat pulse propagation time is faster than τ_E. For simplicity, we assume that $|\nabla T/T|>>|\nabla n/n|$ in the region where heat pulse propagation is studied. Writing the heat flux $q=q_0+\tilde{q}$ and $\nabla T= \nabla T_0+ \widetilde{\nabla T}$, we have $\tilde{q}=2.5\chi_{eff}\ \widetilde{\nabla T}$, where χ_{eff} is the ratio between q_0 and $|\nabla T_0|$ (i.e., χ in this article). From this relation, we see that the heat transport coefficient, which is derived from the heat pulse propagation, χ_{HP}, satisfies the relation

$$\chi_{HP} = 2.5\ \chi_{eff}. \qquad (9)$$

Fifth, the relative perturbation of density is smaller than that of the potential. We have $D_0 \sim 60\kappa_p a\beta(0)$ and $s\sim 4$ for Heliotron-E plasma[4], which gives $\tilde{n}/n \sim [2(\kappa/\kappa_p)^2\beta(a)/\beta(0)]e\tilde{\Phi}/T$ ($\kappa_p= |\nabla p/p|$). This number is order of one tenth. Fluctuation measurements in high power heating experiments have shown that $\tilde{n}/n$ is smaller than $e\phi/T$[26,27], confirming our model. This relation also suggests that $(\tilde{n}/n)/(e\tilde{\Phi}/T)$ increases as the pressure profile becomes broader.

These results are consistent with experiments including (I)-(IV).

In summary, we have developed a new model for the anomalous transport in the toroidal helical plasma with magnetic hill and magnetic shear and presented an analytic formula. The microscopic current-diffusive interchange mode (λ-mode) is analyzed by keeping the transport coefficients χ, ν, and λ. Mixing length estimate is used to derive the transport coefficient from the mode growth rate and structure. The mean filed theory is employed so that the obtained transport coefficient is equated with the given value of χ. By this theoretical analysis we derived the formula of the anomalous transport coefficient. The mode analysis gives that the nornalized density perturbation is usually smaller than the normalized potential fluctuation. The comparison with experimental result shows that the derived formula recovers the scaling law, radial shape of χ and difference between χ_{HP} and χ_{eff}, and that the relation between the amplitudes of the density and potential perturbations is also reproduced. This formula also explains the weak effects of ion mass and magnetic shear/rotational transform on τ_E.

We would like to note that Eq.(6) is derived apart from a numerical coefficient of the order of unity. The previous analyses on resistive interchange mode by two point renormalization method have shown the factor 5 enhancement over the mixing length estimate[11,13]. Equation (6) will be changed by a factor like that, but the physical dependences of χ is not altered.

In this work the importance of the currewnt diffusivity is shown. The resistivity is negligible if $\bar{\eta}<\bar{\lambda}k_\theta^2$ holds. This condition is rewritten by using the result of α ($\simeq 1/k_\theta$) as $\bar{\chi}/\bar{\eta}>(a/\delta_s)^2\bar{\eta}s^{-2}\sqrt{D_0}$, .which is usually satisfied for experimental plasmas for which transport analysis is made.

We compare Eq.(6) to the formula derived by Ohkawa for magnetic turbulence[28]. Compared to the Ohkawa formula, $\chi\sim\delta_s^2 v_e/R$, Eq.(6) has an additional dependence on β. In our model, the current diffusion is proportional to δ_s^2, so that the similar dependence on δ_s^2 is obtained, though the perturbation is assumed to be electrostatic.

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References

[1] C. Gouldon, et al.: Plasma Physics and Controlled Nuclear Fusion Research (IAEA, Vienna, 1968) Vol.1, p847.

[2] A. Mohri: J. Phys. Soc. Jpn. **28** (1970) 1549;
A. Mohri and M. Azumi: J. Phys. Soc. Jpn. **29** (1970) 1580.

[3] K. Uo: Plasma Physics **13** (1971) 243.

[4] K. Uo, et al.: Plasma Physics and Controlled Nuclear Fusion Research 1986 (Proc. 11th Int. Conf. Kyoto, 1986) Vol.2, IAEA, Vienna (1987) 355.

[5] S. Sudo, et al.: Nucl. Fusion **30** (1990) 11.

[6] M. Murakami, et al.:Plasma Physics and Controlled Nuclear Fusion Research 1990 (Proc. 13th Int. Conf. Washington, 1990) Vol.2, IAEA, Vienna (1987) 455.

[7] H. Iguchi, et al.: in Controlled Fusion and Plasma Physics (Proc. 16th Eur. Conf. Venice, 1989) Vol.14B, European Physical Society, (1990) 451.

[8] F. Sano, et al.: Nucl. Fusion **30** (1990) 81.

[9] H. Zushi: private communications. (1991)

[10] M. N. Rosenbluth and C. L. Longmire: Ann. Phys. (1957) 1120.

[11] B. Carreras, L. Garcia, P. H. Diamond: Phys. Fluids **30** (1987) 1388.

[12] K. C. Shaing, B. A. Carreras: Phys. Fluids28 (1985) 2027.

[13] H. Sugama, M. Wakatani: J. Phys. Soc. Jpn. **57** (1988) 2010.

[14] M. Yagi, M. Wakatani, K. C. Shaing: J. Phys. Soc. Jpn. **57** (1988) 117.

[15] B.B. Kadomtsev: in Plasma Turbulence (Academic Press, New

York, 1965).

[16] J. W. Connor and J. B. Taylor: Nucl. Fusion **17** (1977) 1047.

[17] T. H. Dupree: Phys. Fluids **9** (1966) 1773, **15** (1972) 334.

[18] M. Yagi: PhD Thesis, Kyoto University (1989).

[19] K. Itoh, K. Ichiguchi, S.-I. Itoh: 'Beta Limit of Resistive Plasma in Torsatron/Heliotron Devices', Research Report NIFS-131 (National Inst. Fusion Science, 1992).

[20] H. Strauss: Plasma Phys. **22** (1980) 733.

[21] K. Ichiguchi, Y. Nakamura, M. Wakatani: Nucl. Fusion **29** (1991) 2073.

[22] J. Greene, J. L. Johnson: Phys. Fluids **4** (1961) 875.

[23] P. J. Kaw, E. J. Valeo, P. H. Rutherford: Phys. Rev. Lett. **43** (1979) 1398. See also A. J. Lichtenberg, et al.: 'Role of Stochasticity in Sawtooth Oscillation', Nucl. Fusion **31** (1992) in press.

[24] The reason to choose the edge value of F is discussed in K. Itoh and S.-I. Itoh: Comments Plasma Phys. Cont. Fusion **14** (1991) 1.

[25] M. Sato, et al.: in Controlled Fusion and Plasma Heating (Proc. 15th Eur. Conf. Dubrovnik, 1988) Vol.13B, European Physical Society, (1988) 470.

[26] H. Zushi, et al.: Nucl. Fusion **28** (1988) 433.

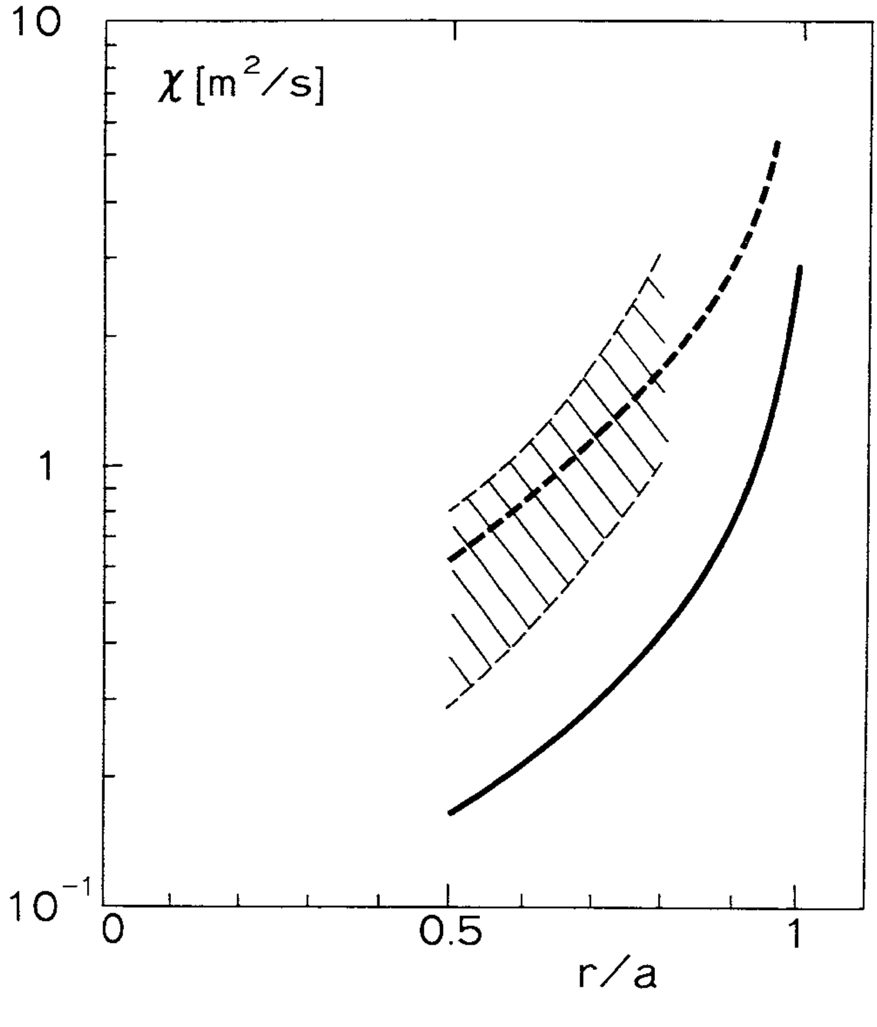
[27] C. P. Ritz, et al.:Plasma Physics and Controlled Nuclear Fusion Research 1990 (Proc. 13th Int. Conf. Washington, 1990) Vol.2, IAEA, Vienna (1987) 589.

[28] T. Ohkawa: Phys. Letters **67A** (1978) 35.

Figure Caption

Fig.1 Example of the prediction of Eq.(6) in the model of Heliotron E ($\not{\iota}(\rho)=\not{\iota}_0+1.6\not{\iota}_1\rho^2$, $\varepsilon=0.1$, B=2T, T(0)=500eV, $n(0)=5\times10^{19}m^{-3}$). Profiles are chosen such that $p_{eq}(\rho)=1+\Delta-\rho^2$ and $n(\rho)/n(0)=(1+\Delta-\rho^2)^{1/2}$ ($\Delta=0.05$). Thick dashed line indicates 4-times of the formula (6). Shaded region shows the range of experimental data, which is quoted from Ref.[18,25].

Fig.1



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NIFS-134 Y. Miura, F. Okano, N. Suzuki, M. Mori, K. Hoshino, H. Maeda, T. Takizuka, JFT-2M Group, S.-I. Itoh and K. Itoh, *Rapid Change of Hydrogen Neutral Energy Distribution at L/H-Transition in JFT-2M H-mode ;* Feb. 1992

NIFS-135 H. Ji, H. Toyama, A. Fujisawa, S. Shinohara and K. Miyamoto *Fluctuation and Edge Current Sustainment in a Reversed-Field-Pinch;* Feb. 1992

NIFS-136 K. Sato and F. Miyawaki, *Heat Flow of a Two-Electron-Temperature Plasma through the Sheath in the Presence of Electron Emission;* Mar. 1992

NIFS-137 T. Hayashi, U. Schwenn and E. Strumberger, *Field Line Diversion Properties of Finite β Helias Equilibria;* Mar. 1992

NIFS-138 T. Yamagishi, *Kinetic Approach to Long Wave Length Modes in Rotating Plasmas*; Mar. 1992

NIFS-139 K. Watanabe, N. Nakajima, M. Okamoto, Y. Nakamura and M. Wakatani *Three-dimensional MHD Equilibrium in the Presence of Bootstrap Current for Large Helical Device (LHD)*; Mar. 1992