NATIONAL INSTITUTE FOR FUSION SCIENCE

Confinement Improvement in H-Mode-Like Plasmas in Helical Systems

K. Itoh, S.-I. Itoh, A. Fukuyama, H. Sanuki and M. Yagi

RESEARCH REPORT
NIFS Series

NAGOYA, JAPAN

Confinement Improvement in H-Mode-Like Plasmas in Helical Systems

K. Itoh[*], S.-I. Itoh[†], A. Fukuyama[**], H. Sanuki[*], M. Yagi[††]

[*] National Institute for Fusion Science, Nagoya 464-01, Japan

[†] Research Institute for Applied Mechanics, Kyushu University 87,
Kasuga 816, Japan

[**] Faculty of Engineering, Okayama University, Okayama 700, Japan

[††] Japan Atomic Energy Research Institute, Ibaraki 311-01, Japan

Abstract

The reduction of the anomalous transport due to the inhomogeneous radial electric field is theoretically studied for toroidal helical plasmas. The self-sustained interchange-mode turbulence is analysed for the system with magnetic shear and magnetic hill. For the system with magnetic well like conventional stellarators, the ballooning mode turbulence is studied. Influence of the radial electric field inhomogeneity on the transport coefficients and fluctuations are quantitatively shown. Unified theory of the transport coefficients in the L-mode and H-mode-like plasmas are presented.

Keywords: Toroidal Helical System, H-mode, Anomalous Transport, Radial Electric Field, Self-Sustained Turbulence

1

The finding of the H-mode in tokamaks (Wagner et al 1982, ASDEX Team 1989) has not only shortened the path to the ignition plasmas but also motivated the confinement physics studies. The modelling on the H-mode has been developed focusing on the role of radial electric field structure (Itoh et al 1988, 1989a), which either gives rise to the bifurcation in the confinement states (Itoh et al 1988, 1989a, Shaing et al 1989a) or suppresses micro-instabilities thus reducing the anomalous transport (Itoh et al 1989b, Shaing et al 1989b, Bigrali et al 1989, Itoh et al 1990). The important role of radial electric field has then been confirmed experimentally (Groebner et al 1990, Ida et al 1990).

For toroidal helical systems (stellarators), the influence of the radial electric field has long been recognized at least from the view point of the absolute trapping of particles and neoclassical transport. It is an urgent task to study the effect on the anomalous transport in this configuration, which has been known to be the dominant loss mechanism in experiments (Grieger et al 1986, Itoh et al 1989c, Lyon 1990).

The inhomogeneous radial electric field affects the micro-instabilities and associated anomalous transport. Since the poloidal gyroradius can be of the order of the gradient length of E_r in the Wendelstein VII-A (WVII-A) stellarator (Grieger et al 1986), the suppression could be considerable. We have studied the coupling between the temperature gradient and electric field (Itoh et al 1992a) and found that the link between the anomalous transport and them has the property to cause the bifurcation (Itoh et al 1992b). This mutual interaction allows a multiple

2

solution of the gradient for the given heat flux in the whole plasma column. The transition to the improved confinement state was thus concluded to be slower in comparison with the L-H transition in tokamaks. This prediction was confirmed by the recent finding of the H-mode like discharges in WVII-AS stellarator (Erckmann et al 1993).

Compared to the progress in the transition physics, the theories on the transport coefficients remained premature. The quantitative explanation for the L-mode and H-mode has long been remained to be mystery. Recently, theory for the self-sustained turbulence has been progressed. By solving the interchange-mode turbulence by this novel method, the better understanding of the L-mode transport in torsatron/Heliotron was given (Itoh et al 1992c). The analysis has been extended to treat the ballooning-mode turbulence in the system with magnetic well (Itoh et al 1993a, 1993b, Yagi et al 1993). The influence of the inhomogeneous radial electric field was then analysed for the tokamaks (Itoh et al 1993c). We here apply this formalism to toroidal helical plasmas and present the unified formula of the anomalous transport coefficient for the L and H-like mode in helical systems.

We first study torsatron/Heliotron plasma with the cylindrical coordinates (r, θ, z). The reduced set of equations (Strauss 1980) is employed. The basic equations consist of the equation of motion, $n_i m_i \{d(\nabla_\perp^2 \phi)/dt - \mu \nabla_\perp^4 \phi\} = B^2 \nabla_\parallel J + (B\Omega'/r)\partial p/\partial\theta$, generalized Ohm's law, $E + v \times B = J/\sigma - \nabla_\perp^2 \lambda J$, and the energy balance equation,

3

$dp/dt = \chi \nabla_\perp^2 p$. Here m_i is the ion mass, n_i is the ion density, ϕ is
the static potential, B is the main magnetic field, Ω' is the mag-
netic curvature, p is the plasma pressure, J is the current and σ
is the classical conductivity. The E×B nonlinear interactions
are renormalized in a form of χ, μ and λ. The detailed deriva-
tion was reported in Itoh 1993d. The time derivative is defined
as $\partial/\partial t + [\phi, \ ]/B$, where $[\ ,\ ]$ denotes the Poisson bracket. The
doppler shift of frequency is offset for the homogeneous E×B
rotation. Only the contribution of E_r' to d/dt is retained.

We solve the mode structure in the vicinity of the mode
rational surface, r_s. The parallel wave number is expressed as k
$= k_\theta s x/qR$ ($x = r - r_s$, q is the safety factor). Fourier transforma-
tion is used as $\tilde{p}(r, \theta, z) = \Sigma \exp(\tau t + im\theta - inz/R) \int \tilde{p}(k) \exp\{-ikx\} dk$.
Eliminating $\tilde{\phi}$ and $\tilde{J}$ from basic equation, we have the eigenmode
equation for $\tilde{p}$. The marginal stability condition is obtained by
setting $\tau = 0$, as

$$\frac{d}{dk} \frac{1}{\hat{\lambda} k_\perp^2} \frac{d}{dk} \left[\hat{\chi} k_\perp^2 + \omega_{E1} \frac{d}{dk} \right] \tilde{p} + \frac{D_0}{s^2} \tilde{p}$$

$$- \frac{1}{k_\theta^2 s^2} \left[\hat{\mu} k_\perp^2 + \omega_{E1} \frac{d}{dk} \right] k_\perp^2 \left[\hat{\chi} k_\perp^2 + \omega_{E1} \frac{d}{dk} \right] \tilde{p} = 0. \tag{1}$$

We use the normalization $r/a \to \hat{r}$, $t/\tau_{Ap} \to \hat{t}$, $\chi \tau_{Ap}/a^2 \to \hat{\chi}$, $\mu \tau_{Ap}/a^2 \to \hat{\mu}$,
$\lambda \tau_{Ap}/\mu_0 a^4 \to \hat{\lambda}$, $\tau_{Ap} \equiv a\sqrt{\mu_0 m_i n_i}/B_p$, $\tau \tau_{Ap} \to \hat{\tau}$, and notation τ is the
growth rate, $s = r(dq/dr)/q$, $D_0 = \Omega' \beta'/2\varepsilon^2$, $B_p = Br/qR$, $\varepsilon = r/R$, a and
R for the major and minor radii, $\beta = 2\mu_0 p/B^2$, and $\beta' \equiv d\beta/d\hat{r}$. The

4

parameter ω_{E1} denotes the effect of the radial electric field shear,

$$\omega_{E1} = \tau_{Ap}(mdE_r/d\hat{r})(rB)^{-1}. \qquad (2)$$

If we neglect ω_{E1}, Eq.(1) reduces to the transport-driven interchange mode equation for the L-mode plasma (Itoh et al 1992c).

Equation (1) determines the relation between the anomalous transport coefficients $\{\hat{\chi}, \hat{\lambda}, \hat{\mu}\}$ and the plasma inhomogeneity $\{\beta', E_r'\}$ (Itoh et al 1992c, 1993a, 1993b, 1993d, Yagi et al 1993). We here treat the effects of ω_{E1} by the perturbation method as in Itoh et al 1993c. The linear term of ω_{E1} is kept and Eq.(1) is rewritten as

$$\frac{d}{dy}\frac{1}{F}\frac{d}{dy}F\tilde{p} + H\left[1-\frac{F^3}{b}\right]\tilde{p} + L\tilde{p} = 0 \qquad (3\text{-}1)$$

and

$$L\tilde{p} \equiv \hat{\omega}_{E1}\sqrt{\frac{b}{D_0}}\left[\frac{d}{dy}\frac{1}{F}\frac{d^2}{dy^2}\tilde{p} - H\left(\frac{d}{dy}F^2\tilde{p} + F^2\frac{d}{dy}\tilde{p}\right)\right]. \qquad (3\text{-}2)$$

We use notaions $H=D_0^{3/2}\hat{\lambda}\hat{\chi}^{-3/2}\hat{\mu}^{-1/2}$, $F=b+y^2$, $b = k_\theta^2/k_0^2$, $y = k/k_0$, $k_0^4=D_0/\hat{\chi}\hat{\mu}$, and $\hat{\omega}_{E1}=\tau_{Ap}(dE_r/dr)B^{-1}$. The approximate relation $\hat{\chi}=\hat{\mu}$ is used in simplifying the expression of the operator L. (The validity of the approximation of $\mu\approx\chi$ is shown in Itoh et al 1993e.)

For the strongly localized mode, $y^2 < 1$, this eigenvalue equation is approximated in a form of the Weber type equation by neglecting the dp/dy term (Itoh et al 1993a, 1993b, 1993d, Yagi et al 1993) as

$$d^2 \tilde{p}/dy^2 + H\{(1-b^2)-3by^2\}\tilde{p} + L\tilde{p} = 0. \tag{4}$$

The stability boundary is obtained by the perturbative method. Let $\{u_j\}$ be the j-th eigenfunction of the unperturbed equation $(\omega_{E1}=0)$. The fundamental eigenmode u_0 and the first harmonics u_1 are expressed as $u_0 = \xi^{1/4}\pi^{-1/2}\exp\{-\xi y^2/2\}$ and $u_1 = \sqrt{2/\pi}\xi^{3/4}y\exp\{-\xi y^2/2\}$, respectively. The odd and even parity modes are mixed by the operator L when $\omega_{E1}\neq 0$. We write the eigenfunction as

$$\tilde{p}(y) = u_0 + \rho u_1 \cdots, \tag{5}$$

where the coefficient ρ indicates the coupling between the even and odd modes. The eigenvalue is approximately given as

$$\frac{\hat{H}^2}{\xi^2} \simeq 1 - \frac{\langle 0|L|1\rangle\langle 1|L|0\rangle}{\xi^2} \tag{6}$$

where

$$\hat{H} \equiv H(1-b^2), \tag{7-1}$$

and

$$\xi^2 = 3bH . \tag{7-2}$$

The coefficient ρ is given as

$$\rho = \langle 1 | L | 0 \rangle (\hat{H} - 3\xi)^{-1} . \tag{8}$$

Substituting the eigenfunctions, the integrals $\langle 0 | L | 1 \rangle$ and $\langle 1 | L | 0 \rangle$ are computed. We have

$$\langle 0 | L | 1 \rangle \simeq -\frac{2b}{D_0} \hat{\omega}_{E1} \left[\frac{3\xi b}{4} - \frac{3}{8} + H(b^2 + \frac{b}{\xi} + \frac{3}{4\xi^2}) \right] \tag{9-1}$$

$$\langle 1 | L | 0 \rangle \simeq \frac{2b}{D_0} \hat{\omega}_{E1} \left[\frac{3\xi b}{4} - \frac{7}{8} + H(b^2 + \frac{b}{\xi} + \frac{3}{4\xi^2}) \right] \tag{9-2}$$

For the unperturbed mode, the least stable mode is specified (Itoh et al 1993d) by the condition $b \simeq 0.34$ and $H = H_0 = 1.26$. Substituting these numbers into Eq.(9), we have $\langle 0 | L | 1 \rangle \langle 1 | L | 0 \rangle \simeq -0.58 \hat{\omega}_{E1}^2 / D_0$. Equation (6) gives the relation

$$\frac{D_0^{3/2} \hat{\lambda}}{s^2 \hat{\chi}^2} = H_0 \left[1 + G \hat{\omega}_{E1}^2 \right] \tag{10}$$

and

$$G = 0.52 D_0^{-1} . \tag{11}$$

From Eq.(10), the anomalous transport coefficient in the presence
of the inhomogeneous radial electric field is obtained as

$$\hat{\chi} = \frac{\hat{\chi}_L}{1 + G\hat{\omega}_{E1}{}^2} \qquad . \qquad (12\text{-}1)$$

and

$$\hat{\chi}_L = \frac{0.8D_0{}^{3/2}\hat{\lambda}}{\hat{\chi}s^2} \qquad (12\text{-}2)$$

The form of $\hat{\chi}_L$ is the anomalous transport obtained for the L-mode
plasma. The coefficient $\hat{\lambda}/\hat{\chi}$ is given by δ^2/a^2 where δ is the
collisionless skin depth (Itoh 1993e). Equation (12) quantifies
the effect of E_r' on the thermal conductivity, unifying the L-
and H-mode plasmas. It is emphasized that the coefficients are
given explicitly in terms of the equilibrium quantities. This is
because the self-sustained turbulence is solved by our theoreti-
cal formalism. The suppression of the transport is prominent
when $\hat{\omega}_{E1} \sim \sqrt{D_0}$.

The theory also predicts the change in the fluctuations.
The relations $k_\theta{}^2 = bk_0{}^2$ and $k_0{}^4 = D_0\chi^{-2}$ (note that the relation $\chi \simeq \mu$
is used) show that poloidal mode number becomes larger as χ is
reduced. Using Eq.(12), we have

$$k_\theta{}^2 \simeq s^2\delta^{-2}D_0{}^{-1/2}\left[1 + G\hat{\omega}_{E1}{}^2 \right]. \qquad (13)$$

8

Fluctuation level is also reduced. The renormalized diffusivity has a relation $\chi \sim (r\tilde{E}/B)^2/(\chi k_\perp^2)$ (Itoh 1993d), which gives the estimate, $\tilde{\Phi}/B \sim \chi$. Using Eq.(12), we have

$$e\tilde{\Phi}/T \sim (\chi_L eB/T)\left[1 + G\hat{\omega}_{E1}^2 \right]^{-1}. \qquad (14)$$

The fluctuation level is reduced and the radial and poloidal correlation lengths become shorter as χ is subject to considerable reduction.

Figure 1 illustrates the dependences on D_0 (the drive of the pressure gradient) and $\hat{\omega}_{E1}$ (influence of the E_r') of the thermal conductivity. The influences of the radial electric field inhomogeneity on the correlation length and the amplitude of fluctuations are shown in Fig.2. Reduction of the anomalous transport in the range of $\hat{\omega}_{E1} > \sqrt{D_0}$ is shown.

The case for the system with magnetic well, such as tokamaks and conventional stellarators, was studied in a separate article (Itoh et al 1993c). The result was given as

$$\hat{\chi} = \frac{\hat{\chi}_L}{1 + G_w \omega_{Es}^2} \qquad (15)$$

where $\omega_{Es} = \tau_{Ap}(dE_r/d\hat{r})(srB)^{-1}$, $\hat{\chi}_L = 0.6\alpha^{1.5}\hat{\lambda}/\hat{\chi}$, $(\alpha = q^2\beta'/\varepsilon)$ and $G_w \sim 1/2\alpha^2$ in the small shear limit. The influence of the curvature of the radial electric field was also obtained. The reduction of χ is realized when ω_{Es} becomes of the order of α.

9

In summary, we have developed the theory of the anomalous transport in toroidal helical plasmas under the influence of the pressure gradient and inhomogeneous radial electric field. The marginal stability condition of the nonlinear interchange mode was solved. The explicit relation of the transport coefficients and the plasma inhomogeneity $\{p', E_r'\}$ was obtained keeping the geometrical factors such as q, R/a and magnetic shear. This theory explains the plasma confinement in H-mode as well as in L-mode simultaneously.

This theory also predicts that the fluctuation level could be reduced strongly when the inhomogeneity of the radial electric field establishes. At the same time, the correlation length becomes shorter. This theory could be tested by experiments not only on the macroscopic quantity such as the thermal conductivity (Eqs.(12), (15)), but also on the microscopic fluctuations (Eqs.(13), (14)). Since the H-mode-like improvement was observed in experiments (Erckmann et al 1993, Toi et al 1993), the comparison would be an urgent task.

Compared to the results predicted for tokamaks (Itoh et al 1993c), we find that the difference in transport coefficients appears only in the geometrical factors. This was concluded for L-mode plasmas in Itoh et al 1993d, and is now extended to the improved confinement. The generic features of the anomalous transport, i.e., the driving by the pressure gradient, the role of the collisionless skin depth and the effect of the radial electric field inhomogeneity, are unchanged. The similar

10

statement is found in the report on experiment (Erckmann et al 1993). This theory quantifies, from the first principle, the differences in transport coefficients in various toroidal plasmas, which are caused by the difference in the geometry.

This theory confirms the previous qualitative arguments on the E_r' stabilization Itoh et al 1989b, 1990, 1991, Shaing et al 1989b, Bigrali et al 1989, Sugama et al 1991). The main progresses are that the coefficients of ω_{E1}^2 in χ is explicitly given in terms of the plasma parameters, by solving the self-sustained turbulence, that formula for the L- and H-mode confinement are obtained in a unified manner, and that the fluctuation level is simultaneously obtained. These have become possible by the new theoretical framework, i.e., the ExB nonlinearity is renormalized in a form of diffusion operator and the mean-field approximation is employed (Itoh et al 1993d).

The present result (12) is obtained except for the numerical factor. Nonlinear simulation such as those in Wakatani et al 1992 would give this coefficient and allow us to examine the validity of the ansatz in detail. Here the analytic nonlinear solution was obtained under the very simplified situations: in order to explain the experiments precisely, aso necessary would be the investigation of effects such as the finite ion gyroradius, diamagnetic drift for kinetic corrections, parallel flow or perpendicular compressibility. These research topics are open for future study.

References

ASDEX Team: Nuclear Fusion **29** (1989) 1959.

Bigrali H, Diamond P H, Terry P W (1989) Phys. Fluids **B2** 1.

Erckmann V, Wagner F, Baldzuhn J, et al. (1993) Phys. Rev. Lett. **70** 2086.

Grieger G and W VII-A Team (1986) Plasma Physics and Controlled Fusion **28** 43.

Groebner J, Burrel K H and Seraydarian R P (1990) Phys. Rev. Lett. **64** 3015.

Ida K, Hidekuma S, Miura Y, et al (1990) Phys. Rev. Lett. **65** 1364.

Itoh K and Itoh S-I (1989c) Kakuyugo Kenkyu **62** 112.

Itoh K, Sanuki H, Itoh S-I (1992a) Nucl. Fusion **32** 1047.

Itoh K, Itoh S-I, Sanuki H, Fukuyama A (1992b) Comments Plasma Phys. Cont. Fusion **15** 343.

Itoh K, Itoh S-I, Fukuyama A (1992c) Phys. Rev. Lett. **69** 1050.

Itoh K, Itoh S-I, Fukuyama A, Yagi M, Azumi M (1993a) in Proc. 14th Int. Conf. on Plasma Physics and Controlled Nuclear Fusion Research, Wurzburg, 1992, paper H-2-2 (in press).

Itoh K, Yagi M, Itoh S-I, Fukuyama A, Azumi M (1993b) Plasma Physics Controlled Fusion **35** 543.

Itoh K, Itoh S-I, Fukuyama A, Yagi M, Azumi M (1993d) 'Self-sustained turbulence and L-mode confinement in toroidal plasmas' Research Report NIFS-219 (NIFS) submitted to Plasma Physics Controlled Fusion.

Itoh K, Itoh S-I, Yagi M, Fukuyama A, Azumi M (1993e) 'Prandtl Number of Toroidal Plasmas', submitted to J. Phys. Soc. Jpn.

Itoh S-I and Itoh K (1988) Phys. Rev. Lett. **60** 2276,

Itoh S-I and Itoh K (1989a) Nucl. Fusion **29** 1031.

Itoh S-I, Itoh K, Ohkawa T, Ueda N (1989b) in <u>Plasma Physics</u> <u>and Controlled Nuclear Fusion Research 1988</u>, Proc. 12th Int. Conf. Nice, 1988 (IAEA, Vienna) Vol.2, p23.

Itoh S-I and Itoh K (1990) J. Phys. Soc. Jpn. **59** 3815.

Itoh S-I, Sanuki H, Itoh K (1991) J. Phys. Soc. Jpn. **60** 2505.

Itoh S-I, Itoh K, Fukuyama A, Yagi M (1993c) 'Theory of anomalous transport in H-mode plasmas' Research Report NIFS-226 (NIFS) submitted to Phys. Rev. Lett.

Lyon J (1990) Plasma Phys. Controlled Fusion **32** 1041.

Shaing K C, Crume E C (1989) Phys. Rev. Lett.: **63** 2369.

Shaing K C, Lee G S, Carreras B, Houlberg W A, Crume E C (198) in <u>Plasma Physics and Controlled Nuclear Fusion Research 1988</u>, Proc. 12th Int. Conf. Nice, 1988 (IAEA, Vienna, 1989) Vol.2, p13.

Strauss H (1980) Plasma Phys. **22** 733.

Sugama H, Wakatani M (1991) Phys. Fluids **B3** 1110.

Toi K, et al (1993) in Proc. 14th Int. Conf. on Plasma Physics and Controlled Nuclear Fusion Research, Wurzburg, 1992, paper H-1-6 (in press).

Wagner F, Becker G, Behringer K, et al (1982) Phys. Rev. Lett. **49** 1408.

Wakatani M, et al. (1992) Phys. Fluids **B4** 1754.

Yagi M, Itoh K, Itoh S-I, Fukuyama A, Azumi M (1993) 'Analysis of current diffusive ballooning mode', Research Report NIFS-216 (NIFS), to be published in Phys. Fluids B.

Figure Caption

Fig. 1   Bird's eye view of the D_0 and $\hat{\omega}_{E1}$ dependence of the thermal conductivity $\hat{\chi}$ (a). The normalized value $\hat{\chi}/\hat{\chi}_0$ ($\hat{\chi}_0 \equiv \hat{\lambda}/\hat{\chi}s^2$) is plotted.

Fig. 2   Bird's eye view of the D_0 and $\hat{\omega}_{E1}$ dependences of the the correlation length ℓ_θ ($\equiv 1/k_\theta$) (a) and the fluctuation amplitude ϕ (b). In the graph, the normalized values $(\ell_\theta s/\delta)^2$ and $\phi/[B\hat{\chi}_0]$ ($\hat{\chi}_0 \equiv \hat{\lambda}/\hat{\chi}s^2$) are plotted.

Fig.1.

Fig. 2

a

$$\left(\frac{s\,\ell_0}{\delta}\right)^2$$

D_0

$\widehat{\omega}_{E1}$

b

$$\frac{\widetilde{\phi}}{\chi_0 B}$$

D_0

$\widehat{\omega}_{E1}$
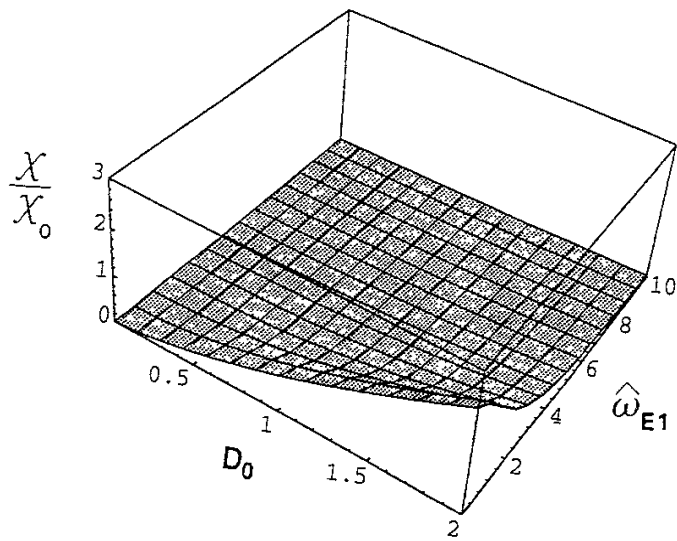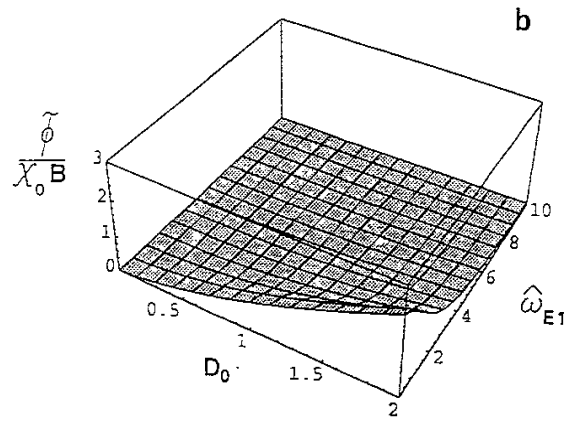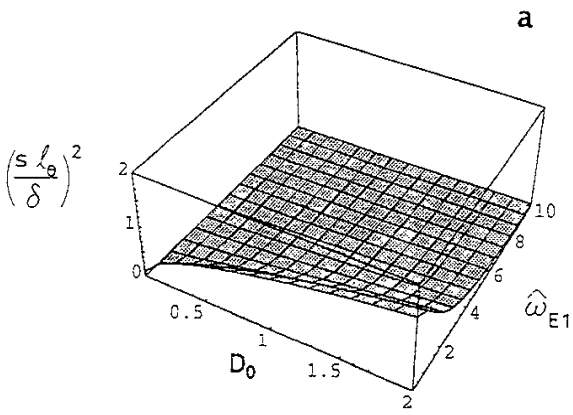
Recent Issues of NIFS Series

Discretization (KOND) Algorithm Applied to Parabolic and Hyperbolic Equations : Oct. 1992

NIFS-192   K. Itoh, M. Yagi, S.-I. Itoh, A. Fukuyama and M. Azumi, *L-Mode Confinement Model Based on Transport-MHD Theory in Tokamaks* ; Oct. 1992

NIFS-193   T. Watari, *Review of Japanese Results on Heating and Current Drive* ; Oct. 1992

NIFS-194   Y. Kondoh, *Eigenfunction for Dissipative Dynamics Operator and Attractor of Dissipative Structure* ; Oct. 1992

NIFS-195   T. Watanabe, H. Oya, K. Watanabe and T. Sato, *Comprehensive Simulation Study on Local and Global Development of Auroral Arcs and Field-Aligned Potentials* ; Oct. 1992

NIFS-196   T. Mori, K. Akaishi, Y. Kubota, O. Motojima, M. Mushiaki, Y. Funato and Y. Hanaoka, *Pumping Experiment of Water on B and LaB_6 Films with Electron Beam Evaporator* ; Oct., 1992

NIFS-197   T. Kato and K. Masai, *X-ray Spectra from Hinotori Satellite and Suprathermal Electrons* ; Oct. 1992

NIFS-198   K. Toi, S. Okamura, H. Iguchi, H. Yamada, S. Morita, S. Sakakibara, K. Ida, K. Nishimura, K. Matsuoka, R. Akiyama, H. Arimoto, M. Fujiwara, M. Hosokawa, H. Idei, O. Kaneko, S. Kubo, A. Sagara, C. Takahashi, Y. Takeiri, Y. Takita, K. Tsumori, I. Yamada and H. Zushi, *Formation of H-mode Like Transport Barrier in the CHS Heliotron / Torsatron* ; Oct. 1992

NIFS-199   M. Tanaka, *A Kinetic Simulation of Low-Frequency Electromagnetic Phenomena in Inhomogeneous Plasmas of Three-Dimensions* ; Nov. 1992

NIFS-200   K. Itoh, S.-I. Itoh, H. Sanuki and A. Fukuyama, *Roles of Electric Field on Toroidal Magnetic Confinement*, Nov. 1992

NIFS-201   G. Gnudi and T. Hatori, *Hamiltonian for the Toroidal Helical Magnetic Field Lines in the Vacuum*; Nov. 1992

NIFS-202   K. Itoh, S.-I. Itoh and A. Fukuyama, *Physics of Transport Phenomena in Magnetic Confinement Plasmas*; Dec. 1992

NIFS-203   Y. Hamada, Y. Kawasumi, H. Iguchi, A. Fujisawa, Y. Abe and M. Takahashi, *Mesh Effect in a Parallel Plate Analyzer*; Dec. 1992

NIFS-204   T. Okada and H. Tazawa, *Two-Stream Instability for a Light Ion Beam*

-Plasma System with External Magnetic Field; Dec. 1992

NIFS-205   M. Osakabe, S. Itoh, Y. Gotoh, M. Sasao and J. Fujita, *A Compact Neutron Counter Telescope with Thick Radiator (Cotetra) for Fusion Experiment;* Jan. 1993

NIFS-206   T. Yabe and F. Xiao, *Tracking Sharp Interface of Two Fluids by the CIP (Cubic-Interpolated Propagation) Scheme,* Jan. 1993

NIFS-207   A. Kageyama, K. Watanabe and T. Sato, *Simulation Study of MHD Dynamo : Convection in a Rotating Spherical Shell;* Feb. 1993

NIFS-208   M. Okamoto and S. Murakami, *Plasma Heating in Toroidal Systems;* Feb. 1993

NIFS-209   K. Masai, *Density Dependence of Line Intensities and Application to Plasma Diagnostics;* Feb. 1993

NIFS-210   K. Ohkubo, M. Hosokawa, S. Kubo, M. Sato, Y. Takita and T. Kuroda, *R&D of Transmission Lines for ECH System* ; Feb. 1993

NIFS-211   A. A. Shishkin, K. Y. Watanabe, K. Yamazaki, O. Motojima, D. L. Grekov, M. S. Smirnova and A. V. Zolotukhin, *Some Features of Particle Orbit Behavior in LHD Configurations;* Mar. 1993

NIFS-212   Y. Kondoh, Y. Hosaka and J.-L. Liang, *Demonstration for Novel Self-organization Theory by Three-Dimensional Magnetohydrodynamic Simulation;* Mar. 1993

NIFS-213   K. Itoh, H. Sanuki and S.-I. Itoh, *Thermal and Electric Oscillation Driven by Orbit Loss in Helical Systems;* Mar. 1993

NIFS-214   T. Yamagishi, *Effect of Continuous Eigenvalue Spectrum on Plasma Transport in Toroidal Systems;* Mar. 1993

NIFS-215   K. Ida, K. Itoh, S.-I.Itoh, Y. Miura, JFT-2M Group and A. Fukuyama, *Thickness of the Layer of Strong Radial Electric Field in JFT-2M H-mode Plasmas;* Apr. 1993

NIFS-216   M. Yagi, K. Itoh, S.-I. Itoh, A. Fukuyama and M. Azumi, *Analysis of Current Diffusive Ballooning Mode;* Apr. 1993

NIFS-217   J. Guasp, K. Yamazaki and O. Motojima, *Particle Orbit Analysis for LHD Helical Axis Configurations* ; Apr. 1993

NIFS-218   T. Yabe, T. Ito and M. Okazaki, *Holography Machine HORN-1 for Computer-aided Retrieve of Virtual Three-dimensional Image* ; Apr. 1993

NIFS-219   K. Itoh, S.-I. Itoh, A. Fukuyama, M. Yagi and M. Azumi,
            *Self-sustained Turbulence and L-Mode Confinement in Toroidal
            Plasmas* ; Apr. 1993

NIFS-220   T. Watari, R. Kumazawa, T. Mutoh, T. Seki, K. Nishimura and
            F. Shimpo, *Applications of Non-resonant RF Forces to Improvement
            of Tokamak Reactor Performances Part I: Application of
            Ponderomotive Force* ; May 1993

NIFS-221   S.-I. Itoh, K. Itoh, and A. Fukuyama, *ELMy-H mode as Limit Cycle
            and Transient Responses of H-modes in Tokamaks* ; May 1993

NIFS-222   H. Hojo, M. Inutake, M. Ichimura, R. Katsumata and T. Watanabe,
            *Interchange Stability Criteria for Anisotropic Central-Cell Plasmas
            in the Tandem Mirror GAMMA 10* ; May 1993

NIFS-223   K. Itoh, S.-I. Itoh, M. Yagi, A. Fukuyama and M. Azumi, *Theory of
            Pseudo-Classical Confinement and Transmutation to L-Mode;* May
            1993

NIFS-224   M. Tanaka, *HIDENEK: An Implicit Particle Simulation of Kinetic-
            MHD Phenomena in Three-Dimensional Plasmas;* May 1993

NIFS-225   H. Hojo and T. Hatori, *Bounce Resonance Heating and Transport in a
            Magnetic Mirror;* May 1993

NIFS-226   S.-I. Iton, K. Itoh, A. Fukuyama, M. Yagi, *Theory of Anomalous
            Transport in H-Mode Plasmas;* May 1993

NIFS-227   T. Yamagishi, *Anomalous Cross Field Flux in CHS* ; May 1993

NIFS-228   Y. Ohkouchi, S. Sasaki, S. Takamura, T. Kato, *Effective Emission and
            Ionization Rate Coefficients of Atomic Carbons in Plasmas;* June
            1993

NIFS-229   K. Itoh, M. Yagi, A. Fukuyama, S.-I. Itoh and M. Azumi, *Comment on
            'A Mean Field Ohm's Law for Collisionless Plasmas;* June 1993

NIFS-230   H. Idei, K. Ida, H. Sanuki, H. Yamada, H. Iguchi, S. Kubo, R. Akiyama,
            H. Arimoto, M. Fujiwara, M. Hosokawa, K. Matsuoka, S. Morita, K.
            Nishimura, K. Ohkubo, S. Okamura, S. Sakakibara, C. Takahashi, Y.
            Takita, K. Tsumori and I. Yamada, *Transition of Radial Electric Field
            by Electron Cyclotron Heating in Stellarator Plasmas;* June 1993

NIFS-231   H.J. Gardner and K. Ichiguchi, *Free-Boundary Equilibrium Studies
            for the Large Helical Device,* June 1993