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U.S.-Japan Workshop on
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Contents

Welcome address for the US-Japan workshop on Comparison of Theoretical and Experimental Transport in Toroidal Systems

A. Iiyoshi

National Institute for Fusion Science

It is my great pleasure to welcome you to National Institute for Fusion Science, on occasion of US-Japan workshop on Comparison of Theoretical and Experimental Transport in Toroidal Systems.

The National Institute has been established at the end of last May, in order to pursue various important problems in fusion research, gathering active scientists from the universities, especially IPP, Nagoya Univ., PPL, Kyoto Univ. and FTC, Hiroshima Univ.

One of the main purpose of this institute is to study the physics of toroidal plasmas so as to establish the basic and unified understanding of the confinement properties in toroidal plasmas. The challenge on the anomalous transport has long history including the work on so called pump out phenomena on C-Stellarator, on which I had a chance to work in the very beginning of my academic life. The problem still remains the largest obstacle for us to realize the fusion ignition. This problem, I understand, requires multiple approaches using various confinement configurations, such as tokamaks, helical systems and so on, in both experimental and theoretical aspects.

So, the topic of the workshop is very timely and, without any doubt, is an urgent issue. We know that American research is more and more dedicated to the transport task force. Japanese fusion society has also paid efforts for the progress in this area. The members of this workshop are the specialist in this field, and have done lots of pioneering work. Although it is pity that Professor Bruno Coppi could not come to our institute on this occasion, I believe that the workshop will surely be successful and creative for the new research in this field from now on. I look forward to seeing the outcome of the workshop soon.

Kinetic Microinstability Transport Properties in Tokamaks*

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Low frequency drift-type microinstabilities dependent on trapped electron and ion temperature gradien effects have continued to be the most commonly proposed physics-based candidates accounting for anomalous transport in the bulk ("confinement") region of tokamak plasmas. In order to assess their relevance, experimental studies have primarily focused on theoretical estimates of Q_j (the anomalous thermal flux), Γ_j (the anomalous particle flux), and $|\tilde{n}/n_0|$ (the density perturbation) associated with these instabilities. The present work calls attention to additional important microinstability transport properties which are also amenable to experimental tests. These include ion and electron temperature fluctuation responses, $|\tilde{T}_j/T_j|$, anomalous momentum transport, $(\tilde{Q}_\phi)_j$, from electron drift modes as well as from ion modes, and the anomalous energy exchange between ions and electrons, $\dot{W}_j$, when fluctuations are present. In addition, possible current (I_p) and/or q-scaling in the local thermal diffusivity, χ_j, is examined with the aid of a comprehensive kinetic stability code. Preliminary results from these studies indicate: (*i*) the trend $|\tilde{T}_i/T_i| > |\tilde{n}/n_0|$ for $\eta_i > (\eta_i)_{crit}$ is confirmed by detailed computations including complete trapped-electron dynamics; (*ii*) trapped electron drift modes can cause anomalous momentum transport with $\chi_\phi \sim \chi_e \sim \chi_i$ for a sufficiently collisionless plasma; (*iii*) proper evaluation of anomalous energy exchange (which should be taken into account in any realistic power balance analysis of χ_e *vs.* χ_i) can give results significantly different from earlier estimates which deduced a simple proportionality to the particle flux; and (*iv*) the local growth rate is found to scale roughly as $\gamma \propto q^\alpha$, with $\alpha \sim 3/4$ to 1.5.

*Research performed in collaboration with G. Rewoldt and T. S. Hahm.

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Modelling of Improved Confinement in Tokamaks

[A] Peaked Density Profile and Inward Pinch
[B] Change of Transport at L/H mode Transition

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[A] A model of peaked density profile and inward flux of ohmic discharges in tokamak is presented. Anomalous particle fluxes in the presence of radial electric field, E_r, and the radial current in the presence of plasma rotation are consistently obtained in a stationary state. Viscous damping of the differential flow due to E_r balances with the particle diffusion, which determines density and E_r structures. In viscous plasma, peaked profile is expected. The model theory is applied to the transition from SOC to IOC discharges. Reduction of edge neutrals changes the boundary condition and causes the steepning of density gradient. Initiated by this, inward flux is induced and density profile becomes peaked. Structural change of E_r associated with ion viscous damping propagates into the center, causing the central ion heating. Our results predict the common feature of improved confinement of density peaking. The relation of the density peaking to the improved particle infinement is also obtained.

An importance of viscous damping to the density profile is emphasized. The result shows that a new column in transport matrix is necessaty to undersatand the acutual transport process in experiment.

[B] A refined model of L/H transition in tokamaks is presented based on the bifircation of E_r near edge. The radial gradient of E_r is newly introduced to explain the sudden change of fluctuations as well as plasma fluxes at the onset of transition. This model predicts that L- to H- mode transition is associated with the decrease of dE_r/dr causing reduction of particle and energy fluxes at critical gradient.

Three-Dimensional Numerical Simulation of Simple Electron Drift Wave Turbulence in a Sheared and Curved Magnetic Field

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A three-dimensional code originally developed to treat η_i drift mode turbulence [1] has been used to study the scaling of a simple electron drift mode turbulence model with respect to shear and toroidicity in tokamak geometry. The code is written in an (m, n, r) representation with bounded multiple helicities $q_0 < m/n < q_1$. Three nonlinear equations of motion are time advanced: the ion continuity equation, ion parallel motion equation, and in hot ion cases, the adiabatic ion pressure equation. The electrons are modeled with a linear near Boltzmann response: $\tilde{n}/n_0 = e\tilde{\phi}/T_e(1 - i\delta)$, where $\delta = k_\theta \rho_s \cdot \delta_0$. Several new results are obtained. For cases set up to resemble a sheared slab (uniform shear and density gradient lengths L_s and L_n) and curvature terms suppressed, the results are well described by the mixing length rules for turbulence levels and diffusivity: $\tilde{n}/n \propto \Theta^{1/2}\Delta_x/L_n$ and $D \propto \Theta\gamma^d\Delta_x^2$. $\Theta = \gamma/\bar{\omega}$ where γ is the linear growth rate, $\bar{\omega}$ is a characteristic frequency, and $\gamma^d = \omega_*\delta/(1+\delta^2)$ is the driving rate. The mixing length $\Delta_x \propto \rho_s(L_s/L_n)^{1/2}$ scales as the linear harmonic mode width and the average poloidal mode number scales to the gyroradius $k_\theta\rho_s \sim$ constant. These results are consistent with the weak turbulence ($\Theta \ll 1$), single helicity helicity theory of Tange, Nishikawa, and Sen [2]. The parametrer space with toroidal coupling from curvature is complex since $L_s = Rq/\hat{s}$ ($\hat{s} = dlnq/dlnr$) is replaced by three independent parameters L_s (or q), R, and $\hat{s}$. In the strong shear regime ($\hat{s} > 1/2$), the results appear to be consistent with a mixing length scaling as $\Delta_x \propto \rho_s(L_n/R)^{1/2}$ independent of L_s and $\hat{s}$. This unexpected result contradicts theoretical conjectures based on the poloidal harmonic widths of the ballooning modes or on the spacing between singular surfaces. Apart from these scaling studies, the possibility of nonlocal convecture effects are examined. For weak turbulence cases in a nonuniform cylindrical plasma, it is found that turbulence and transport at one location can be increased by excess driving at a distance larger than an ion Landau damping length. Thus, some possibly important convective effects may be left out of local homogeneous "microturbulence" theories as suggested by Prakash, Chu, and Hasegawa [3].

This is a report of work sponsored by the U.S. Department of Energy under Contract No. DE-AC03-89ER53277.

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Drift-Wave Transport Model and Role of Fast Particles

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Transport process during ICRF heating is studied with the drift-wave-turbulence (DWT) model and the results are compared with the experiments on JET. The 1D wave code is linked to the anisotropic Fokker-Planck code and to the 1D radial transport code. Wave excitation, propagation and absorption, fast ion generation, thermalization of the absorbed power and spatial transport are analyzed in a consistent manner. The anomalous diffusion coefficients of the DWT model are employed for bulk electrons and ions. Coefficients are so chosen as to reproduce the ohmic discharge. Our analysis shows that the presence of fast minority ions leads to the offset linear scaling of the stored energy. The increase of the tail energy compensates the saturation of the bulk energy which is roughly proportional to $P_{\rm in}$. The saturation of majority ion temperature $T_{\rm i}$ in a high power range is also explained. Effects of radial transport of the fast ions is examined in a simplified model. If the thermal diffusivity of the fast ions is assumed to be the same as that of the majority ions, the heating efficiency decreases by 40 % compared with the case where the fast ion transport is neglected. The reduced value is close to the experimentally-observed one on JET.

Review of Measured Density Fluctuation Properties in Tokamaks at PPPL and Future Plans

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Since the first observation with scattering of electromagnetic waves of a low frequency ($\omega << \omega_{ci}$), small scale ($k_\perp a << 1$) turbulence in the ATC tokamak, the same microturbulence has been observed in every tokamak where similar measurements have been attempted. What follows is a summary of observations on plasma microturbulence in tokamaks at the Princeton Plasma Physics Laboratory.

In Ohmic plasmas, the observed turbulence is characterized by broad frequency spectra, at a fixed wavevector, with widths of the order of ω_{*e}. In general, the spectra are shifted towards the electron diamagnetic side, but the opposite has been observed on the high field side of the PDX tokamak. In neutral-beam heated plasmas with strong toroidal rotations, the observed spectra are explained by a Doppler shift with $k_\parallel << k_\perp$. It is not known whether the spectra observed in Ohmic plasmas are affected by Doppler shifts, as well.

In ATC plasmas and in the outer region of those of PLT, the observed $k_\perp$-spectra show a clear maximum at $k\rho_s \approx 1$, while in the central regions of PLT and PDX they decrease monotonically with $k_\perp$. In Ohmic plasmas of PDX, the spectral width, $\Delta k_\perp$, increases as the magnetic field increases. If the quantity $(\Delta k_\perp)^{-1}$ is interpreted as the fluctuation correlation length, this is consistent with a ρ_s^{-1} or ρ_i^{-1} scaling of the spatial scale of the turbulence. However, no noticeable difference was observed in the shape of the $k_\perp$-spectrum between ohmically heated plasmas and neutral-beam heated plasmas with the same toroidal magnetic field, in spite of the different values of ρ_s or ρ_i in the two cases.

The relative fluctuation level, estimated with the assumption of isotropy perpendicularly to the magnetic field, is generally within the range of $10^{-3} - 10^{-2}$ which corresponds to levels of $\tilde{n}/n \approx (0.3 - 1.0)/k_\perp L_n$. However, the observed values do not scale like the mixing-length criterion. The ballooning properties of the observed fluctuations are different in different plasmas. In ATC and PLT Ohmic plasmas, the ballooning structure is very pronounced, while in other cases the difference in the fluctuation levels of the inside and outside regions is within the experimental errors.

In PDX plasmas limited by rails, the fluctuation levels are correlated with the energy confinement as plasma current (during beams), beam power and heating regime (i.e. Ohmic vs. neutral beam) are changed. In all these cases, the fluctuation levels increase as the plasma energy confinement time decreases. In PDX plasmas limited by a magnetic divertor, the fluctuation level in the H-mode regime is lower than in the L-mode regime. However, the fluctuation levels of the Ohmic and L-mode plasmas are similar in spite of their different confinement properties.

An attempt at detecting fluctuations induced by the ion temperature gradient in a PLT Ohmic plasma was made by flattening the electron density profile with intense gas puffing. No fluctuation propagating along the ion diamagnetic direction was observed.

In summary, there is at present no conclusive evidence that the observed fluctuations are induced by known plasma instabilities or that they are the cause of anomalous transport. Indeed, it is possible that the observed fluctuations are not the main (or the only) phenomenon which affects the plasma confinement in tokamaks.

A significant gap exists in our experimental knowledge of long wavelength fluctuations with scale size between those of fluctuations which are detectable with scattering techniques and those visible on soft x-ray or interferometric signals. Microwave reflectometry is a technique which offers the possibility of high resolution detection of long wavelength ($k_\perp \rho_i << 1$) plasma fluctuations. This method, widely used in atmospheric studies, uses the reflection of electromagnetic waves from plasma cutoffs to measure the electron density of a nonuniform plasma. This technique, used on ATC for the first time in a tokamak, can be considered a special kind of interferometer where the phase of the received wave is determined by both the change of the refractive index along the wave trajectory and by the shift of the reflecting layer. The latter becomes the dominant effect when the scale size of the plasma fluctuation is 3-4 times larger than the wavelength of the probing wave. Hence, by using the extraordinary mode of propagation in a TFTR-like tokamak, microwave reflectometry should provide spatially resolved information about plasma fluctuations which presently are not detectable with other diagnostic techniques.

Measurement of Density Fluctuations in the JIPP T-IIU Tokamak

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Low frequency density fluctuations caused by the microinstabilities which universally exist in tokamak plasmas have been considered to enhance particle and energy losses of the confined plasma across the magnetic field. For the study of the microinstabilities, it is necessary to know their characteristics; frequency and wave number spectra, spatial distribution, and absolute level of density fluctuations.

The collective scattering method with sub-millimeter waves is an ideal mean for the study of microinstabilities in a tokamak plasma. In the JIPP T-IIU tokamak (R = 93 cm, a_p = 23 cm, $B_t \le$ 3T), an HCN laser scattering system with a hetorodyne detection has been developed. The main radiation source is a 5 m long HCN laser which delivers a linearly polarized beam of 0.5 W with a wave length λ_i = 337 μm. For the heterodyne detection another HCN laser is operated as a local oscillator at the beat frequency of 2 MHz.

In low density ohmically heated (OH) plasma, the density fluctuations mainly propagate in the direction of the electron diamagnetic drift, and the peak in the power spectra shows a linear dispersion relation for various wavenumber. In high density OH plasmas, it has been found that the energy confinement time deviates from the Alcator scaling and at the same time the ion mode which propagates in the ion diamagnetic drift direction is excited in addition to the electron mode. The value of η_i = $(d\ell T_i/d\ell n n_i)$ evaluated experimetnally is about 1.0 - 1.2 when the ion mode is excited. Effects of an ice pellet injection on the instabilities and electron density profiles will be also discussed.

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The Role of the Radial Electric Field in Producing Confinement Enhancement in Tokamaks*

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Reported by

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ABSTRACT

The radial variation of the poloidal $\mathbf{E} \times \mathbf{B}$ drift frequency can lead to an effective enhancement of the decorrelation rate between adjacent fluid elements when turbulence is present. Simple clump estimates for fluid pressure and resistivity gradient-driven turbulence suggest that a more negative value of E_r can reduce the magnitude of fluctuation spectrum, for the usual case of $dP/dr < 0$ and $dT/dr < 0$. These estimates are in agreement with preliminary numerical calculations and suggest various mechanisms for improving plasma energy confinement, based on directly controlling the sign of the radial electric field.

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Transport Analysis on JT-60

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Ion temperature profiles of neutral beam heated plasmas in JT-60 have been studied by using thermal diffusivities based on the ion temperature gradient mode (η_i mode) turbulence. Ion temperature profile is calculated by using a one dimensional tokamak transport code, while other plasma parameter such as the electron density, the electron temperature, the effective charge number and power deposition profile are fixed. The calculated ion temperature profile is compared with the experimental data measured by charge exchange recombination reaction. We adopted two different formula of χ_i based on η_i mode turbulence. One is proposed by Dominguez & Waltz [1], the other is by Lee & Diamond [2].

The results of calculation show that the profile of ion temperature becomes similar to that of density profile. That is, flat density profile accompanies flat ion temperature profile and pedestal density profile accompanies pedestal ion temperature profile in the calculation. This situation is almost the same for both χ_i model.

Almost all L-mode plasmas in JT-60 have flat density profile. This result in flat ion temperature profile in the calculation if we only take account of η_i mode in χ_i, which makes difference from profile in experiments. Only high ion temperature plasma case, which is accompanied by pedestal density profile, can be reproduced. The adoption of model on the η_i mode threshold value η_i^{th} [3],[4], in which η_i^{th} varies according to the characteristic length of density L_n, makes no big difference, because η_i^{th} increases only near plasma center and is unchanged in the peripheral region.

As χ_i becomes small toward the plasma peripheral region with η_i mode turbulence model, we must consider the χ_i enhancement mechanism in the plasma peripheral region. If we take account of the trapped electron mode contribution to χ_i, good agreement of ion temperature profile with experimental data can be seen on the condition that the electron temperature is not so high (utmost about 4 KeV at the plasma center). However, since χ_i by dissipative trapped electron mode has strong dependence on temperature ($T_e^{3.5}$), high ion temperature plasma with high electron temperature cannot be reproduced by this model. Intor type χ_i is not available either, because the enhancement of χ_i is limited near the plasma surface. Other possible χ_i enhancement mechanism is under investigation.

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Diagonal and Off-Diagonal Anomalous Transport Coefficients in Tokamaks

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It has often been assumed that the anomalous transport from saturated plasma instabilities is "diffusive" in the sense that the particle flux, Γ, the electron energy flux, q_e, and the ion energy flux, q_i, can be written in forms that are *linear* in the density gradient, dn/dr, the electron temperature gradient, dT_e/dr, and the ion temperature gradient dT_i/dr. In the simplest form, $\Gamma = -D_n^n(dn/dr)$, $q_e = -D_e^e n(dT_e/dr)$, and $q_i = -D_i^i n(dT_i/dr)$. A possible generalization of this is to include so-called "off-diagonal" terms, with $\Gamma = nV_n - D_n^n(dn/dr) - D_n^e(n/T_e)(dT_e/dr) - D_n^i(n/T_i)(dT_i/dr)$, with corresponding forms for the energy fluxes. Here, general results for the quasilinear particle and energy fluxes, resulting from tokamak linear microinstabilities, are evaluated to assess the relative importance of the diagonal and the off-diagonal terms. A further possible generalization is to include also contributions to the fluxes from higher powers of the gradients, specifically "quadratic" contributions proportional to $(dn/dr)^2$, $(dn/dr)(dT_e/dr)$, and so on. A procedure is described for evaluating the corresponding coefficients, and results are presented for illustrative, realistic tokamak cases. Qualitatively, it is found that the off-diagonal diffusion coefficients can be as big as the diagonal ones, and that the quadratic terms can be larger than the linear ones. The results thus strongly suggest that the commonly used "diffusive" approximation with only diagonal terms, $\Gamma = -D_n^n(dn/dr)$, and correspondingly for the energy fluxes, is not adequate in practice.

Reference: G.Rewoldt, Princeton University Plasma Physics Laboratory Report PPPL-2650 (1989), submitted to Physics Fluids B.

Study on H-mode and Improved Confinement in JFT-2M

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presented by M.Mori

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The H-mode was achieved in many tokamak devices. However, the H-mode has a problem to be overcome. H-mode in a stationary state has never been obtained without frequent ELMs so far. A plasma density continues to increase during the H-mode until the H-mode is terminated by itself.

We found one way to achieve a stationary improved confinement state in JFT-2M. This type of improved confinement modes has been obtained after a termination of H-mode in both divertor and limiter discharges. The density and the temperature have peaked profiles compared with those in the H-mode. The confinement improvement is realized mainly in the core region. Since edge phenomena are similar to those in the L-mode and the edge confinement is not improved, we call this mode Improved L-mode(IL-mode). Sawtooth is always suppressed in the IL-mode, and its suppression seems to be essential to obtain the IL-mode. The value of the surface safety factor q_s also affects the onset of the IL-mode, because sawtooth activity is affected by q_s. It has been necessary for achieving the long IL-mode that the value of q_s is around 3 in the single null divertor configuration in JFT-2M. It seems that a high density at the center is also necessary for the IL-mode. This is probably a reason why the IL-mode is observed only after a long pulse H-mode which makes the central density high enough. Impurity profile (titanium) is compared with impurity transport code[MIST](1). Particle transport of H-mode is greater than that of IL-mode in core region. It seems to be shown within experimental accuracy that an inward velocity of impurity ion is approximately neoclassical in the core region of IL-mode, but particle diffusion coefficient is still greater than neoclassical one.

We are trying another way to achieve stationary state in H-mode with Elgodic Magnetic Limiter(EML)(m/n=7/1,7/2). Preliminary result shows that EML can reduce density rise in H-mode. In some cases, stationary H-mode with ELMs has been established.

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See also: M. Mori, et al., Nucl. Fusion 28 (1988) 1892,
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H-mode Simulation

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H-mode phenomena has improved the degraded energy confinement in the auxiliary heating phase. A number of effort have been made experimentally and theoretically to understand the mechanism of the H-mode. However the H-mode mechanism has not been understood well. Drs. S-I. Itoh and K. Itoh have proposed the model to explain the H-mode transition. According to this model, which take into account of the effect of the radial electric field E_r on the particle diffusion, the plasma edge has the bifurcation nature in the particle fluxes associated with the change in E_r. This model is incorporated into the one dimensional transport code. The H-mode transition observed in JT-60 diverter discharge with the outside X-point is investigated numerically by using this code. It is shown that the threshold power for the H-mode transition and the threshold density agrees well with the experimental data. The change of the plasma parameter after the transition is also investigated. (Recently, Drs. S-I. Itoh and K. Itoh have proposed the new model including the structure of E_r. But the H-mode model used in our simulations do not include this effect.)

The simulation results shows that the edge parameter plays an important role in the H-mode transition. We also show the transition condition of the plasma edge parameter obtained experimentally in JT-60 and JET. The clear threshold in the edge density and the edge temperature is observed for the H-mode transition. Both the threshold temperature and threshold density increases with the plasma current, I_p.

3-D GYROKINETIC PARTICLE SIMULATION ON INTERNAL KINK MODES

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Three dimensional gyrokinetic particle simulation code for finite beta plasmas was completed and applied to the internal kink mode simulation. Basic equations are given by Hahm et al.[1]. The system ($L_x x L_y x L_z$) is a rectangular slab surrounded by the perfectly conducting wall in the x- and y-directons. Strong external magnetic field is assumed in the z-direction and periodic boundary condition is employed in this direction. Transverse magnetic field (B_x and B_y) are generated self-consistently by the internal current produced by the electron drifting in the z-direction. The compressional component of the magnetic field (perturbed B_z) is neglected in the low beta approximation. The particle dynamics parallel to the magnetic field are followed as well as the ExB drift. The electron gyroradius is assumed to be zero (drift kinetic) whereas ion finite Larmor radius effects are properly included (gyrokinetic). The electrostatic potential is calculated from the gyrokinetic Poisson equation in which ion polarization shielding effect is incorporated. The z-component of the vector potential (A_z) is calculated by Ampere's law. The formulation using the canonical momentum (p_z) is employed in which inductive electric field is not appear explicitly.

For the test of the code, dispersion realtions of shear Alfven waves were verified without the internal current as well as the energy conservation properties. In order to excite a internal kink mode L_y is determined to be twice as large as L_x. Due to this elongation effect, the internal kink mode has a large growth rate on the order of the shear Alfven mode real frequency. The moment equations of the basic gyrokinetic equations become the Strauss's two fluid model [2] in the longwavelength limit when we neglect the electron inertia and pressure terms[3]. Therefore it is expected that this code can produce almost similar results as Strauss' with some kind of modification due to kinetic effects and the non vanishing E_z field etc. The motivation to simulate a internal kink mode is to demonstrate the possibility that gyrokinetic particle code can simulate the global MHD modes by including the non-MHD kinetic effects and this was done. Next step will be to include the kinetic effects comming from curvature and gradient B drifts of high energy particles (may be alpha particles) as well as making a toroidal version of the code.

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Numerical Analysis of the Relationship Between Local Transport and Global Confinement in Tokamaks*

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Reported by

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ABSTRACT

The global energy confinement time τ_E is widely used to characterize the confinement efficiency of tokamaks. Its use as a guide to deducing the dependence of the local heat diffusivity χ on plasma parameters is limited by the presence of many non-diffusive processes which themselves have strong parametric and profile dependencies. Radiation losses, heating profile effects, and the synergistic effects they produce can obscure the parametric dependence of χ resulting from regression analysis. Correlations between operating parameters (e.g., density and current interrelation) further weaken the deducible relationship between τ_E and χ. This relationship has been examined using the detailed physics of the WHIST code. Data from this code are loaded into a LOCUS database and processed in a similar manner to actual experimental data, to deduce global confinement laws. Examples of Ohmic, neutral beam and RF heating are computed to illustrate the importance of profile and synergistic effects when deducing τ_E and χ.

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Anomalous Transport Studies for Heliotron/Torsatron

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Recently Heliotron E experiments showed the electron thermal transport is anomalous for almost all plasma parameters particularly in the edge plasmas [1]. For the heliotron/torsatron configuration with a bad average curvature, g mode turbulence is the most probable candidate to explain the edge anomalous transport [2]. Another candidate is the collisional drift wave turbulence [3]. We developed fluid model equations describeing a drift interchange mode or a coupling between the g mode and the collisional drift wave [4]. As a nonlinear phenomenon of the drift interchange mode we pointed out an appearance of zonal flow in a cylindrical plasma model [5]. Also we applied the scale invariance [6] and the two point renormalized theory [7] to the drift interchange turbulence. It is shown that the collisional drift wave turbulence gives a pseudoclassical diffusion which is larger than the diffusion based on the electrostatic g mode turbulence [6].

We also discuss a possibility of anomalous ion thermal transport in heliotron/torsatron based on the η_i mode coupled to the g mode. The bad average curvature destabilize the new ion pressure gradient driven drift mode for wide parameter regions [8]. We show an indication of the anomalous thermal transport in Heliotron E.

References

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2) K.C.Shaing and B.A.Carreras: Phys.Fluids 28(1985) 2027.
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US/Japan Workshop on Anomalous Transport in Tokamaks
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Gyrokinetic Particle Simulation of Ion Temperature Gradient Drift Instabilities*

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Ion temperature gradient drift instabilities in sheared slab geometry have been investigated using gyrokinetic particle simulation techniques. The results from a three-dimensional simulation with multiple rational surfaces ($k_{\parallel}=0$) indicate that the fluctuation spectrum for the electrostatic potential is dominated by the fundamental ($\ell = 0$) radial eigenmodes with moderate poloidal wavelength of $k_\theta \rho_s \lesssim 1$, and the steady state thermal flux is considerably smaller than the (quasilinear) flux at the onset of saturation.[1] It is also found that the corresponding thermal diffusivity, χ_i, is weakly dependent on the shear scale length, L_s. To have a better understanding of these issues in less turbulent situations, we have also carried out the simulations in two dimensions for which there is only one single rational surface present. It is found that nonlinear wave-particle interactions are important for the eigenmode formation and that the nonlinear **ExB** advection enhances the outward energy propagation for the higher harmonics of the radial modes.[2] As for the thermal flux, simulations in a 2D shearless slab have exhibited the same behavior as the 3D sheared cases, i.e., the decrease of the flux in the steady state. As it has been shown earlier[3], the steady state flux is closely related to the dissipation in the simulation.

Based on these simulation results, we are able to develop some theoretical understanding for the nonlinear saturation of the instability and the ensuing transport. For example, the zero-frequency ion parallel velocity and pressure generated by the ExB nonlinearity are found to be related to the saturation.[2,3] From the entropy balance properties of the gyrokinetic equations, we can then ascertain the importance of the collisionless (nonlinear wave-particle interaction) and collisional dissipation for steady state transport.[3] The shear scaling trend on χ_i can be understood from the $\gamma / k_{\perp}^2$ argument.

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Us Japan Workshop on Comparison of
Theoretical and Experimental Transport in Toroidal Systems

Transport in Scrape-off Layer and Its Effect on Core Confinement

K. Itoh and S-I. Itoh

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The importance of the role of edge plasmas for core confinement has recently been widely recognized. The modelling of the H-mode and improved confinement has shown that how the population of the neutral particles changes the core plasma and that how important the edge plasma parameters are.[1,2)]

The edge parameters are also important for L-mode plasma itself. The connections of the local plasma transport with the global scaling and the plasma profile have been discussed, but the role of the boundary condition has not been clarified. For instance, assume that the local thermal conductivity strongly increases when the gradient of the temperature exceeds the critical value, $|a\nabla T/T| > f$ (a is the minor radius). In such a case, the plasma temperature shows a profile resiliency to the form $T=T(a)\exp(\int_r^a f dr)$. The global confinement time is dictated how the edge plasma parameter depends on the heating power.

We apply the UEDA code (unified edge divertor analysis code) to the tokamak with poloidal divertor configuration. This code solves the plasma and neutral profiles in the SoL and divertor regions for given heat and particle sources from the core plasma, Γ_{out} and P_{out}.[3)] We assume that the parallel conduction is classical and perpendicular conduction is Bohm-like. Performing the numerical simulation, we find that the edge temperature scales as $T(a) \propto P_{out}^{0.5}\,\Gamma_{out}^{-0.25}$. The weak dependence of T(a) on heating power is confirmed[4)]. This dependence of T(a) and the T dependence of thermal conductivity lead the L-mode scaling and similarity in the temperature profile.

Discussion with Dr. N. Ueda is acknowledged.

[1] S.-I. Itoh and K. Itoh, Phys. Rev. Lett. 60 (1988) 2276.
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TRANSPORT PHENOMENA IN ULTRA-LONG DISCHARGE

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Steady-state tokamak operation is one of the important issues for realizing a tokamak power reactor, and it would require noninductive current drive of the full plasma current. The experiments on steady-state tokamak operation have been successfully carried out in the superconducting tokamak TRIAM-1M and an ultra-long operation for more than 7 minutes has been achieved by lower hybrid current drive [1]. We report here the ultra-long tokamak operation and the confinement properties of the steady-state current-drive plasma.

TRIAM-1M is a compact high-field tokamak (R = 0.8 m, a_L = 0.12 x 0.18 m^2, B_t = 8 T, I_p = 0.5 MA) with Nb_3Sn superconducting toroidal field coils [2]. The RF system for the lower hybrid current drive consists of a 2.45 GHz klystron with the output power of 50 kW and a launcher with four waveguides.

In the first stage of the experiments on steady-state operation, the plasma position control was performed by a conventional method with magnetic probes and the plasma discharge duration was extended up to 3 minutes. In the second stage, a new method with Hall generators for the plasma position control has been developed and the ultra-long tokamak operation for more than 7 minutes has been achieved. These long duration discharges were obtained by the precise plasma position control and the gas feed control for keeping the plasma density constant. The plasma current of about 30 kA and the line average electron density of about 2 x 10^{12} cm^{-3} were kept constant during the discharge.

In order to study the confinement properties of the steady-state current-drive plasma, we are investigating the confinement of high energy electrons and bulk plasma, and the impurity behavior. The radial profiles of the hard X-ray emission indicated that the high energy electrons exist mainly within the inner region of the plasma column in a typical long-duration discharge. The variation of the profile for the parameter scans can be explained by the accessibility effect and the confinement properties of the high energy electrons. The electron and ion temperatures of RF driven plasma were about 1 keV and 0.5 keV, respectively, and the confinement properties of the bulk plasma in the lower density region seem to be improved in comparison with Ohmic ones as observed in ASDEX experiments. Impurity behavior has been investigated by visible and VUV spectroscopy. The spectral lines of impurities such as Fe, Cr, O were observed in the long-duration discharges and the impurity radiation intensities were kept almost constant during the discharge.

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[2] S. Itoh et al., Proc. 11th Int. Conf. on Plasma Phys. and Contr. Nuclear Fusion Res., Kyoto, 1986 (IAEA, Vienna, 1987), Vol.3, p 321.

U.S.-Japan Workshop on
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National Institute for Fusion Science
(8F Conference room)

<u>October 23 (Mon.)</u>

9:30	Registration	
10:30	A. Iiyoshi	Welcome
	K. Itoh/ W.M. Tang	Introduction

Session I (chairman: K. Itoh)

11:00 - 12:00	W.M. Tang	Kinetic Microinstability Transport Properties in Tokamaks
12:00 - 13:30		Lunch

Session II (chairman: S.P. Hirshman)

13:30 - 14:30	S.-I. Itoh	Modelling of Improved Confinement in Tokamaks
14:30 - 15:30	R.E. Waltz	Three-Dimensional Numerical Simulation of Simple Electron Drift Wave Turbulence in a Sheared and Curved Magnetic Field
15:30 - 16:00		Coffee break
16:00 - 17:00	A. Fukuyama	Drift-Wave Transport Model and Role of Fast Particles

Group dinner

<u>October 24 (Tue.)</u>

Session III (chairman: W.M. Tang)

9:45 - 10:45	E. Mazzucato	Review of Measured Density Fluctuation Properties in Tokamaks at PPPL and Future Plans
10:45 - 11:00		Coffee break
11:00 - 12:00	K. Kawahata	Measurement of Density Fluctuations in the JIPP-T-IIU Tokamak
12:00 - 13:30		Lunch

Session IV (chairman: M. Wakatani)

13:30 - 14:30	S.P. Hirshman	The Role of the Radial Electric Field in Producing Confinement Enhancement in Tokamaks
14:30 - 15:30	H. Shirai	Transport Analysis on JT-60
15:30 - 16:00		Coffee break
16:00 - 17:00	G. Rewoldt	Diagonal and Off-Diagonal Anomalous Transport Coefficients in Tokamaks

<u>October 25 (Wed.)</u>

Session V (chairman: K. Toi)

9:45 - 10:45	M. Mori	Study on H-mode and Improved Confinement in JFT-2M
10:45 - 11:00		Coffee break
11:00 - 12:00	K. Shimizu	H-Mode Simulation
12:00 - 13:30		Lunch

Session VI (chairman: R.E. Waltz)

13:30 - 14:30	H. Naitou	3-D Gyorokinetic Particle Simulation on Internal Kink Modes
14:30 - 15:30	S.P. Hirshman	Numerical Analysis of the Relationship Between Local Transport and Global Confinement in Tokamaks
15:30 - 16:00		Coffee break
16:00 - 17:00	M. Wakatani	Anomalous Transport Studies for Heliotron/Torsatron

Discussion time for Summary

<u>October 26(Thu.)</u>

Session VII (chairman: T. Kamimura)

9:45 - 10:45	W.W. Lee	Gyorokinetic Particle Simulation of Ion Temperature Gradient Drift Instabilities
10:45 - 11:00		Coffee break
11:00 - 12:00	K. Itoh	Transport in Scrape-off-Layer and Its Effect on Core Confinement
12:00 - 13:30		Lunch

Session VIII (chairman: E. Mazzucato)

13:30 - 14:30	Y. Nakamura	Transport Phenomena in Ultra-Long Discharge
14:30 - 15:00		Coffee break
15:00 - 16:30		Summary of the Workshop

<u>October 27(Fri.)</u>

Reserved for the visits to JT-60/JFT-2M (JAERI)
JIPP-TIIU/CHS (NIFS)
Heliotron-E/WT-III (KYOTO)
TRIAM-1M (KYUSHU)
or free discussions

To those who are interested in visiting Machines:
Please contact, in advance, K. Itoh or members of above groups.