ISSN 0915-633X

NATIONAL INSTITUTE FOR FUSION SCIENCE

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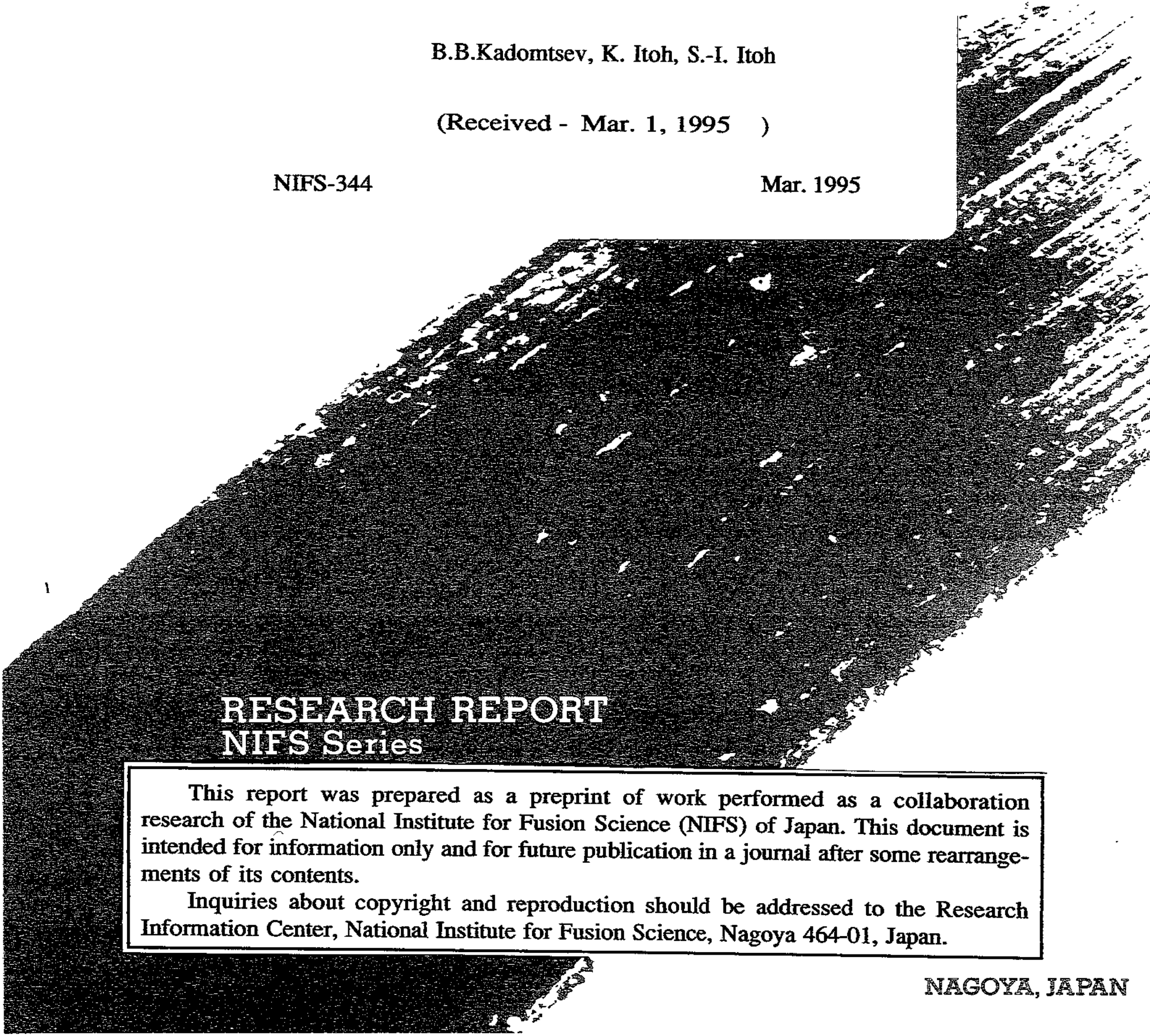
(Received - Mar. 1, 1995)

NIFS-344 Mar. 1995



RESEARCH REPORT
NIFS Series

NAGOYA, JAPAN

Fast Change in Core Transport after L-H Transition

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Abstract

The transport in the core tokamak plasma is known to change very rapidly after the L-H transition in the edge plasma. A qualitative discussion is given for this fast transmission of the transport change. A picture based on the successive bifurcations is presented.

keywords: L-H transition, bifurcations, control parameter, self-organized criticality

The H-mode in tokamak plasmas has revealed many complex features of the plasma transport phenomena [1]. Most dramatic is the establishment of the edge transport barrier: much experimental as well as theoretical work has been done to understand the bifurcation nature of the edge transport. In addition to the fast phenomena near the edge, the transport in the core plasma was also found to respond very rapidly at the L-H transition [2]. The confinement in the core plasma has been known to become better in the H-mode plasma. The recent experiment on JET has shown that the improvement in the core starts to occur only a few milli-seconds or less after the L-H transition at the edge. This delay time of few ms is much smaller than the time scale of the diffusive transport a^2/χ (a: the distance of propagation such as the minor radius, χ: the thermal diffusivity deduced from the power balance of plasmas). This phenomenon of the rapid change in core would be related to other experimental observations, (e.g., the heat pulse propagation after the pellet injection [3] or sawtooth crash [4]) . These experimental results suggest that the energy flux in the plasma is governed by some 'nonlocal' mechanism, in addition to the diffusive flux driven by the local gradient. Yoshizawa has analyzed the distant interaction of fluctuations [5] in a form of the diffusion equation for fluctuations. It is not enough to explain the fast change in the transport.

In this article, we discuss a possible physical picture of the rapid change of the transport in the core plasma. A control parameter, such as an axisymmetric electric potential, is used to describe the difference between the high transport state (L-mode) and the low transport state (H-mode) in the core plasma. A successive mode change (from L-to H-state) propagates from the edge to the center in a form of avalanche, causing a rapid change in a core. Analogy with the 'sand pile model' is discussed.

Figure 1 illustrates the radial distribution of the plasma temperature. The region I is the edge and II denotes the core plasma. Figure 2 shows that, in L and H modes of confinement, the dependencies $q = -\chi \nabla T$ are very different each other. But we can consider them as two different branches of the same nonlinear $q = q[\nabla T]$ dependence keeping in mind the possibility for the existence of some control parameter C. In the edge plasma, the parameter C was the radial electric field E_r or its gradient [6,7]. Hence we can imagine a single nonlinear $q[\nabla T]$ dependence for the L- and H-modes in the edge plasma [6]. Here the shear flow, i.e., n=0/m=0 mode is responsible for the turbulence suppression (m and n are the poloidal and toroidal mode numbers). Similar type of the gradient-flux relation for the core plasma could be again nonlinear one, either the N-figure type or the S-figure type, and the following argument applies to both cases. These multiple states can be considered again as produced by the effect of the hidden variable or the control parameter [6]. Figure 2(c) schematically describes the transport coefficient as a function of the control parameter C. In the core plasma, the candidate for the control parameter is extended to the general axisymmetric potential variation. In other words, not only the n=0/m=0 component but the n=0/m≠0 components as well can work for the control parameter. The influence of the n=0/m=0 electric field is known for the core plasma [7]. Those of the n=0/m≠0 modes are also plausible: for instance, the nonlinear gyro-fluid simulation on the ITG mode turbulence [8] has shown that the presence of such components can reduce the transport coefficient considerably.

The successive L to H transition can propagate quite rapidly. Consider for instance the case when the layer 1 in Fig.1 is just jumped to the H-state and the adjunct layer 2 still remains in the L-state. Small change δT is induced in layer 2 by the L-H transition in the layer 1. If this change is enough to cause the transition in the layer 2, the ratio between the heat flux q and $N\delta T$ provides the propagation velocity V (N being the density). Writing the heat flux q as $-N\chi\nabla T$, the velocity V can be estimated as

$$V = \frac{T}{\delta T}\frac{\chi}{a}$$

where we use the simplification $-\nabla T \simeq T/a$. The V value can be much larger than χ/a. Thus, this high propagation velocity allows a rapid transmission of the information. The characteristic time

$$\tau = a/V$$

is estimated as

$$\tau = \frac{\delta T}{T} \frac{a^2}{\chi}$$

This is much smaller than a^2/χ if $\delta T/T << 1$ holds.

The argument here is based on the model that all the core plasma is close to the condition $q = q^*$, which is expressed by the ridge point in Fig.2(b). This may be seen as a very special case, if one uses a static relation of Fig.2(b). The ridge point q^* could depend on various plasma parameters, so that the condition $q(r) = q^*(r)$ may not be necessarily satisfied in a wide region of the core plasma. [The numerical simulation of the transport barrier, based on the static form of Fig.2(a) has been done [9]. This analysis found the transport barrier formation and ELMs, but the transport barrier did not propagate into the core.]

The induced jump over q^* could be possible if one consider the dynamic situation. Figure 3 illustrates the $q[\nabla T]$ relation in the layer 2. In the L-phase, the functional relations and the gradients are shown by the curve and the open symbol, respectively. When the layer 1 in Fig.1 enters into the H-phase, the gradient at the interface of the layers 1 and 2 starts to increase. The control parameter is also enhanced by the strong inhomogeneity associated with the touching the H-phase and L-phase. The state in the layer 2 changes as shown by the arrow in Fig.3. The region 2 also turns into the H-phase (denoted by the solid symbol). This would be considered as the "tunneling" of the peak in the $q[\nabla T]$ curves.

This picture of the continuous transitions has a similarity to the 'sand-pile model' [10]. If the profile at some location of the mountain of the sand reaches the critical profile of the avalanche, then the avalanche happens. Owing to the local perturbations associated with the avalanche, the barrier of the static frictional force is overcome, and the dynamic friction becomes smaller. The avalanche continues to start in the neighborhood. Due to the successive triggering of the avalanche, the event at the top propagates very fast to the bottom. The self-organized criticality in this problem leads to the formation of the self-similar form of the sand pile. The case of the successive L-H transition in tokamaks can also provide a particular class of the plasma profile, i.e., those of the L mode and the H-mode. These classes of the profiles could be called phenomenologically as 'natural profiles' or 'profile resilience' in various confinement modes [11].

Thus the very fast propagation of the confinement region from the edge inside the plasma core can be treated as a triggered L to H transition over all the plasma cross section similar to a sand pile formulation.

Acknowledgements

This work is performed during the visit of one of the authors (BBK) to NIFS as a visiting professor. He thanks Prof. Iiyoshi for hospitality during his stay at NIFS. Discussion with Dr. Kerbel is also acknowledged.

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Figure Captions

Fig.1 Plasma profile. The regions I and II indicate the edge and core, respectively. The layers 1 and 2 define the propagating front of the L-H transition domain.

Fig.2 Relation between the gradient and the heat flux at the plasma edge (a) and that in the plasma core (b). At the edge (a), both the hard-type and soft type bifurcations are possible to occur. q* is the critical heat flux for the transition. The dependence of the transport coefficient on the control parameter C is shcematically given in (c).

Fig.3 Change of the gradient-flux relation in the region 2 of Fig.1. This region is located in front of the propagated L-H transition domain.

Fig.1

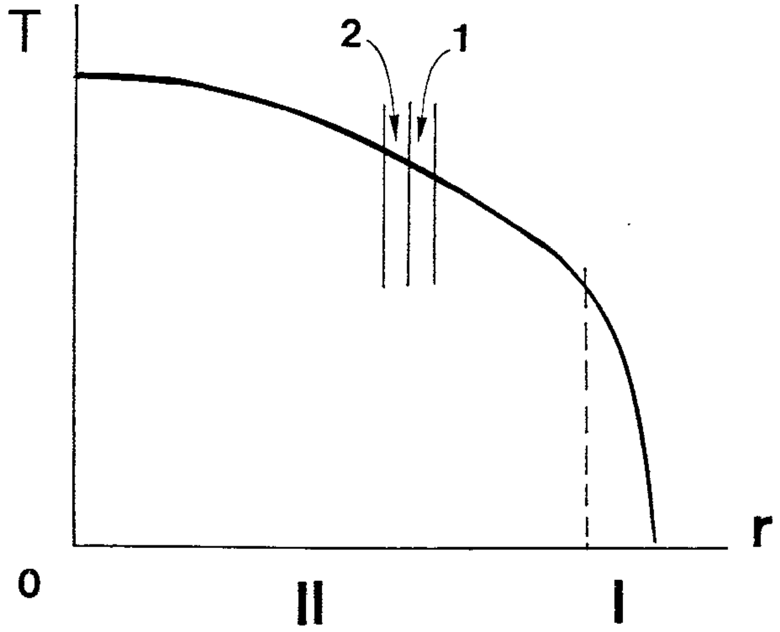


Fig.2

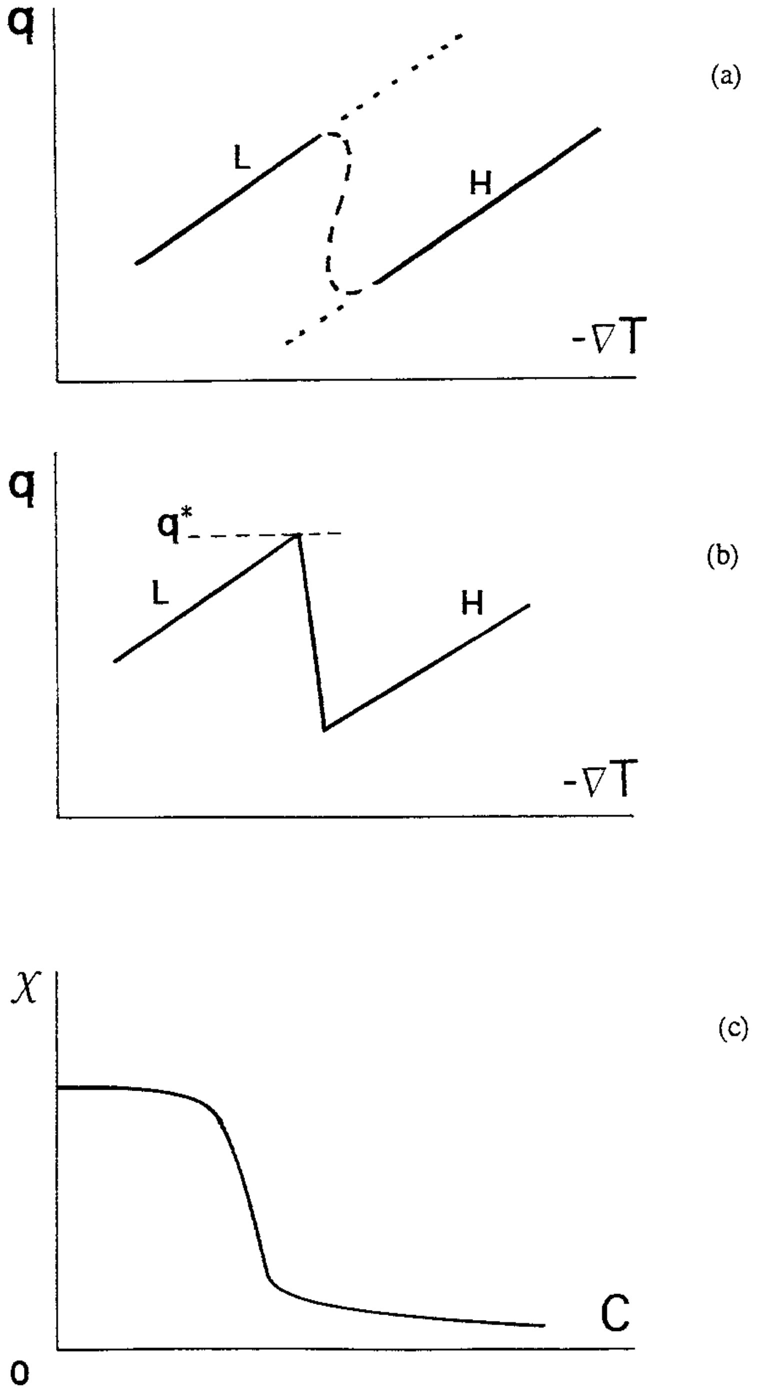
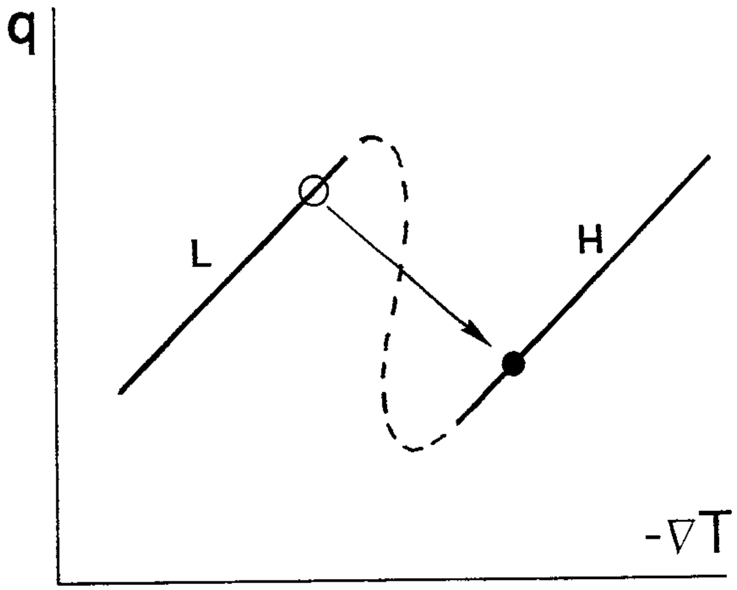


Fig.3



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