BEHAVIOR OF ELECTRON AND ION TRANSPORT IN DISCHARGES WITH AN INTERNAL TRANSPORT BARRIER IN THE DIII-D TOKAMAK*

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Recent experiments on the DIII–D tokamak have further elucidated the conditions of and underlying physics behind the formation of internal transport barriers (ITB). Building on previous work where tokamak plasmas with neoclassical transport in the ion channel were produced [1], further experiments have been performed where the initial formation and spatial expansion of these barriers were more thoroughly explored. Many, if not all, of these plasmas continue to exhibit anomalous transport in the electron channel, even with neoclassical ion transport. Further investigation of this phenomenon reveals that this may be related to short wavelength turbulence which has, in most cases, relatively minor impact on the ion channel.

In agreement with theory [2], observations in several tokamaks have shown that an internal transport barrier (ITB), most evident in the ion temperature and rotation profiles, can be formed in a plasma when the calculated linear growth rates for ion temperature gradient (ITG) modes are exceeded by the **E**×**B** shearing rate [3]. This can only occur, however, when other factors, including locally weak or negative magnetic shear and Shafranov shift, combine to partially stabilize the mode so that a region of high **E**×**B** shear can begin to form with the addition of sufficient heating power density [4]. This line of reasoning leads to the prediction of a threshold in heating power, which is experimentally observed in full-field (B_T = 2.1 T) discharges in DIII–D at approximately 2.5 MW. The ITB usually forms in the core almost immediately upon the addition of this power, accompanied by a localized turbulence reduction. Spatial expansion of this region is minimal unless additional heating power is added. The slow expansion observed at moderate (≤6 MW) power levels occurs in a theoretically predicted [5] stepwise fashion rather than as a continuous process (Fig. 1), and is observed both as spatially localized broadening of the kinetic profiles (dashed lines in Fig. 1; also observed in toroidal rotation, electron temperature and density) and as turbulence reduction characterized by quiescent periods of increasing duration. These steps usually do not correlate with integer values of the safety factor, *q*. More rapid expansion occurs after the onset of additional power, as has been documented previously [1,3].

Typically, the electron diffusivity χ_e remains anomalously high even when ITB is established for ions. We have observed, furthermore, that additional electron heating can *increase* transport in both the electron and ion channel. Such a discharge is shown in Fig. 2, where 2.6 MW of fast wave (60–83 MHz) power was added to a discharge similar to that shown in Fig. 1 after the transport barrier had developed. Following the addition of the rf power, the central ion temperature decreases by about 25%, corresponding to an increase of

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about a factor of two in the ion diffusivity χ_i. A similar decrease in toroidal rotation is observed at the same time. The lack of a sufficient increase in the electron temperature while the central electron heating is increased by nearly an order of magnitude implies a large increase in χ_e.

A possible explanation for this behavior is that as T_e/T_i increases to near 1 over most of the plasma, ITG turbulence is destabilized, thereby increasing χ_i. Increased TAE-like activity due to longer neutral beam slowing down times may also contribute to an elevated apparant χ_i These effects, however, do not explain the observed increased transport in the electron channel. Linear growth rate calculations indicate that electron temperature gradient (ETG) modes are likely to exist in these discharges, and might well be large enough to impact transport in the observed manner. They are predicted to be manifested as short wavelength turbulence in the $k_\theta \geq 10\ \mathrm{cm}^{-1}$ range, making them difficult to observe directly. Since these instabilities are not predicted to respond to **E**×**B** shear as a stabilizing mechanism, this may pose an interesting challenge for future work. This effect may also represent an opportunity in applications for transport barrier control.

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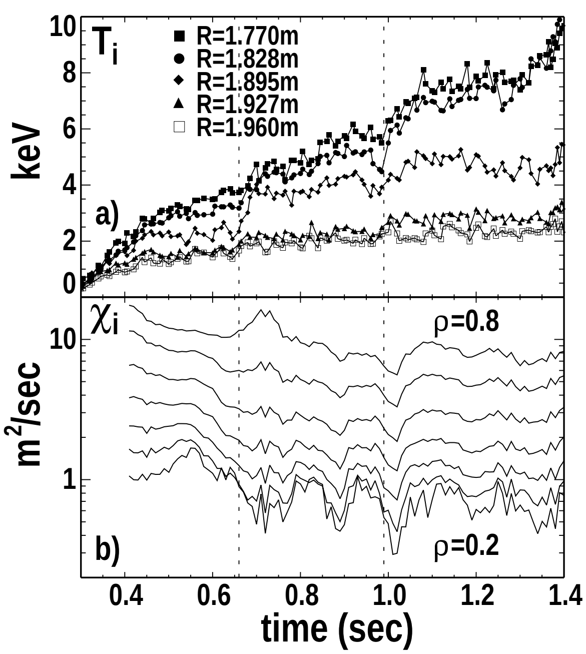

Fig. 1. The transport barrier forms almost immediately after the application of 5 MW of neutral beam heating power at 0.3 s into the discharge, and expands in steps. Such steps are most readily apparent at 0.66 and 1.0 s. (a) Core ion temperature from charge exchange recombination spectroscopy shows localized sudden jumps at the barrier growth steps, (b) Ion diffusivity calculated by TRANSP indicates barrier expansion at these times. DIII–D 89943.

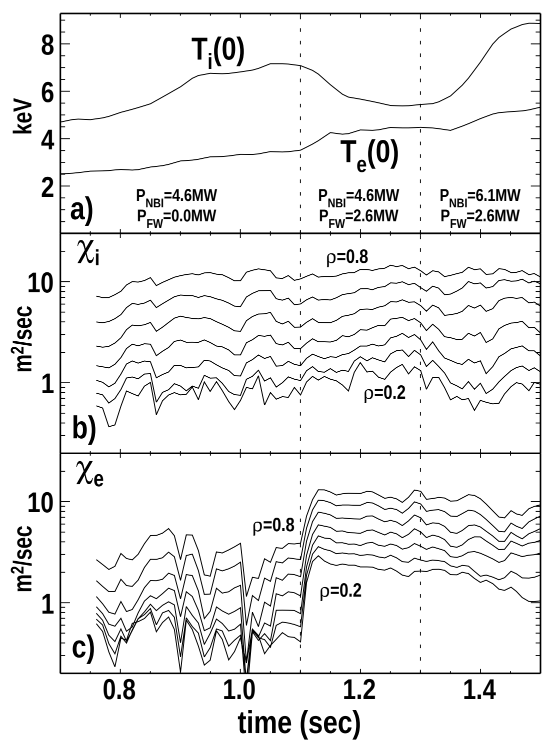

Fig. 2. Application of fast wave rf power, heating only electrons, interrupts the formation of an internal transport barrier in a discharge similar to that in Fig. 1. (a) Core ion temperature is reduced at application of rf while electron temperature undergoes a slight increase, (b) core ion diffusivity increases by about a factor of two, but (c) electron diffusivity increases by a full order of magnitude. DIII–D 89986.