GA–A27249

EXPERIMENTAL TESTS OF STIFFNESS IN THE ELECTRON AND ION ENERGY TRANSPORT IN THE DIII-D TOKAMAK

by
T.C. LUCE, K.H. BURRELL, J.C. DeBOO, J.E. KINSEY, A. MARINONI, C.C. PETTY, E.J. DOYLE, C. HOLLAND, G.R. McKEE, J.C. ROST, S.P. SMITH, P.B. SNYDER, W.M. SOLOMON, G.M. STAEBLER, A.E. WHITE, Z. YAN, and L. ZENG

APRIL 2012

GENERAL ATOMICS

DISCLAIMER

GA–A27249

EXPERIMENTAL TESTS OF STIFFNESS IN THE ELECTRON AND ION ENERGY TRANSPORT IN THE DIII-D TOKAMAK

by

T.C. LUCE, K.H. BURRELL, J.C. DeBOO, J.E. KINSEY, A. MARINONI,* C.C. PETTY, E.J. DOYLE,† C. HOLLAND,‡ G.R. McKEE,# J.C. ROST,* S.P. SMITH, P.B. SNYDER, W.M. SOLOMON,¶ G.M. STAEBLER, A.E. WHITE,* Z. YAN,# and L. ZENG†

This is a preprint of the synopsis for a paper to be presented at the Twenty-fourth IAEA Fusion Energy Conf., October 8-13, 2012 in San Diego, California.

*Massachusetts Institute of Technology, Cambridge, Massachusetts.
†University of California Los Angeles, Los Angeles, California.
‡University of California San Diego, La Jolla, California.
#University of Wisconsin-Madison, Madison, Wisconsin.
¶Princeton Plasma Physics Laboratory, Princeton, New Jersey.

Work supported in part by
the U.S. Department of Energy
under DE-FC02-04ER54698, DE-FG02-04ER54762, DE-FG02-08ER54984, DE-FG02-07ER54917, DE-FG02-89ER53296, DE-FG02-08ER54999, DE-AC02-09CH11466, and DE-FC02-99ER54512

GENERAL ATOMICS PROJECT 30200
APRIL 2012

GENERAL ATOMICS

Experimental Tests of Stiffness in the Electron and Ion Energy Transport in the DIII-D Tokamak

EX-C

T.C. Luce[1], K.H. Burrell[1], J.C. DeBoo[1], J.E. Kinsey[1], A. Marinoni[2], C.C. Petty[1], E.J. Doyle[3], C. Holland[4], G.R. McKee[5], J.C. Rost[2], S.P. Smith[1], P.B. Snyder[1], W.M. Solomon[6], G.M. Staebler[1], A.E. White[2], Z. Yan[5], and L. Zeng[3]
Email: luce@fusion.gat.com

[1]General Atomics, San Diego, California 92186-5608, USA
[2]Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
[3]University of California Los Angeles, Los Angeles, California 90095-7099, USA
[4]University of California San Diego, La Jolla, California 92093-0417, USA
[5]University of Wisconsin-Madison, Wisconsin 53706 USA
[6]Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543-0451, USA

Drift wave theories (ion or electron temperature gradient modes) have an onset threshold in gradient beyond which the flux transported is predicted to increase very rapidly. For fixed boundary condition, this type of behavior would manifest itself as a strong resistance to change in the temperature profiles or “stiffness”. A new series of experiments exploiting the unique tools available in the DIII-D tokamak have explored this concept of stiffness in the electron channel in L-mode plasmas and in the ion channel in H-mode plasmas, specifically as a function of applied torque. In L mode, the electron temperature scale length in a narrow region was varied by a factor of 4 by changing the deposition location of the electron cyclotron heating (ECH) and changing the electron heat flux by a factor of 10. The response of the temperature profile is not dependent on the applied torque, as seen by self-similar response of the profile with balanced, co-current, and counter-current injection of neutral beams (NBI). One ECH source was also modulated to probe the flux/gradient relationship dynamically. The response is consistent with a threshold in gradient or scale length at quite low values, which is exceeded for virtually all cases with auxiliary heating in DIII-D. A similar tool for variation of the ion heat deposition is not available in DIII-D. However, the majority of the NBI heating power is deposited in the ions, so the response of the ion temperature profile to a power scan in H mode with low and high torque was obtained. The ion temperature gradient response to more heating power decreases with increasing radius. The response is also smaller with low torque input at a given radius, in contrast to the electron profile results in L mode.

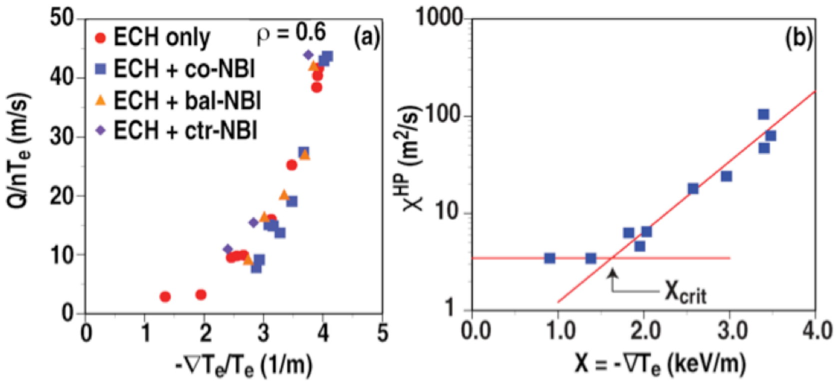

Fig. 1. (a) Normalized heat flux from power balance analysis vs electron temperature scale length, (b) Diffusivity estimate from heat pulse behavior vs electron temperature gradient.

The strong resistance of the electron temperature profile to change in L mode can be seen in Fig. 1(a). The normalized electron heat flux exhausted by the plasma at a normalized radius ρ=0.6 increases by nearly an order of magnitude as the temperature scale length varies only from around

2.5 to 4. To obtain these results, the six gyrotron ECH system was steered to change the heating location in increments of a single gyrotron. The heating profile ranged from all gyrotrons at ρ=0.7 to all but one modulated gyrotron at ρ=0.5. This holds constant the edge boundary condition outside ρ=0.7 while varying the electron heat flux between ρ=0.5 and ρ=0.7 substantially. The normalized heat flux exhausted by the plasma is strongly nonlinear as a function of scale length, which is consistent with global power degradation of confinement. The mechanism responsible is not a function of the applied torque [Fig. 1(a)], as indicated by the lack of variation with balanced, co-current, counter-current NBI or ECH alone. Modulation of the ECH results in heat pulses that move across the plasma radius and can be analyzed to yield information on the stiffness. The "effective" diffusivity in the ECH-only case increases strongly at higher scale length [Fig. 1(b)]. At the lowest fluxes possible (ohmic minus electron-ion collisional exchange), the heat pulse diffusivity deviates from the trend seen at higher values and may indicate the plasma is below a threshold for turbulence onset. Alternate explanations, such as a heat pinch, are not yet conclusively ruled out.

The response of the ion temperature profile to increased power in H mode shows significant variation with both radius and applied torque (Fig. 2). At the innermost radius shown (ρ=0.4), the plasma response to increased heating is very similar at low and high torque, with a change in gradient (not shown) of up to a factor of 3. Moving to larger radius, the profile shape varies much less for both low and high torque, as indicated by the steeper lines in Fig. 2. This increasing "stiffness" is most apparent in the plasmas with low applied torque, with the profile shape at ρ=0.7 hardly varying at all under these conditions. The variation with radius could be related to the increase in trapped ion fraction with radius. The variation with torque input may be due to decreased *ExB* shear in the low torque case.

The difference in the electron and ion temperature scale length behavior with low and high-applied torque is quite striking. Comparison with model predictions should help understand whether there is a fundamental difference in the electron and ion transport (for example, sensitivity to turbulence at different wavelengths) or the parameter regimes probed in these L-mode and H-mode plasmas is sufficiently separate as to yield the observed differences with a single type of turbulence.

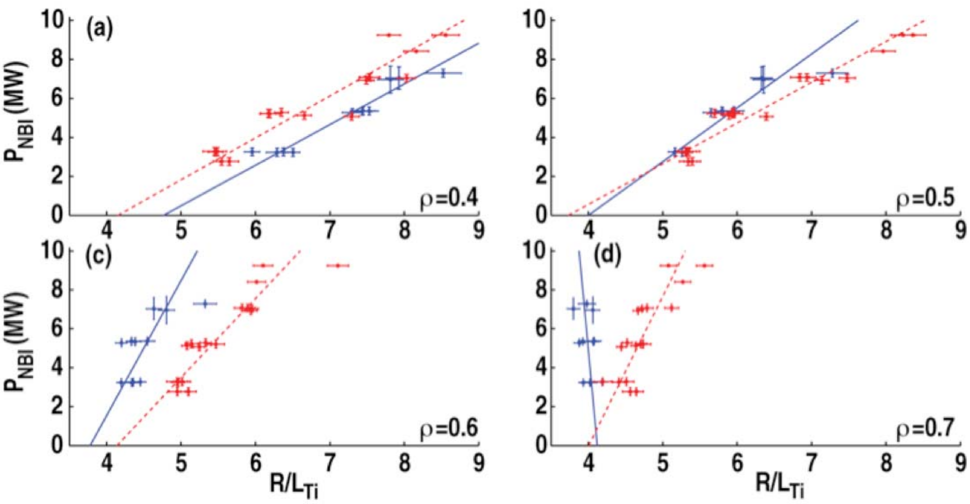

Fig. 2. Input power from NBI heating vs normalized ion temperature scale length at (a) ρ=0.4, (b) ρ=0.5, (c) ρ=0.6, and (d) ρ=0.7 for low (blue) and high (red) applied torque. The power that is transported in the ion channel (NBI – ion-electron collisional exchange) is 60%-65% of the total NBI power.

This work was supported by the US Department of Energy under DE-FC02-04ER54698, DE-FG02-04ER54762, DE-FG02-08ER54984, DE-FG02-07ER54917, DE-FG02-89ER53296, DE-FG02-08ER54999, DE-AC02-09CH11466, and DE-FC02-99ER54512.