COMPARISON OF L–H TRANSITION MEASUREMENTS WITH PHYSICS MODELS*

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Global scaling of the H–mode power threshold (P_{TH}) and local conditions at the edge of the plasma just before an L-H transition have been studied in the DIII–D tokamak. Besides the usual dependence on density and toroidal field, at least three other effects have been found to have a significant influence on P_{TH}. These include the effect of a sawtooth crash, which can trigger an L-H transition, the direction and magnitude of the ion ∇B drift relative to the X–point location, which can change P_{TH} by factors of 2 to 3, and the effect of neutrals, which can have more subtle and counter intuitive effects on P_{TH}. The observed variability of the power threshold with the wall conditioning in many devices suggests that atomic physics may be important and an obvious potential mechanism is the coupling of the neutral dynamics to the transition mechanism. Each of these effects has been studied experimentally and compared with physics models or numerical calculations. In addition, parameters measured at the plasma edge just before an L-H transition have been analyzed and compared to theories of the L-H transition. Operational space of L– and H–mode is given in terms of dimensionless edge parameters. It is found that edge gradients of temperature and pressure may be more important than the magnitude of the edge values themselves.

Over half of the L-H transitions in the DIII–D database are triggered by sawteeth. The sawtooth crash provides an additional transient power flow to the edge of the plasma where the L-H transition takes place. This power flow depends on the inversion radius of the sawtooth, the stored energy in the plasma, and the dissipation of the power as it flows to the plasma edge. In an experiment in which the sawteeth were suppressed by neutral beam heating during the early current ramp phase of the discharge, P_{TH} increased from 3 MW in the sawtooth triggered case to 5 MW when the sawteeth were suppressed. Thus edge power flow due to sawteeth may significantly influence the observed P_{TH} scaling.

The direction of the ion ∇B drift relative to the X–point location has a dramatic influence on the magnitude of P_{TH}. Hinton [1] and later Hinton and Staebler [2] have attributed this effect to neoclassical cross-field fluxes of both heat and particles driven by poloidal temperature gradients on the open field lines in the scrape-off-layer (SOL). In its simplest form, these fluxes influence P_{TH} by either adding to or subtracting from the power flow to the edge of the plasma. A 1D analysis of heat conduction in the SOL shows that these cross-field fluxes can be a large fraction of the input power. It is proposed that some of the observed scaling of P_{TH} is due to the variation of the magnitude of these fluxes and may not be intrinsic to the scaling of the physics of the L–H transition itself. Many qualitative features of this model are in agreement with observations of P_{TH} scaling, such as the existence of a density threshold, the importance of the X–point position, and the increase of P_{TH} in double-null configurations.

The effect of neutrals on the L-H transition has been studied in a series of experiments where heavy gas puffing was used to ramp up the density and divertor cryopumping was used to ramp down the density during an L-H transition[3]. Transport and neutral modeling of the plasma edge region using B2.5 and DEGAS indicates that during heavy gas puffing, an

*Work supported by the U.S. Department of Energy under Contract Nos. DE-AC03-89ER51114, DE-AC05-96OR22464, W-7405-ENG-48, DE-AC04-94AL85000 and Grant No. DE-FG03-95ER54294.

increase of neutral density in the SOL creates an increase in plasma density that, in turn, increases the opacity to the neutrals and reduces the neutral density inside the separatrix. This reduces the neutral effects in this region and lowers P_{TH}. When the cryopump is used, the neutral penetration is greater and P_{TH} increases. Analysis shows that P_{TH}/n correlates well with the normalized neutrals penetration, λ_n/r_s, (r_s=separatrix radius), or with the ratio of the neutrals charge-exchange damping rate to the neoclassical damping rate, ν_{cx}/μ_{neo}, in the region $0.9 < r/r_s < 0.95$ inside the separatrix. A mechanism possibly responsible for the neutrals effect on the transition threshold is a change in the damping of the poloidal component of the $E\times B$ shear flow [6], [7].

A technique of fitting a hyperbolic tangent to the edge profiles has eliminated the scatter caused by the flux surface reconstruction [4] and has improved the localization of the edge measurements [5]. With this technique, the position of the maximum edge density gradient remains relatively constant across the L-H transition, and is therefore, a good location to evaluate the local edge conditions relevant to the formation of the edge transport barrier in H–mode. At this location, T_e increases with increasing toroidal field. Modeling of heat flow in the SOL suggests that this increase may be due to a higher T_e necessary to drive parallel heat conduction. In an operational space diagram of T_e and n_e evaluated at the pedestal of the density profile shown in Fig. 1, the pre-transition data are not well separated from the normal L mode data, indicating these measurements do not clearly resolve the L-H transition operating space.

The improved localization of the edge parameters now permits more detailed comparisons with L-H transition theories. Collisionality of the edge plasma varies in the range of 5–50, and is not likely to be a key parameter. In a model based on 3D simulations of edge turbulence by Rogers and Drake [8], the threshold condition is parameterized in terms of α_{MHD} and α_{DIAM}, both of which contain edge gradients. Figure 2 shows that α_{MHD} may provide a better separation of the L–mode and pre-transition data than T_e and n_e shown in Fig. 1, indicating edge gradients may be important for the L-H transition. Due to the lack of separation of the data with α_{DIAM}, the importance of this parameter is not clear. Quantitative comparisons will require improvements in the model to include realistic geometry.

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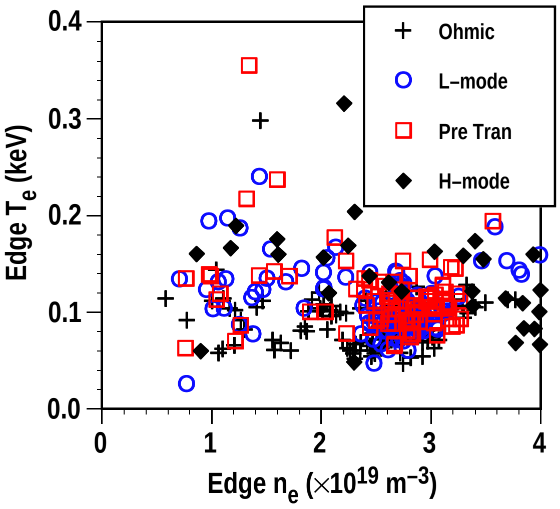

Fig. 1. T_e versus n_e evaluated the the n_e pedestal.

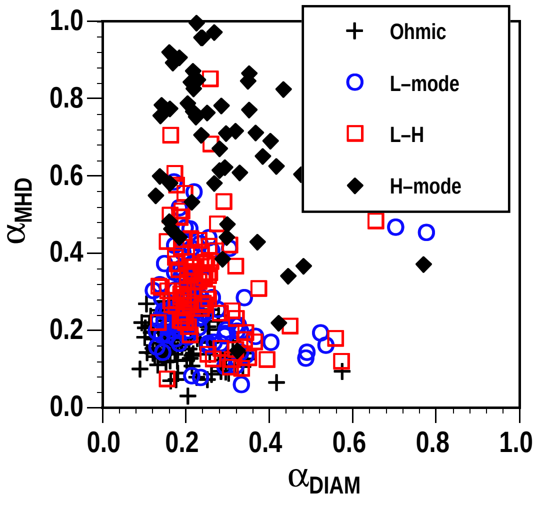

Fig. 2. α_{MHD} as a function of α_{DIAM}.