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Critical edge parameters for H–mode transition in DIII–D

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Abstract. Measurements in DIII–D of edge ion and electron temperatures (T_i and T_e) just prior to the transition to H–mode are presented. A fitting model based on a hyperbolic tangent function is used in the analysis. The edge temperatures are observed to increase during the L-phase with the application of auxiliary heating. The temperature rise is small if the H–mode power threshold is close to the Ohmic power level in the absence of auxiliary heating and is large if the H–mode threshold is well above the Ohmic power level. The edge temperatures just prior to the transition are approximately proportional to the toroidal magnetic field B_t, for the field either in the reversed or forward direction. However, for the reversed magnetic field, the temperatures are at least a factor of two higher than for the forward direction.

1. Introduction

Studies of edge parameters observed just prior to the transition to the H–mode in DIII–D [1,2], ASDEX-U [3], and CMOD [4] have focused attention on some function of edge temperature as playing a role in producing the transition. If this is true, it would be expected that the edge temperature should gradually increase in the L–mode prior to the transition. One goal of this paper is to present evidence from DIII–D for this effect. This effect is rather subtle for discharges which require relatively little auxiliary power to produce the H–mode and also is not observed for positions in the plasma too near the separatrix.

Another area of general agreement is that DIII–D [5], ASDEX-U [3] and CMOD [4] have all reported that the edge T_e required for H–mode increases, approximately linearly, as the toroidal magnetic field B_t is increased. In addition, ASDEX-U and CMOD have reported that the required value of T_e approximately doubles when the direction of the ∇B drift is changed from being in the favorable to the unfavorable direction. This paper presents data from DIII–D which show that the edge T_i shows a similar behavior.

II. Analysis method

The data presented in the paper are obtained by fitting edge measurements with a hyperbolic tangent function plus appropriate linear terms [6]. This approach both eliminates the magnetic equilibrium from the analysis procedure (as opposed to the analysis procedure used in references 1 and 2) and provides a way to determine edge parameters in a consistent way, based on details of the profiles themselves. It has the additional benefit that it can be readily used to analyze timeseries data.

The definition of the fitting function is shown in Fig. 1. The fitting process looks for a region of steep gradient at the plasma edge. This approach is very well adapted to the analysis of H–mode profiles which exhibit transport barriers in density and temperature profiles. In contrast, L–mode temperature profiles do not exhibit a region of steep gradient at the plasma edge. However, edge electron and C VI density profiles do exhibit a pronounced steepening at the plasma edge even in L–mode and the fits to these profiles are used to determine where to evaluate the temperature profiles. For either the n_e profile, as measured with a multichord Thomson Scattering system or for the edge C VI profile, as measured with a multichord Charge Exchange Recombination spectroscopy system, the fit provides two unique spatial points. One of these points is the "density symmetry" point, which is the symmetry point of the hyperbolic tangent part of the fit; this position corresponds to the center of the steep gradient region. The second point is the "density knee" which is one-half "width" in from the symmetry point, where the "width" is the denominator of the tanh function, as shown in Fig. 1. The density knee corresponds to the region where the steep edge and gentle core portions of the profile connect together.

III. Temporal variation of edge temperature in L–mode

As noted previously, if some critical value of temperature is required for the H–mode transition, then the edge temperature must increase during the L–mode. However, in many DIII–D H–mode threshold studies, it is often difficult to perceive a significant evolution of the edge temperature in L–mode. These discharges typically require little auxiliary heating power to trigger the H–mode. Evidently, even in the Ohmic phase, the edge conditions are close to those required for H–mode and thus not much change need occur with auxiliary heating for the transition to be triggered. In order to observe a temperature evolution under such conditions, it is advantageous to examine a discharge with a long L-phase and to use some averaging of the edge temperatures to smooth scatter and fluctuations of the data. In fact, in the relatively few discharges examined in this way, there is good evidence that the edge temperatures, particularly at the density knee, do rise in L- mode.

Figure 2(a–d) is an example of a discharge in which the H–mode threshold power of 1.1 MW was almost identical to the Ohmic power prior to auxiliary heating. This discharge had an L–mode phase of approximately 700 ms. With a 25 ms time average applied to the edge temperatures, it can be seen that T_i and $T_{e,}$ as measured at their respective density knees, both increased by 10%–20% during the L–mode phase. T_i as measured at the

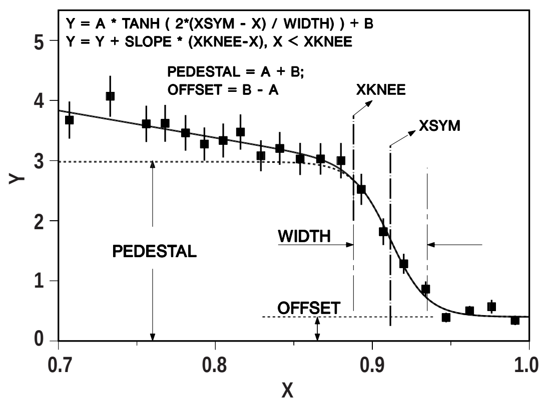

Figure 1. Definition of hyperbolic tangent fit to edge profile. The solid squares are measurements of some quantity Y as a function of some spatial coordinate X. The solid line is the fit to the data of the hyperbolic tangent function plus a constant offset term plus a linear term for points inside the knee of the profile.

density symmetry point also increased during the L–mode phase but it is less clear if T_e at the density symmetry point actually increased or remained unchanged. The value of n_e at the knee increased very slightly during the L–mode while n_e at the symmetry point remained unchanged.

If these ideas are correct, then a larger temperature increase should be seen in the L-phase of discharges which have a high H–mode power threshold relative to the Ohmic power prior to auxiliary heating. This phenomenon is also observed, as illustrated in Fig. 2(e–h). For the discharge shown, the H–mode power threshold of 5.8 MW was a factor of 5–6 larger than what the Ohmic power would have been in the absence of auxiliary heating. The large power threshold is due to the fact that the ∇B drift was in the unfavorable direction. The values of T_i and T_e at their respective density knees both increased continuously during the L-phase and more than doubled by the time of the H–mode transition. This trend was due primarily to an increase in the temperature gradients during the L-phase. For the data shown in Fig. 2, the density symmetry point was 1.5-2.5 cm from the separatrix and the density knee was 3-5 cm from the separatrix, as measured on the midplane. A less dramatic change was seen in T_i at the density symmetry point and little if any change in T_e at the density symmetry point. Little change occurred in n_e at either the knee or symmetry point.

IV. Scaling of edge temperature with toroidal field

Measurements of the edge T_i variation with the magnitude and direction of B_t have been made in DIII–D and are presented here. Figure 3 shows that both T_i and T_e at their respective density knee positions increase approximately linearly with B_t for both signs of the toroidal field. (Positive B_t corresponds to the ∇B drift in the favorable direction; negative B_t corresponds to the ∇B drift in the unfavorable direction.) For both species,

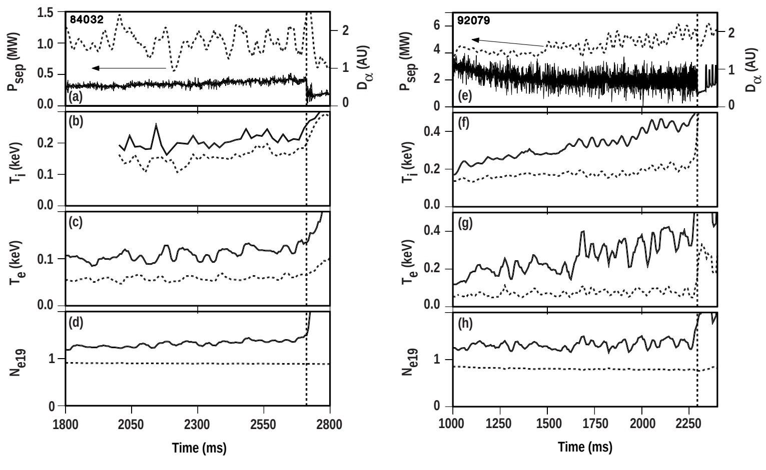

Figure 2. Panels (a–d) and (e–h) show waveforms for discharges in which the H–mode power threshold was respectively close to and much larger than the Ohmic power in absence of auxiliary heating. Vertical dashed lines indicate time of L–H transition. P_{sep} is power flow through the separatrix. N_{e19} is electron density in units of 10^{19} m^{-3}. In panels (b–d) and (f–h), solid lines show data at density knees and dashed lines show data at density symmetry points.

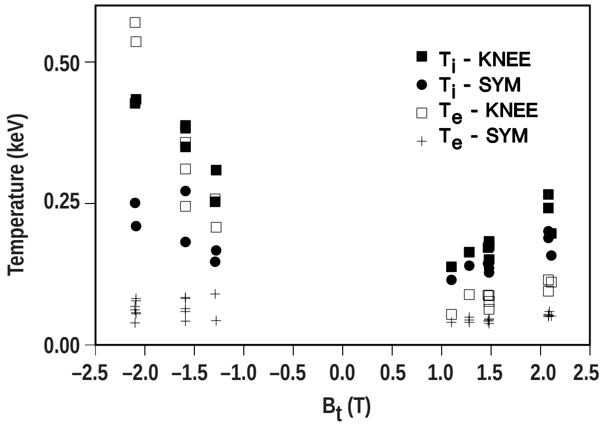

Figure 3. Edge temperatures as function of toroidal magnetic field and direction. Positive (negative) magnetic field corresponds to normal (reversed) direction of B_t and the ∇B drift is in the favorable (unfavorable) direction.

the temperatures are considerably higher for the case of reversed B_t as opposed to forward B_t; the ion temperature is roughly doubled for reversed B_t whereas the electron temperature increases by a factor of about 3–5. At the density symmetry point, T_e shows a weak, if any, dependence on either the magnitude or direction of B_t. In contrast, T_i at the symmetry point increases roughly linearly with B_t and is somewhat larger with reversed field as opposed to the normal direction of the field.

The dataset for the normal direction of B_t is the same dataset as was used in Ref. [1,2] where it was concluded that temperature did not vary significantly with the magnitude of B_t. In Ref. [1,2], the data were analyzed with a technique which required mapping of the data to magnetic equilibria. When the toroidal field scan was analyzed in this way, it was noted that the separatrix location moved a small amount relative to the region of steep gradient in the density profiles, thus suggesting that there was a small but systematic error which affected the scaling results. With the technique used in this paper, this problem is eliminated. It is also clear that the density knee as determined here corresponds to a region further into the plasma than was used in Ref. [1,2]. This choice of position might provide different results than positions chosen too close to the separatrix, where small variations in the edge parameters are seen.

V. Summary and conclusions

The research presented here is consistent with the idea that some function of "edge" temperature plays an important role in producing the H–mode transition. The summary and conclusions are:

1. In the L–mode phase of discharges which transition to H–mode, both T_i and T_e at the density knee positions gradually increase with the application of auxiliary heating; the values of temperature, particularly of T_e, at the density symmetry point do not necessarily show significant changes during the L–mode phase.
2. The percentage increase of edge temperatures (at the density knee) in L–mode increases as the H–mode power threshold increases above the Ohmic power present without auxiliary heating.

3. Both edge T_i and T_e increase roughly linearly with B_t for either sign of the field. For reversed B_t (∇B drift in the unfavorable direction), the edge values of T_i and of T_e are significantly larger than for the forward direction. This result implies that a transition criterion as simple as T_i or T_e being some constant is not correct. The transition condition must include additional variables.

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References

[1] R.J. Groebner *et al.*, Plasma Phys. Control. Fusion **38** (1996) 1249.
[2] T.N. Carlstrom *et al.*, Phys. Plasmas **3** (1996) 1867.
[3] H. Zohm et al., to be published in Proceedings of 1996 IAEA meeting.
[4] A.E. Hubbard *et al.*, to be published in Proceedings of 1996 IAEA meeting.
[5] T.N. Carlstrom *et al.*, Proc. 16th EPS Conference on Controlled Fusion and Plasma Physics.
[6] R.J. Groebner *et al.*, to be published in Proceedings of 1996 IAEA meeting.