H-MODE THRESHOLD EDGE PARAMETER SIMILARITY DISCHARGES IN ’JET’ AND ’ASDEX’ UPGRADE

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Abstract

Similarity experiments in JET and ASDEX Upgrade have been performed so that a comparison of local edge parameters at the time of the L- to H-mode transition can be made. It is found that the transition can be obtained at similar values of ρ^*, $\nu*$, and β at the edge in the two machines, indicating that no contradiction exists to H-mode transition models based on electron and ion dynamics. It is found in both machines that $\rho*$ and β at the transition depend weakly on $\nu*$.

1. Introduction

The transition to high confinement mode (H-mode) not only leads to a strong transport reduction especially at the plasma edge but the occurrence of the transition itself depends on edge parameters, especially the edge temperature [1]. Previous experiments in JET [2] and ASDEX Upgrade [3] showed that the critical edge temperature for the L- to H-mode transition depends only weakly on the edge density, but has a noticable dependence on the magnetic field. Current understanding of the H-mode attributes the transport reduction to sheared $E \times B$ velocity [4]. However, it is not clear to date which forces affect (drive or inhibit) this $E \times B$ velocity. Many H-mode models have been proposed so far which involve very different mechanisms (e.g. $E \times B$ spin-up by Reynolds stress [5], ion orbit loss [6] poloidally asymmetric particle transport [7]). Models based on electron and ion dynamics generally allow the threshold for $E \times B$ flow buildup to be expressed in dimensionless parameters describing the plasma and the magnetic field shear, e.g., $\rho*$, $\nu*$, β and q or combinations thereof. In contrast, if strong interaction with neutral particles affects the momentum balance, one expects different parameters, such as mean free path lengths for charge exchange reactions, to become important. An important experimental test is to measure the dimensionless parameters at the plasma edge at conditions near the H-mode transition in machines of different dimensions.

The experimental approach taken here is an inter-machine comparison between JET and ASDEX Upgrade where it is attempted to match the dimensionless edge parameters by adjustment of edge density n, magnetic field B and plasma current I in each machine according to the Kadomtsev constraints for dimensionally similar discharges [8]. The heating power is ramped up slowly until the L- to H-transition occurs. The edge temperature T is measured at the time of the L-H transition and cannot be chosen independently. Since only three independent parameters (B, I, n) can be varied, a series of experiments is carried out where q and two out of the three parameters $\rho*$, $\nu*$, and β are attempted to be made identical at a time and the remaining parameter is measured. The matching conditions for the toroidal field B and the local edge density n are:

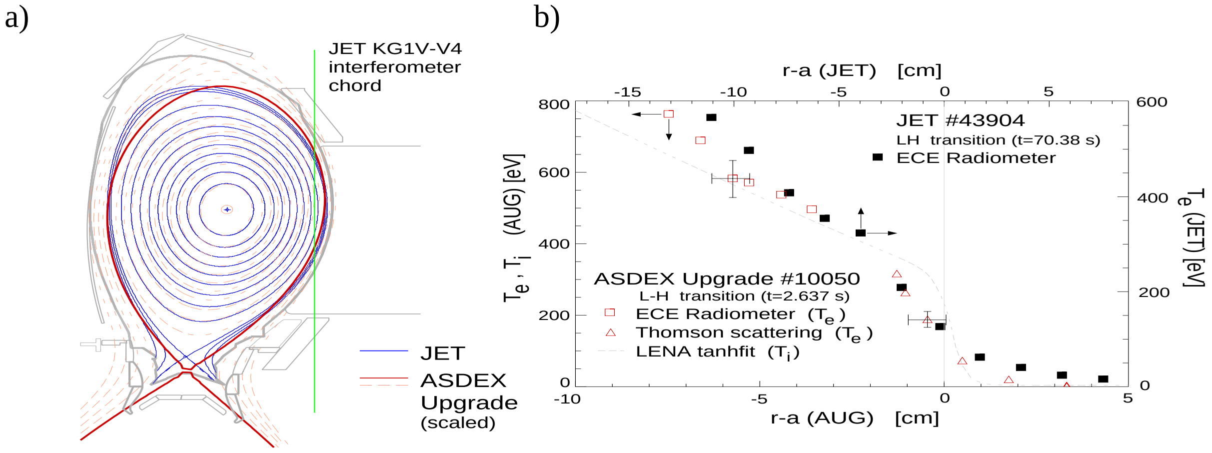

Figure 1. a) Plasma shape and b) edge temperature profiles at the L-H transition in JET and ASDEX Upgrade. Distances are scaled according to minor radii a, the temperature axis is scaled with $a^{-1/2}$ according to similarity constraints (see text)

$$\begin{array}{lll} \beta,\nu^* \;\; \mathrm{matching:} & B_a/B_j = (\frac{R_j}{R_a})^{1/2}(\frac{T_a}{T_j})^{3/2} & n_a/n_j = \frac{R_j}{R_a}(\frac{T_a}{T_j})^2 \\ \rho^*,\beta \;\; \mathrm{matching:} & B_a/B_j = \frac{R_j}{R_a}(\frac{T_a}{T_j})^{1/2} & n_a/n_j = (\frac{R_j}{R_a})^2 \\ \rho^*,\nu^* \;\; \mathrm{matching:} & B_a/B_j = \frac{R_j}{R_a}(\frac{T_a}{T_j})^{1/2} & n_a/n_j = \frac{R_j}{R_a}(\frac{T_a}{T_j})^2 \end{array} \qquad (1)$$

where R is the major radius and indices a and j denote parameters of ASDEX Upgrade and JET, respectively.

2. Experimental results

Comparison discharges in JET and ASDEX Upgrade have been performed in lower single-null geometry using deuterium neutral beam heating into a deuterium plasma. In order to exclude possible shape effects, the separatrix shape of ASDEX Upgrade is closely emulated in JET (Figure 1a). The experiments are carried out at two different values of the edge safety factor q. No attempt is made to match the core heating power deposition profile and only edge profiles are compared. For inter-machine comparison, data must be taken at a fixed fraction of the minor radius. We use electron temperatures at 95 % poloidal flux, corresponding to 1.6 cm and 3 cm inside the separatrix for the equilibria used in ASDEX Upgrade and JET, respectively. The uncertainty of the radial separatrix position in JET by magnetic equilibrium reconstruction is about 2 cm, therefore the separatrix radius is adjusted such that the edge electron temperature is compatible with parallel heat conduction to the divertor, which fixes the separatrix temperature to about 100 eV. Figure 1b) shows edge temperature profiles measured just before the L-H transition in ASDEX Upgrade and in JET for a pair of similar discharges. In the figure, the radial and temperature axes for ASDEX Upgrade and JET profiles are scaled with a and $a^{-1/2}$, respectively, according to the Kadomtsev constraints. One sees that within 5 cm just inside the separatrix, T_e profiles match within experimental errors and show only a slight difference inside this region. For the present comparison, only electron temperatures are used because they can be measured routinely at the plasma edge with sufficient accuracy and spatial resolution. Ion temperature measurements by Low Energy Neutral particle Analysis (LENA) from the edge of ASDEX Upgrade (dashed curve in Figure 1b) show that the edge pedestal ion temperature is close to the electron temperature, which is a general finding at medium and high edge density. Nevertheless, using a tanh fit function [9] to obtain T_i from LENA spectra, the width of the edge ion temperature gradient region seems to be smaller and the ion temperature gradient larger than the respective parameters of the electron temperature profile. The auxiliary heating power at the time of the transition for the discharge pair shown is $P_{NBI} = 3$ MW in JET and 3.5 MW in ASDEX Upgrade, equivalent to $P_{heat} \propto R^{-0.3}$. This is a somewhat weaker dependence than $P_{heat} \propto R^{-3/4}$ expected for a dimensionally correct confinement scaling [10] but is much stronger than a scaling $P_{heat} \propto R$, required for divertor similarity (replacing identity of β with identity of edge or divertor temperature, [11]). However, one has to note that in the present study it was not attempted to achieve identical edge temperatures at the H-mode transition.

The edge density is measured on ASDEX Upgrade by the Li beam method, complemented inside the Li beam penetration range by a deconvolution of the DCN laser interferometer chords with prescribed edge profile. At JET, as no similar measurement is available, the line-averaged density from the edge interferometer cord (KG1V-V4 sightline, tangential at about 85 % poloidal flux) is used. Line averaged densities along a similar sightline are computed from ASDEX Upgrade profiles in order to make a comparison possible. Hence due to diagnostics shortcomings, the data quoted subsequently is not strictly measured locally, but rather represents a combination of local edge temperatures with peripheral line averaged densities.

Exp.	discharge no.	q_{95}	B_t (T)	I_p (MA)	$\overline{n}_{e,edge}$ (10^{19} m^{-3})	$T_{e,95}$ (eV)	ρ^* (10^{-4})	β (10^{-4})	ν^*
JET	$43896^\diamond$	2.9	1.66	1.65	1.1	230	9.1	3.7	1.3
AUG	10250	3.4	3	1.4	2.7	280	9.8	3.4	1.5
AUG	10217	3.4	3	1.4	3.2	250	9.2	3.6	2.2
AUG	10234	3.4	3	1.4	4.5	200	8.8	4.6	3.4
JET	$43899^\diamond$	3.1	2.15	1.95	1.8	300	8.0	4.8	1.4
JET	43907	2.93	2.02	1.97	1.6	270	8.1	4.3	1.5
JET	$43897^\diamond$	3.0	1.76	1.75	1.3	265	9.2	4.4	1.2
JET	$43904^\diamond$	4	1.76	1.26	1.24	280	9.5	4.5	1.4
AUG	10050	4	3	1.2	3.4	350	10.8	5.1	1.4
JET	$43905^\diamond$	4	2.15	1.57	1.9	280	7.7	4.6	2.1
AUG	10249	4	3	1.2	3.8	280	9.8	4.7	2.5

$^\diamond$ASDEX Upgrade shape emulated

Table 1. Best matching discharges in JET ($R = 2.9$ m) and ASDEX Upgrade (AUG, $R = 1.65$ m). Edge parameters are measured just before the L-H transition

In JET 13 discharges were performed, followed by 22 discharges in ASDEX Upgrade (AUG) with an iteration of the line density in order to match edge parameters. The comparison is carried out at two different values of $q_{95} = 2.9 \ldots 3.4$ and $q_{95} = 4$. Due to limitations in plasma current at high B_t, the value of $q_{95} = 3$ in JET could not be matched in ASDEX Upgrade. Table 1 summarizes the results for the closest matching discharges. It is found that β and ρ^* can be matched simultaneously within the experimental error which is dominated by the edge temperature uncertainty of $\Delta T \approx 10\%$ and the uncertainty of the separatrix radius (ASDEX Upgrade: ± 5 mm), while ν^* varies in one machine by 50 % or more (AUG pulses 10250/10217, 10050/10249). For all cases with matching ν^* and β, also ρ is found to differ only little (worst case difference 27% in JET 43905/AUG 10249). We conclude that β and ρ^* are critical parameters for the transition whereas the threshold depends at most weakly on ν^*.

A similar observation has been made by parameter variation in ASDEX Upgrade [3]. It should be noted that at the transition ρ^* is similar in JET and ASDEX Upgrade and varies only little in each machine.

Variation of q_{95} results in similar values of ρ^* and β at the transition, indicating a weak q dependence of the local edge parameter threshold. Plasma shape variation in JET (pulse 43899, AUG shape, vs. 43907, "JET shape") with constant q and I_p (i.e. different B_t) leads to a variation in dimensional edge parameters, but the H-mode transition can be obtained at the same dimensionless parameters.

3. Summary and conclusions

The dimensional comparison between JET and ASDEX Upgrade shows that the L-H transition is obtained in both experiments whenever β, ρ^* and ν^* at the plasma edge are matched. The value of ν^* seems to be not very critical. This result is compatible with H-mode physics models entirely based on Maxwell and Fokker-Planck equations and not invoking, e.g., the atomic physics of main or impurity neutrals. It appears that variations of the poloidal plasma cross section, safety factor q, and edge collisionality ν^* have no effect on threshold values of β and ρ^*. It is difficult to see how this result could be explained by H-mode theories based on ion orbit loss currents, which crucially depend on the geometry of loss orbits and the probability of scattering into and out of loss orbits.

However, one must be careful when generalizing this result. First, at low edge densities and near the H-mode threshold, the scrape-off layer may become increasingly transparent to neutrals which can affect the poloidal and toroidal rotation by neutral friction. An indication of this effect might be the observed increase of H-mode power threshold power at low edge density in several experiments (e.g. [12,13]). Second, the overlap of JET and ASDEX Upgrade in dimensionless parameter space is restricted to medium edge collisionality. At higher collisionality, there may indeed be a collisionality boundary which affects radial transport as observed near the H-mode density limit in ASDEX Upgrade [14] and indicated by numerical turbulence simulations [15].

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