Edge Ion Temperature Profiles in L- and H-Mode Discharges of ASDEX

O. P. Heinrich, R. Schneider, H. Verbeek, D. Reiter* and the ASDEX-Team
Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany
Institut für Plasmaphysik, Forschungszentrum Jülich, EURATOM-KFA Association, D-52425 Jülich, Germany

Introduction

A common, and widely believed unalterable, feature of the H-mode is the formation of a steep gradient region of the radial electric field $\boldsymbol{E}_r$ at the transport barrier of the plasma edge. $\boldsymbol{E}_r$ in turn is connected with the ion pressure gradient ∇p_i and the rotation velocity through the radial force balance equation. Although it is not yet clear what the triggering mechanism for the L-H transition is, the ion temperature respectively its gradient is seen to play a crucial role in the feedback loop of the radial force balance. On ASDEX edge ion temperature profiles have been made accessible with the help of low energy neutral fluxes in an analysis after shutdown. Therefore these profiles are now available for ASDEX L- and H-mode plasmas.

Experimental

Neutral deuterium fluxes in the energy range 15 to 700 eV/amu were measured with the LENA diagnostic [1] at ASDEX with a time resolution of 50 to 100 ms. This neutral (CX) spectrum, which originated mainly from the plasma edge, is simulated with the help of the Monte-Carlo neutral particle code EIRENE, including all available data about the plasma and the geometry near the line of sight. From the fit of the simulated to the experimental spectrum an edge ion temperature (T_i) profile of the main plasma species from the separatrix to about 10 cm inside (in the case of ASDEX) can be deduced [2]. This method has been further developed and is now also used on ASDEX-Upgrade [3].

It is known from spectroscopic measurements on ASDEX and other experiments, that the edge T_i increases at the L-H transition. A look at the LENA CX spectra during a H-mode discharge also shows a significant change of shape in different phases. This can be clearly seen in the upper picture of Fig. 1.1: starting from the ohmic phase over the L- to the ELM-free H*-phase the slope of the high energy part increases indicating already a higher T_i. At the same time a sharp bend at low energies (100 eV) occurs. The lower picture compares the corresponding ion and electron temperature (T_e) profiles and the T_i profile of a comparable L-mode discharge, i.e. where no L-H transition took place. A significant difference between L- and H-phases is found: in the H-Mode, the absolute T_i value and the gradient is much higher than in the L-Mode. The temperature in the H-mode increases from around 50 eV at the separatrix to more than 400 eV within 1-2 cm inside the separatrix, which is even much higher than the electron temperature. The radial range of the steep T_i gradient becomes clearer in Fig. 1.2, where the gradient at the separatrix and some cm inside are compared during the H-mode discharge. From this the transport barrier can be located in a narrow

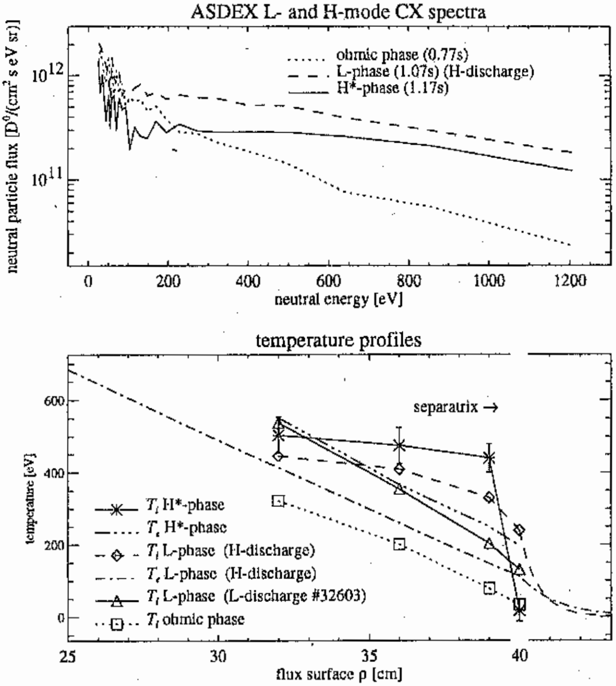

Fig. 1.1: *Low energy neutral spectra and corresponding* T_i *and* T_e *profiles in L- and H-phases. If not indicated, the data refer to discharge #33308.*

range of 1-2 cm at the separatrix, which is in agreement with similar observations on ∇T_i and $\boldsymbol{E}_r$ in other machines.

These T_i profiles correct earlier interpretations of the L-H transition at ASDEX [4], where, due to the lack of appropriate edge T_i measurements, the main influence on the transition has been attributed to the edge electron temperature. The T_i profiles in Fig. 1.1 also reveal that already the L-phase prior to the H-transition has a higher edge T_i than in a pure L-Mode discharge. This supports the major role of the ion temperature or its gradient in the L-H transition.

Discussion

One possible interpretation of the L-H transition follows from the obviously different LENA T_i edge profiles: a minimal T_i at the edge seems to be a prerequisite of the H-mode. Therefore

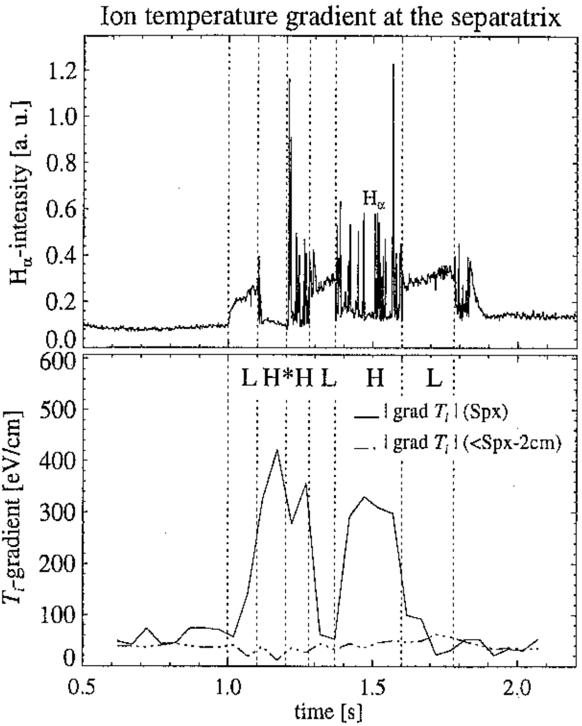

Fig. 1.2: *Ion temperature gradient at and inside the separatrix (Spx) with the H_α-intensity for the identification of the phases in the H-mode discharge #33308.*

we have used the T_i edge profiles as an input parameter of the ion orbit loss model of Shaing and Crume [5]. This assumes the loss of collisionless ions across the separatrix as the trigger, which in turn induce the radial electric field. The critical parameter is the ion collisionality ν_{*i}, which forces the L-H transition at values $\nu_{*i} \lesssim 1$. Table 1.1 lists the effective collisionality

$$\nu_{*i}^{eff} = \nu_{*i}\left(\frac{Z_{eff}\, n_e}{Z_i^2\, n_i}\right) , \tag{1.1}$$

where the impurities are taken into account by a Z_{eff} [6], about one poloidal gyroradius inside the separatrix for the L-and H-phases. A typical value of $Z_{eff} = 4$ with an impurity charge of 7 has been assumed. The phenomenological explanation for the pure L-mode discharge is found probably in the double null (DN) configuration (vertical shift $z = 0$), which has a higher power threshold than the single null (SN). It is clearly seen, that in the L-mode #32603 the high value of $\nu_{*i}^{eff} \approx 4$ prevents the L-H transition, whereas in #33308 the

discharge	time [s]	mode	P_{NI} [MW]	$\bar{n}_e$ [cm^{-3}]	$T_{i,39}$ [eV]	$\rho_{\Theta,i}$ [cm]	ν_{*i}^{eff}
#32603 (DN $z = 0\ cm$)	1,46	L	2,5	$3 \cdot 10^{13}$	180	1,2	3,9 $\pm 1,2$
#33308 (SN $z = 1\ cm$)	1,07	L	2	$2,8 \cdot 10^{13}$	350	1,9	0,7 $\pm 0,2$
	1,17	H*			450	2,1	0,8 $\pm 0,25$
	1,47	H			380	2,0	0,8 $\pm 0,25$
#33301 (SN $z = 2\ cm$)	1,07	H	2	$3 \cdot 10^{13}$	540	2,0	0,2 $\pm 0,05$

Table 1.1: *Effective collisionality ν_{*i}^{eff} and poloidal gyroradius $\rho_{\Theta,i}$ of the ions for different L- and H-phases. ν_{*i}^{eff} and $\rho_{\Theta,i}$ are calculated 1 cm inside ($\rho = 39$ cm) the separatrix. The errors in ν_{*i}^{eff} follow from the ±30% uncertainty in electron density at the edge.*

$\nu_{*i}^{eff} = 0.7$ is sufficient for the transition and consequently no change in the H-mode is seen. The long H-phase in #33301 with regular ELMs has due to the low edge density an even smaller ν_{*i}^{eff}. Therefore the L-H transition with respect to our T_i observations is in good agreement with the prediction by the ion orbit loss modell.

Conclusions

With the help of the low energy neutral fluxes it has been possible to obtain T_i edge profiles in L- and H-mode plasmas for the first time in ASDEX, the machine, which first discovered the H-mode. High T_i with a large gradient at the separatrix are found in the H-mode, in concurrence with T_i measurements on other experiments. The comparison with the ion orbit loss model of Shaing is in good agreement, however it offers no direct evidence for this explanation.

References

[1] H. Verbeek (1986), Journal of Physics E: Scientific Instruments, 19, 964-970

[2] O. Heinrich (1995), report of MPI für Plasmaphysik, IPP III/207

[3] J. Stober et al., this conference

[4] ASDEX Team (1989), Nuclear Fusion, 29 (11), 1959-2040

[5] Shaing and Crume (1989), Phys. Rev. Lett., 63 (21), 2369-2372

[6] M. Mori et al. (1994), Plasma Phys. Contr. Fus., **36**, A39-A49