Isotope Dependence of Ohmic Discharge Parameters of Asdex

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Abstract

This paper summarizes results of regression analyses of various discharge parameters of ohmic hydrogen and deuterium plasmas of Asdex. Special emphasis is put on the dependence on the ion mass A_i. Besides the confinement time the highest sensitivity on A_i is shown by the central electron temperature, the sawtooth repetition time, and the edge electron density and temperature. The possible role of the electron density profile shape on the confinement and its A_i -dependence is discussed in detail.

Introduction: The motivation for studying the isotope effect on confinement comes (1) from the observation that τ_E improves with A_i and that A_i is the only scaling parameter observed in all confinement regimes of Asdex / 1 / and (2) from the fact that theory does not yet explain it. A_i is a scaling parameter in regimes which are dominated by electron transport (like the OH - linear regime or the L - mode) , in ion transport dominated regimes (like the saturated SOC regime), in degraded or improved regimes (L - or H - modes) at low or high β, or at low or high collisionality.

Experimental details: Two sets of ohmic discharges were carried out on Asdex - one in deuterium the other in hydrogen - for the single purpose of studying the dependence of various ohmic plasma parameters on the external parameters I_p, B_t, $\overline{n}_e$, Z_{eff}, and A_i. (Z_{eff} is regarded as an external parameter though it was not varied externally.) During a discharge the line density was kept constant but - to reduce the number of discharges - the current was increased in steps. Up to three current plateaus were possible in a discharge. The length of each plateau was sufficient for the loop voltage to reach steady state. Single plateau discharges were carried out for control purposes. A total of 244 (120) data points were collected for D_2 (H_2). The external parameters were varied in the following ranges: 150 kA $\leq I_p \leq$ 440 kA, 1.9 T $\leq B_t \leq$ 2.45 T, ($2.3 \leq q_a \leq 8.4$), 0.8×10^{13} cm^{-3} $\leq \overline{n}_e \leq 5.5\times10^{13}$ cm^{-3}. For control of the plasma impurities and to remain in the SOC regime also with deuterium operation, the vessel walls were carbonized; oxygen was removed from the discharge by Ti - gettering in the outer divertor chambers. β_p was measured with equilibrium coils (Λ+1) and from a well compensated diamagnetic loop (β_p^{dia}). $l_i / 2$, necessary to determine β_p^{equ} ($= \Lambda + 1 - l_i / 2$) was obtained from a statistical analysis of the ohmic T_e - profiles of Asdex. For D_2, $l_i = 0.7 + 0.45 \times \ln(q_a)$. The electron energy content β_p^e was determined from the quasi-stationary Thomson system on Asdex; the kinetic β_p^{kin} was determined from β_p^e and the central ion temperature T_{io} (passive and active charge exchange). Z_{eff} is measured via Bremsstrahlungsradiation in the infra-red. $Z = 6$ is assumed in the calculation of the proton density n_i. The three β_p - values give an average value β_p^{av} which is used in the determination of τ_E and the total energy content E_o. A fit to the experimental l_i ($= 2 \times (\Lambda + 1 - \beta_p^{av})$) - values gives : $l_i = 0.75 + 0.46 \times \ln(q_a)$ - in excellent agreement with the l_i- result from the T_e - profile analysis.

Results: The results of the regression analysis for the global parameters is given in table I for the linear (1a) and the saturated (1b) confinement regime. Because of the potential importance of the edge parameters for the isotope effect of confinement, edge parameters are anaysed in great detail. The results are summarized in table 2 for the SOC regime only.

Discussion: T_{eo}, the sawtooth repetition time τ_{st}, and the edge electron density $n_e(a)$ show the most sensitive dependence on A_i. The dependence of T_{eo} on A_i does not seem to be the corollary of the A_i scaling of τ_{st}. Also T_e calculated at the respective $q = 1$ surface (the pivot point of the sawtooth oscillation) increases with A_i. τ_E depends in both regimes an A_i. In the linear confinement regime, the A_i dependence is weaker than in the SOC regime. However, at low density the species composition is less controlled. It is interesting to note that the ion mass affects the electron transport as seen from the A_i dependence of τ_E in the linear regime or of the electron temperature T_e or energy content E_e. The moderate A_i scaling of T_e affects both the energy content E_o and the ohmic heating power P_{OH} and leads to the strong dependence of τ_E on A_i. In the SOC regime, A_i is the only scaling parameter of τ_E. The strong dependence of the edge electron density on A_i is shown independently by the Thomson and the Li-beam results. This dependence exists obviously only at the plasma edge and quickly disappears further in. The density fall-off length does not depend on A_i; obviously the ion mass just cancels in the two competing movements - parallel drift and perpedicular diffusion - which determine the radial extent of the scrape - off - layer. A possible A_i dependence of the edge electron temperature is not well recovered. Nevertheless, the clear increase of the mean energy $<E_{cx}>$ of the low energy charge exchange flux indicates that the edge ion temperature increases. The analysis of the A_i scaling of various plasma parameters does not reveal a clear origin for the dependence of the heat transport on the ion mass. Nevertheless, an interesting relation between edge and central parameters is observed.

Further results of the regression analysis are the close to linear relation between plasma current and the energy content (electrons and total) or the ohmic heating power, respectively. In the τ_E determination, the current as the leading scaling parameter just cancels and τ_E depends on secondary paramters only. This is clearly shown by the regression coefficients. $R^2 = 0.95$ and $= 0.93$ for E_o and P_{OH}, respectively, but drops to $R^2 = 0.73$ in the τ_E regression (saturated regime).

The linear current scaling of E_o and P_{OH} applies both to plasmas in the linear and saturated regime. For a q_a scaling of τ_E - as frequently observed in the linear regime - the linear current scaling of E_o has to be overcompensated by P_{OH}. Instead of a q_a scaling of τ_E in the linear regime we observe a Z_{eff} dependence (using the independently determined Bremsstrahlungs - Z_{eff}). In the linear regime, Z_{eff} varies strongly with $\overline{n_e}$ and I_p. This strong Z_{eff} variation enters P_{OH} and thereby τ_E. On the other hand Z_{eff} decreases strongly with decreasing I_p possibly introducing a fictitious q_a scaling in τ_E. If we substitute the Bremsstrahlungs - Z_{eff} by the Spitzer - Z_{eff} which, however, is no independently measured quantity we indeed obtain a slight q_a dependence of τ_E in the linear regime ($\tau_E \propto q_a{}^{0.25}$).

Z_{eff} does not show a dependence on A_i which is not in agreement with previous experience but which might be typical for carbonized wall conditions.

A strong similarity in the scaling of τ_{st} and τ_E is observed.

The hypothesis that the diffusivity itself does not depend on A_i but the onset condition of an instability does, has been studied for the density profile in a separate investigation. Such a condition exists for the η_i mode which is expected to cause the ohmic τ_E to saturate. A low q_a value was chosen ($q_a = 2.5$) to fix the n_e-profile as much as possible by the large $q = 1$ radius (the ratio in the density profile shape parameter is $n_{eo} / < n_e > \propto A_i{}^{-0.017}$). Furthermore, $\overline{n_e}$ was as high as possible (3% below the density limit; $M = 5.5$) to reduce the electron contribution to the heat conduction as much as possible. Nevertheless, the same A_i dependence of the various parameters as at lower density and higher q_a was observed. ($P_{OH} \propto A_i{}^{-0.23}$, $E_o \propto A_i{}^{0.34}$, $E_e \propto A_i{}^{0.2}$, $\tau_E \propto A_i{}^{0.58}$, $T_{eo} \propto A_i{}^{0.2}$, $T_{eo} / <T_e> \propto A_i{}^{0.12}$). These results indicate that the isotope effect is not caused by the impact of the density profile on transport (because in the chosen case it is the same for D_2 and H_2) and that it exists also under the extreme condition of maximal ion heat transport.

/ 1 / H.D. Murmann, F. Wagner et al. Proc. 15.th Europ. Conf. Contr. Fusion and Plasma Heating, Dubrovnik, 1988, Part 1, p 3.

table 1a

	const	Ip		Bt		ne		Zeff		Ai		R
Poh	9.93E-04	1.02	0.036	-0.45	0.068	0.26	0.046	0.24	0.046	-0.09	0.026	0.96
E o	2.43E-02	1.12	0.038	-0.18	0.072	0.56	0.048	-0.14	0.049	0.21	0.027	0.97
E e	1.69E-02	1.12	0.037	0.00	0.000	0.38	0.047	-0.11	0.046	0.18	0.026	0.97
τ E	3.73E+01	0.00	0.000	0.27	0.115	0.39	0.058	-0.28	0.055	0.31	0.043	0.80
T eo	4.13E+01	0.49	0.046	0.73	0.088	-0.36	0.058	0.14	0.058	0.24	0.032	0.88
< T e >	6.14E+00	0.77	0.043	0.21	0.083	-0.37	0.055	0.12	0.055	0.17	0.031	0.92
Teo/<Te>	6.83E+00	-0.27	0.041	0.51	0.110	0.00	0.000	0.00	0.000	0.00	0.000	0.54
n eo	4.02E+00	-0.14	0.027	0.00	0.000	0.85	0.035	-0.25	0.035	0.02	0.000	0.97
< n e >	2.31E-01	0.33	0.040	-0.17	0.077	0.68	0.051	-0.25	0.051	-0.12	0.029	0.93
neo/<ne>	1.49E+01	-0.46	0.028	0.24	0.073	0.16	0.028	0.00	0.000	0.20	0.027	0.83
T io	5.75E+01	0.40	0.026	0.36	0.067	0.10	0.026	0.00	0.000	0.00	0.000	0.81
τ SZ	5.64E+01	-0.43	0.079	0.00	0.000	0.81	0.064	0.00	0.000	0.25	0.056	0.83
Z eff	2.03E-01	0.56	0.043	0.00	0.000	-0.82	0.042			0.00	0.000	0.86

table 1b

	const	Ip		Bt		ne		Zeff		Ai		R
Poh	7.93E-04	1.09	0.034	-0.40	0.061	0.24	0.039	0.00	0.000	-0.22	0.027	0.96
E o	5.74E-02	0.99	0.034	-0.13	0.063	0.43	0.048	-0.16	0.047	0.28	0.026	0.97
E e	1.40E-02	1.14	0.031	0.00	0.000	0.35	0.038	0.00	0.000	0.27	0.026	0.97
τ E	5.76E+01	0.00	0.000	0.18	0.075	0.00	0.000	-0.27	0.052	0.50	0.032	0.86
T eo	1.53E+02	0.31	0.030	0.79	0.057	-0.63	0.037	0.00	0.000	0.36	0.025	0.94
< T e >	5.92E+00	0.84	0.050	0.19	0.093	-0.62	0.061	0.00	0.000	0.19	0.041	0.88
Teo/<Te>	5.62E+01	-0.67	0.039	0.66	0.074	0.00	0.000	0.00	0.000	0.11	0.033	0.87
n eo	4.66E+00	-0.21	0.028	0.14	0.055	0.84	0.036	-0.11	0.036	0.10	0.023	0.93
< n e >	9.68E-02	0.42	0.030	-0.26	0.058	1.01	0.038	-0.10	0.038	-0.12	0.024	0.97
neo/<ne>	3.73E+01	-0.59	0.027	0.37	0.048	-0.17	0.030	0.00	0.000	0.25	0.021	0.94
T io	1.13E+02	0.29	0.051	0.55	0.095	-0.28	0.067	0.00	0.000	0.16	0.044	0.72
τ SZ	1.57E+01	0.00	0.000	0.00	0.000	0.00	0.000	-0.61	0.085	0.54	0.049	0.82

Given are the results of the regression analysis in the form const × Ip × Bt^{β} .... .The column following the power gives its standard error; R is the regression coefficient. Table 1a shows the results for the linear range ($n_e \leq 2.5 \times 10^{13}$ cm^{-3}), table 1b for the saturation regime.

table 2

	const	Ip		Bt		ne		Zeff ·		Ai		R
ne 39.4	2.26E-02	0.44	0.054	0.00	0.000	1.32	0.048	0.00	0.000	-0.81	0.043	0.94
ne 35.3	6.10E-03	0.73	0.043	-0.18	0.072	1.21	0.042	0.00	0.000	-0.13	0.038	0.95
ne 31.2	4.45E-03	0.89	0.048	-0.44	0.077	1.12	0.049	-0.09	0.022	0.00	0.000	0.95
ne (a)	8.03E-04	1.14	0.060	-0.32	0.129	0.67	0.081	-0.12	0.035	-0.85	0.062	0.90
Te 39.4	1.25E-01	1.27	0.062	-0.37	0.086	-0.74	0.051	-0.09	0.024	0.35	0.044	0.90
Te 35.3	6.86E-02	1.61	0.053	-0.40	0.086	-0.58	0.052	-0.06	0.024	-0.53	0.043	0.95
Te 31.2	1.22E-01	1.56	0.044	-0.43	0.074	-0.58	0.046	-0.06	0.021	-0.21	0.038	0.95
< E cx >	3.62E+00	1.09	0.047	-0.96	0.095	-1.30	0.077	-0.07	0.028	0.89	0.046	0.94
λ	1.78E+02	-0.97	0.055	0.93	0.115	0.34	0.075	0.08	0.032	0.00	0.000	0.82

ne 39.4, Te 39.4 are density and temperature as measured by Thomsonscattering at r = 39.4 cm; ne(a) is the separatrix density as measured by Li-beam; <Ecx> is the average charge exchange energy as measured by time-of-flight; λ is the s.o.l. density fall-off length.