EVALUATION OF PARTICLE TRANSPORT FROM GASOSCILLATION EXPERIMENTS IN OHMIC AND NEUTRAL BEAM HEATED ASDEX PLASMAS

O. Gehre, K.W. Gentle*, B. Richards* (*University of Texas),
A. Eberhagen, J. Gernhardt, O. Vollmer

Max-Planck-Institut für Plasmaphysik
EURATOM Association, Garching, FRG

INTRODUCTION:

Gasoscillation experiments were performed at the divertor tokamak ASDEX to evaluate particle transport under different discharge conditions. These experiments followed a method described in /1/. In order to induce density perturbations in the plasma, the external gas feed was modulated with a sinusoidal wave form of chosen frequency (5, 10 or 20 Hz) and the density modulation at the four horizontal chords (r = 0, 10, 21, and 30 cm) of the ASDEX HCN-laser interferometer was observed. A typical result of this measurement is shown in Fig. 1.

The precision of the technique arises from the extraction of the complex Fourier amplitudes from the full wave form over several periods. The amplitude and phase have an accuracy typical of a signal averaged over several hundred milliseconds.

DETAILS OF THE ANALYSIS

The transport parameters are determined by picking functional forms for the diffusion coefficient $D(r)$ and the inward convection velocity $V(r)$, which is a major improvement to /1/, where only constant D and V were considered. The particle transport equation is solved and the chord integrals are performed, adjusting the free parameters to give the best least-squares fit to the experimental points. Conceptually, the system can be idealized as a boundary-value problem in which the outermost channel gives the edge density and the inner channels are computed from it, although the actual analysis is more complete with a model for the source layer and plasma beyond the separatrix radius. Furthermore, the experimental data are normalized to the centre channel for comparison with the calculations because the centre channel is most accurate, thus propagating the minimum error.

Mathematically, there are three complex numbers (amplitude and phase of the density perturbation) to be fitted and generally three free parameters (two in the density and one in V) to be adjusted for each fit type.

The allowed functional forms for D and V are tabulated below; they may be combined in various ways.

D	**V**
D	$V(r/a)$
$D(1+b(r/a))$	$V((r/a)^2)$
$D(1+b(r/a)^2)$	$V((r/a)^3)$
$D(r<b)$, $D(r>b)$	$V((r/a)(1-r/a))$

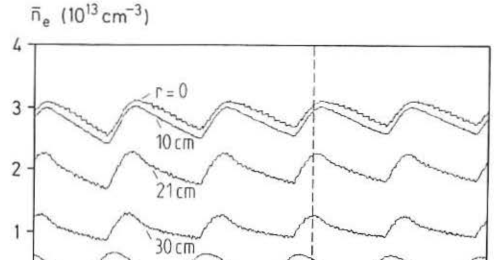

Fig. 1: Density modulation on four chords of the HCN-laser interferometer, induced by sinusoidal modulation of the gas valve (GASV) during a plateau phase of an ohmic discharge. The broken line marks the phase lag between the outer and central channels.

For each set of experimental data and each choice of functional forms, a fitting program will find the two or three free constants. For the two-step D, there is also the radius b at which the step occurs. All solutions are strongly constrained by the transport equation and chord integration.

No choice of free parameters will be able to fit random numbers for the experimental data, similarly, even infinite freedom of D(r) could not provide acceptable fits if V = 0 is imposed.

Questions of accuracy, uniqueness, and robustness must be answered semi-empirically. A measurement of the accuracy of the inferences may be obtained by measuring values of the amplitude and phase in different but apparently identical shots, or by repeating the measurements at different times in a long plateau or at different modulation frequencies. Comparison of the transport coefficients evaluated from several data sets of that kind provides one estimate of the accuracy of the coefficients, which can only be regarded as being determined to within the observed variation.

The quantitative evaluation of the error is based on the "SSQ", the sum of the squares of the differences between observed and computed complex amplitudes at the different radial positions. It determines the choices of functional form and values of the constants and the uniqueness of these choices. When this parameter is used, the coefficients for each data set and fit type are well determined: Convective velocities differing by 20% and diffusion coefficients differing by 10% produce distinctly poorer fits. However, values obtained for different modulation frequencies or shots at the same nominal plasma parameters often differ by more than that. A total error of perhaps 30% in V and 20% in D should be used in assigning transport coefficients to discharge conditions.

TRANSPORT RESULTS

The following discharge conditions were analyzed and the results are summarized in the table below. The functional dependences of the transport coefficients are those which fit the experimental data best. For the diffusion coefficient the most common one is a two-step D, having one D ($r<16$ cm) and another D ($r>16$ cm); the two values are listed in order, D always being larger towards the periphery.

Discharge type	I_p kA	$\bar{n}_e$ 10^{13} cm^{-3}	D m^2 s^{-1}	V m s^{-1}	n
ohmic, H^+	320	1 (carbon-ized)	2.00/4.60	61.0	3
ohmic, H^+	320	1.5 "	1.00/1.10	13.0	3
ohmic, H^+	320	2 "	0.70/9.6	54.0	3
ohmic, H^+	320	4 "	0.40/0.69	3.6	3
ohmic, H^+ →near dens.	320	5.2 "	0.34/0.50	6.6	3
ohmic, H^+ →limit	320	3.1	0.25/1.1	8.5	3
ohmic, H^+	320	1.4	2.00/2.42	48.0	3
ohmic, D^+	380	3.0	0.26/0.50	6.0	1
ohmic, D^+	380	4.2	0.10/0.30	3.0	1
Co-NI, $H^o \rightarrow D^+$ 0.65 MW	380	3.0	0.88/2.20	6.0	1
Ctr-NI, $H^o \rightarrow D^+$ 0.65 MW, with sawteeth	380	3.0	0.80/1.40	8.0	1
Co-NI, $H^o \rightarrow D^+$ 0.35 MW	380	4.2	0.30	3.7	1
Co-NI, $H^o \rightarrow D^+$ 0.67 MW	380	4.2	0.40	2.7	1
Co-NI, $H^o \rightarrow D^+$ 1.35 MW	380	4.2	0.40/0.70	3.0	1

Convective velocities of the form $V(r/a)^n$ are considered. The coefficient V and the exponent n are tabulated. The ohmic hydrogen discharges are best fit with a $(r/a)^3$ convective velocity, the results are less clear for deuterium. In cases where no clear distinction could be made, the simple (r/a) form is listed. With the application of injection power the (r/a) form is better than the other radial dependences for V.

CONCLUSIONS

The analysis of a density scan in hydrogen indicates a decrease in central D of almost an order of magnitude, when $\bar{n}_e$ is increased from 1 x $10^{13}cm^{-3}$ to ~2.3 x $10^{13}cm^{-3}$. In parallel the energy confinement time τ_e linearly increases in this range from ~20 msec to a saturation value of 53 msec (Fig. 2).

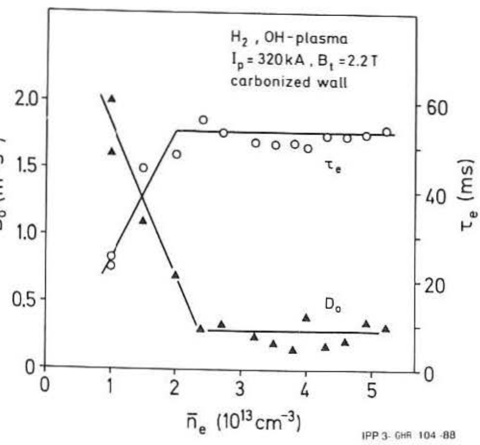

Fig. 2: Density scan in an ohmic hydrogen plasma, showing a pronounced decrease of the central diffusion coefficient D_o in the density range 1 to 2.3 x $10^{13}cm^{-3}$. During the same phase the energy confinement time τ_e linearly increases to its saturation value at higher densites.

The density profile peaks during this phase and the electron temperature monotonically drops, with a slight broadening of the profile. The linear increase in τ_e, found at low densities, seems to be closely connected to an improvement in central particle confinement.

The changes in transport near the density limit and with neutral injection are significant and characteristic of the phenomena.

The behaviour near the density limit can best be described as a decrease in D near the centre, which has the effect of improving the central particle confinement. The decrease is quite marked and the results may well be consistent with neo-classical D on axis. Comparable results have been found for TEXT and a similar behaviour is also known for impurities from ISX-B /2/. With carbonized wall the central D rather shows a flat response over a wide density range up to the density limit.

The effect of neutral injection is to increase the rate of diffusion in relation to the ohmic case for the same isotope. No significant effect on convection is to be seen but the effect on D is pronounced even at low powers and becomes stronger (up to a factor of three) with increasing NI-power. Only L-type cases with sawteeth during injection could be measured and for these no difference of co- versus counter-injection is found. Quantitatively, the increase in particle diffusivity seems to be even greater than the increase in thermal diffusivity associated with the L-mode.

/1/ K.W. Gentle, B. Richards and F. Waelbroeck, Plasma Physics, Vol. 29, No. 9, 1077 (1987)

/2/ R.C. Isler, et al., Phys. Rev. Lett. 55, 2413 (1985)