JET–CP(98)35

Transport of Light Impurities in the JET Tokamak

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INTRODUCTION

During the -94/95 JET Divertor Task Force Campaign impurities where injected into the plasma for divertor studies, and at the end of the -97 Campaign experiments for ITER Physics provided vast quantities of He in the vessel. These shots have been used for impurity transport studies using the Charge Exchange Spectroscopy diagnostics where simultaneous measurements of several ion species allow an iterative procedure for the beam attenuation calculation and their densities [1]. The impurities are detected from charge exchange between the fully ionised desired ions and the neutral beam injection, using several multi-chord Czerny-Turner spectrometers viewing the plasma in 13 radial points horizontally from the centre to the edge. Using measurements from the well understood Carbon VI spectra, ion temperatures and densities for other impurities have been derived. The diffusion as well as convection velocity was then investigated for He, N and Ne in H-mode steady state plasmas. Comparisons made with the Neoclassical transport theory verifies a clear correlation between the experimentally obtained diffusion coefficient D and the ion temperature T_i.

ANALYSIS

The experimentally obtained spectrum is analysed by fitting gaussians to all the spectral components using a non-linear least squares fitting routine. The Active Charge Exchange signals, ACX, are then interpreted as follows. The FWHM corresponds to the ion temperature as in equation 1, and the Doppler shift gives the plasma angular frequency as equation 2.

$$T_i(r) = \frac{m_i c^2}{8 ln 2} \frac{\lambda_{FWHM}^2(r)}{\lambda_0^2} \tag{1}$$

$$v(r) = c \frac{\lambda(r) - \lambda_0}{\lambda_0 \cos\alpha} \tag{2}$$

where λ_0 is the nominal wavelength, m_i is the mass of the impurity ion and α is the angle between the toroidal field and the viewing line. Assuming an initial estimation for the NBI attenuation and knowing the effective emission rate for the ACX signal, one may iterate the attenuation versus the various impurity densities until eq. 3 converges for all impurities n_i.

$$n_i = \frac{4\pi \int \phi_i(\lambda,\psi) d\lambda}{L(\psi) n_b(\psi) < \sigma_{i,cx} v >} \tag{3}$$

where n_b is the neutral beam density, ϕ is the photon flux of the fitted ACX signal, L is the ACX volume segment in each viewing line, ψ is the specific viewing line, v the velocity difference between the interacting particles and σ is the charge exchange cross-section. Since the profile and time/space gradients of n_i will be essential for deriving transport coefficients, a spline function is used to fit the density in both time and radius. The particle flux will then be derived from the time dependent density measurements as :

$$\Gamma_i(\rho,t) = -\frac{\partial}{\partial t}\int_V n_i * \rho / J_v dv + \frac{dN_{TOT}}{dt}\rho / V_{TOT} \tag{4}$$

where ρ is the r/a radius, J_v is the Jacobian volume element dv/dx, V_{TOT} is the total plasma volume, and the second term is the source term, which is only included if the time derivative of the total plasma impurity content, N_{TOT}, is non-zero before the gas puff injection. The diffusion coefficient and the convection velocity may then be given from the following straight line relation of the flow equation.

$$\frac{\Gamma_i(\rho,t)}{n_i} = -D\frac{\nabla n_i}{n_i} + v \tag{5}$$

The beam attenuation factor and CX cross-sections are known to an accuracy of 20%. However, only the statistical fluctuations of the photon flux are relevant for errors in D and v, which then implies a 5-20% accuracy. Sawtooth activity in the centre and sources from the walls are increasing the errors giving an optimal measurement in radius between ρ=0.3-0.6 with an error less than 10%.

ARGUMENTS FOR ANOMALOUS TRANSPORT

It can be shown that for most shots in JET an anomalous and collisional neo-classical theory may very well predict the consistently hollow profiles of light impurities, such as C, N and Ne, and also give an excellent information about the confinement, eq. 6.

$$n_i(\rho,t) = n_i(0,t) * \left[\left(\frac{n_D(\rho,t)}{n_D(0,t)}\right)^Z \left(\frac{T_i(\rho,t)}{T_i(0,t)}\right)^{-\frac{Z-1}{2}}\right]^{\frac{\beta}{1-\beta}} * Exp\left[-\frac{\alpha\rho^2}{2(1+\beta)}\right] \tag{6}$$

According to [2] $\beta = D_{coll}/D_{an}$ is usually about 0.1 but in improved confinement it may be greater than 1, and α is an anomalous peaking factor. Eq. 6 was fitted with a least squares procedure to CXRS measured Carbon densities for 155 shots leaving α and β free, and the fit results are seen in figure 1. With a comparison to the energy confinement time in figure 2 it is evident that β acts as a confinement indicator, whilst α was shown to be is independent of the confinement and equal to -1 ± 0.5.

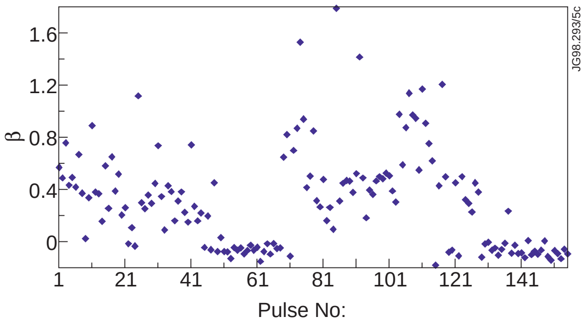

Figure 1: The fitted β values for 155 pulses between #40300- 40600.

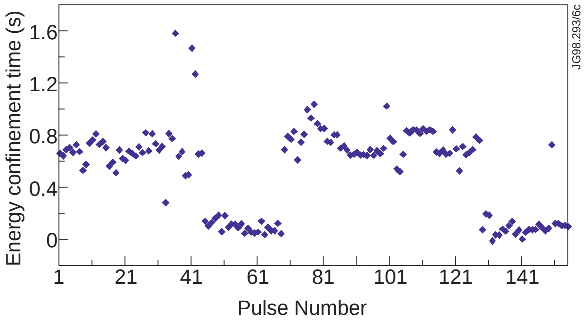

Figure 2: The energy confinement time τ_e .

RESULTS

If D is plotted in radius versus $1/T_i$ it is seen from fig 3 that this relation may be considered as a straight line for three very similar shots with N gas puff injection. In fig 4 it is shown that D for He is in the same order as the neo-classical prediction.

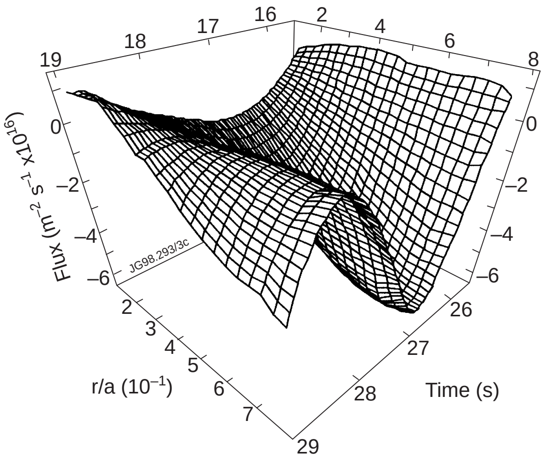

Figure 3: D vs $1/T_i$ for similar N-puff shots.

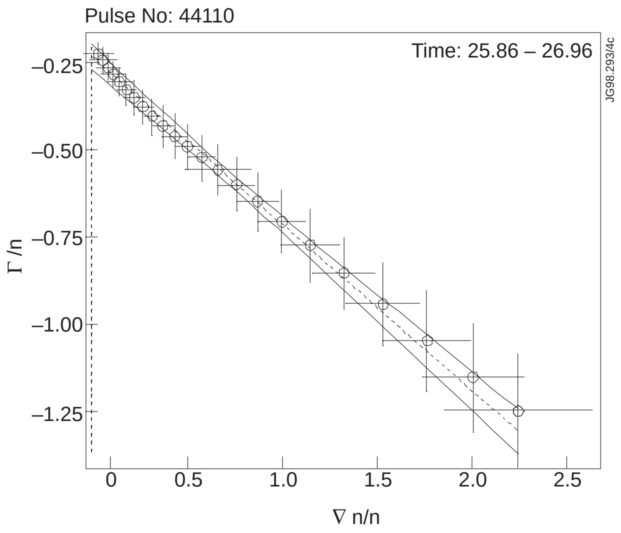

Figure 4: Experimentally measured D_{exp} and theoretically predicted D_{neo} from neo-classical theory.

REFERENCES

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