# CHARGE EXCHANGE RECOMBINATION SPECTROSCOPY OF ASDEX

P G Carolan, B P Duval*, A R Field+, S J Fielding, N C Hawkes and N J Peacock
Culham Laboratory, Abingdon OX14 3DB, UK
(Euratom/UKAEA Fusion Association)

G Fussman, G Janeschitz and F Söldner
Max Planck Institut für Plasmaphysik
Euratom Association D-8046 Garching, Germany

K H Behringer
JET Joint Undertaking, Abingdon, Oxon, OX14, 3EA UK

*Attached Clarendon Laboratory, University of Oxford.
+Attached Royal Holloway College, University of London.

## INTRODUCTION

In this paper we report on experiments and theoretical predictions relating to the spectroscopic observations of charge exchange (C/X) processes occurring between highly ionised impurities in the core of tokamak devices and high power beams of energetic neutral atoms. Our goals were to calibrate a Vacuum Ultraviolet (VUV) spectrometer and to show that fibre optically transmitted visible C/X radiation could be used to diagnose remotely tokamaks up to and including the crucial active phase. The diagnostic potential of these C/X lines has been emphasised in recent years, and has been recently reviewed (Fonck, 1984 and Isler, 1985). Our observations cover emission from hydrogenic ions in both the VUV and the visible, and we have developed a computer code to model the experimental data. This is based on calculated cross sections for charge exchange into the $[n,\ell]$ resolved quantum levels and the subsequent cascade radiative decay.

## VISIBLE SPECTROSCOPY

A 1m Czerny-Turner visible spectrometer viewed the plasma via a quartz window as indicated in Figure 1. This line of sight observes the interaction of one injector beam with half the plasma cross section - a region where the beam attenuation is small (<20%). For survey work it was operated with a PARC Optical Multichannel Analyser (OMA). For faster time measurements a spectrometer fitted with a photomultiplier detector sampled at 100 μs intervals was used. The spectrometer was equipped with gratings of 1200 and 2160 lines/mm, giving dispersions of 0.2Å/OMA-pixel and 0.05 (second order) Å/OMA pixel respectively.

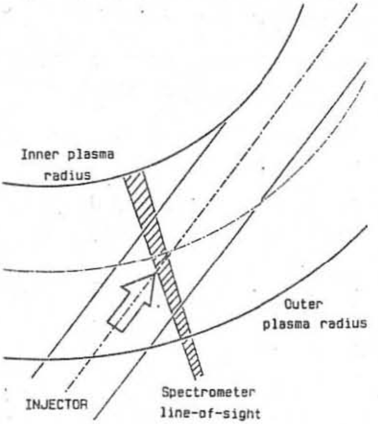

Fig.1 Arrangement of spectrometer line of sight intersecting injector beam.

C/X excited transitions were observed from Hydrogen-like Helium, Carbon, Oxygen, Fluorine, Sulphur and Chlorine. Several lines that bear the C/X signature of very rapid fall off of intensity with the end of injection are as yet unidentified. Figure 2 shows radiation from C, O, and S before and during injection. Of all the C/X lines only the C line was present before injection, but was much stronger during injection.

Least squares fitting a Gaussian to the C line gave ion temperatures of 250 eV before injection but during injection we measured ion temperatures of 750 eV from C and ~1.5 keV from O and S, the reason for this difference is not understood.

Observations of the Doppler shift of the C/X lines yielded bulk rotational velocities of 1-2 x $10^{+5}$ m/s in the co-injected (beam-driven) direction. In the case of the C line, its appearance before injection provided a convenient wavelength reference.

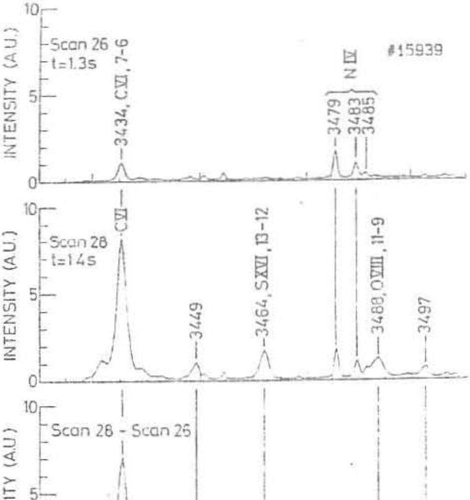

Fig.2 Visible spectrum 3400-3500Å, before injection (at 1.3s), during injection (at 1.4s) and the result of subtracting the spectrum at 1.3s from that at 1.4s (to remove all but the charge exchange features).

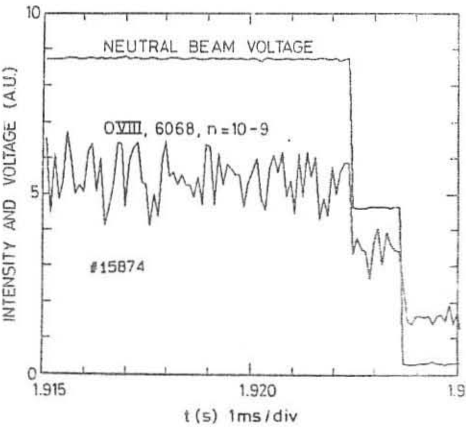

Fig.3 OVIII n=10-9 C/X line intensity fall off at the end of injection. (Neutral Beam Voltage refers to the sum of the voltages across each of two sources in the beam line, and is equivalent to total beam current).

The time histories of the visible Δn=1 transitions of O and C were examined with the photomultiplier. Figure 3 shows the time history of the OVIII n=10-9 line at the end of injection. The double step in the figure is due to the two sources in the neutral beam switching off at slightly different times. The line intensity falls off rapidly with the switch off of the two sources. This drop in intensity is far faster than any changes in the ionisation balance, which would be expected to occur on a timescale of about 1 ms. The step change in intensity is a measure of the C/X contribution to the line intensity, since the C/X excitation process turns off on a timescale much shorter than 100 μs.

For the accurate calculation of C/X line intensities needed for calibration of the VUV instrument, it was necessary to measure the fraction of beam power at each energy. This was done (following Fielding, 1981) by injecting the beams into the torus, when filled with neutral gas, and observing the Doppler shifted components of $H_\alpha$ light corresponding to the different beam neutral velocities. This yielded a power ratio of 40%:40%:20% at energies E, E/2 and E/3 (where E is the primary beam energy component of 42keV).

## VACUUM ULTRAVIOLET MEASUREMENTS

A vacuum ultraviolet spectrometer (Fonck, 1982) covering the wavelength range 100-1700Å (with modest resolution ~2Å) viewed the plasma radially, at the same position as the visible instrument in Figure 1. The spectrometer was equipped with a multichannel detector consisting of a microchannelplate intensifier coupled to an OMA of the same type as used on the visible spectrometer above.

The important C/X lines were identified by scanning the entire spectrum, which could be achieved once every 16 ms. Figure 4 shows half a survey spectrum during beam injection. This clearly illustrates the strong C/X lines, which have negligible intensity before and after injection.

The C/X line intensities could be recorded once every 1-2ms by restricting the detector to scan only specific parts of the spectrum. However the fall off time of the C/X line intensity at the end of injection was still detector limited. Previous observation of these lines in DITE (Duval, 1985) and observations of C/X lines in the visible (discussed earlier in this paper) give us confidence that the fall off time is actually less than 100μs. Despite the relatively poor temporal response of the detector, the time behaviour of these lines is seen to be markedly different from that of the resonance lines in the spectrum. This difference is due to the fact that the resonance lines apparently take many ionisation times to respond to the neutral beam switch-off, while the C/X line intensities change within one scan time of the detector.

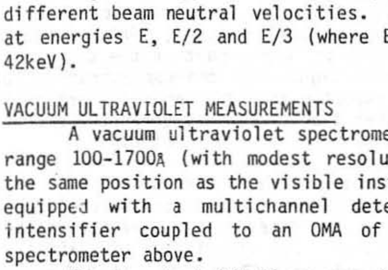

**Fig.4** Portion of VUV spectrum showing the strong C/X lines.

The relative sensitivity of the spectrometer as a function of wavelength was derived using the theoretically modelled excitation cross sections of the C/X transitions, (Isler, 1985). (To this end Olson (1985, 1981) has calculated the C/X cross sections at 42 keV into $[n,\ell]$ levels up to n=12, and n=14 for Carbon and Oxygen respectively.) The results obtained were consistent with a spectrometer sensitivity calibration constructed piecemeal from line ratios observed in JET discharges, and with that of the prototype spectrometer, SPRED. The absolute sensitivity of the spectrometer was established at wavelengths above 1100Å by reference to a calibrated deuterium discharge lamp.

The spectrometer, now absolutely calibrated, was used to make two measurements of impurity concentrations. Firstly, the concentrations of Carbon and Oxygen were calculated using a code for beam decay and impurity excitation rates and the measured volume emissivities of the C/X transitions, this gave typical impurity levels of 2%. A second measurement of impurity concentration was made using a 1-D transport model (Denne, 1985) and line emission from lower ionisation states during the ohmic part of the discharge. The latter measurement gave a rather lower figure for the concentrations of the impurities (about half). It is to be expected that the impurity content of the plasma during injection should be higher than during the ohmic phase.

## CONCLUSIONS

Our experiments in the VUV have borne out calculations of C/X line intensities for the 42 keV primary neutral energy of the ASDEX injectors, and enabled us to calibrate a VUV spectrometer. The time histories of the visible signals confirm them as being C/X in origin. Our efforts are now aimed at correlating the observed intensities in the visible ($n \geq 8$) with the VUV measurements ($n \leq 5$). From the VUV data, the impurity concentrations have been measured, and the visible data has given ion temperatures and bulk plasma velocities. The results appear encouraging regarding the use of visible instruments to derive important plasma parameters which previously required the use of close-coupled vacuum spectrometers. Our experiments are continuing in order to increase confidence in the theoretical models.

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