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Diagnostic Neutral Beams for Spectroscopic Studies of Impurities by Charge-Transfer Reactions*

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The fluxes and concentrations of impurities in tokamak plasmas can be studied by measuring the intensities of spectral lines produced by electron excitation. For low-Z atoms these investigations are confined to the periphery of the plasma where the impurities are not completely ionized. Up to the present time there has been no straightforward method of studying the fully stripped species which exist throughout much of the plasma volume. This incomplete picture has made it difficult to examine the transport of the light impurities in detail and to correlate concentrations and fluxes with the plasma-wall interactions that introduce impurities into the discharge.

We suggest that charge-transfer reactions between hydrogen atoms and impurities can be exploited to measure the concentrations of the completely stripped species. Such collisions produce hydrogen-like impurities in excited states[1,2] that can be observed by spectroscopic techniques. In this paper we present an example of such a measurement of O^{8+} from the ISX-B tokamak where a heating beam provides a source of neutral hydrogen in the center of the plasma, then discuss the possibility of doing more systematic analysis with better spatial resolution by using a diagnostic beam.

The reaction,

$$H^\circ + O^{8+} \rightarrow H^+ + (O^{7+})^*,$$

has a cross section[3] of about 3.3×10^{-15} cm^2 for 40 keV H° beams. Charge transfer goes largely into the n=5 state and the partial cross section for exciting the n=5 → n=4 transition (633Å) is 10^{-15} cm^2. The specific radiation rate is given by,

$$S(\text{photons/cm}^3\text{-sec}) = j(H^\circ)\, n(O^{8+})\, \sigma_{c-x}, \tag{1}$$

where $j(H^\circ)$ is the particle current of the neutral beam, $n(O^{8+})$ is the concentration of fully ionized oxygen, and σ_{c-x} is the cross section for producing the 633Å transition. By using a spectrometer positioned so its field of view includes the beam it is possible to measure the concentration of O^{8+} from the absolute intensity of the 633Å line. Of course the observed signal is the integral of Eq(1) along the line of observation and the spatial resolution depends upon the beam diameter.

Figure 1 shows an example of the charge transfer signal (after subtracting a comparable background of scattered light) and the beam current into the plasma. The radiation does not follow the current exactly because both a mild gas puff and the beams themselves tend to raise $n_e(t)$ and attenuate the beam slightly after the initial current rise. Preliminary calculations of the beam attenuation and dispersion at the position of observation lead to an average value of the oxygen concentration in the inner region of the plasma,

$$n(O^{8+}) = 5.5 \times 10^{11}/\text{cm}^3,$$

with an estimated uncertainty of a factor of two. The value of $\langle Z_{eff} \rangle$ due to this concentration is 1.9. The measured value of $\langle Z_{eff} \rangle$ from an analysis of the resistivity is 2.0, most of the anomaly being due to oxygen.

A diagnostic neutral beam has been planned for ISX-B in order to enhance the signal for the charge-exchanged neutral particle analyzers. However, this beam, which is more flexible and smaller in diameter than the heating beams can also be used to study fully stripped light impurities. In Figure 2 we show schematically one possible arrangement. A normal-incidence monochromater can be attached to the rear of the vacuum chamber which houses the neutral particle detectors. If the detectors are removed the field of view of the monochromator encompasses the plasma and the diagnostic beam. The beam can be steered across the minor radius so that 0^{8+} radial profiles can be determined. At present the beam parameters are intended to be the following: 10 cm diameter, 40 keV, and 3 amperes. The diameter is somewhat large for adequate spatial resulution but it may be possible to reduce it by using a set of collimators. Typical signals into the spectrometer are expected to be about 4 x 10^6 photons/sec, approximately 1% of the signal from the strong OV line at 630Å. Uncertainties of the concentration of 0^{8+} are expected to be 60%. However, absolute values are not required for many experiments, often the relative behavior of impurities during a discharge is satisfactory for studying transport and plasma-wall interactions.

In summation, we believe that the charge transfer process will permit us to study light impurities not only in the periphery of the plasma but also in the center.

REFERENCES

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3. A. Salop, J. Phys. B 12, 919 (1979)

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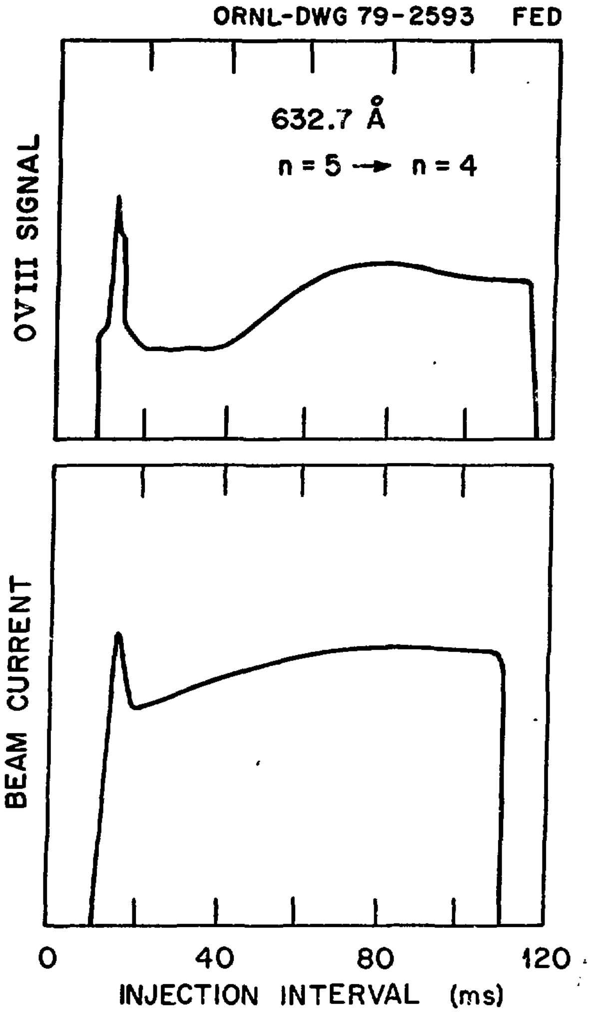
Figure Captions

1. Charge transfer signal and neutral beam heating current during injection into ISX-B.
2. A possible experimental arrangement for spectroscopic studies of charge transfer from a diagnostic beam.


ORNL-DWG 79-2593 FED
632.7 Å
n = 5 → n = 4
OVIII SIGNAL
BEAM CURRENT
0
40
80
120
INJECTION INTERVAL (ms)

ORNL/DWG/FED-77851 A