Observations of H_α emission profiles in Aditya tokamak

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Emissions from the hydrogen Balmer alpha (λ = 656.28 nm) has been recorded for a large number of plasma discharges in the Aditya tokamak using a 1m Czerny-Turner spectrometer equipped with an 1800 grooves/mm reflection grating [5]. Eight simultaneous vertically collimated line-of-sights, using individual lens – fiber combination from a top port of the tokamak view a poloidal cross-section of the plasma. The line-of-sights can be moved along the major radius to obtain emissions from different major-radial positions on a shot–to–shot basis. Abel-like matrix inversion has been performed to obtain radial profile of volume emissivities from these chord-integrated intensities. Considerable H_α emission is observed in the bulk plasma indicating a considerable neutral penetration. Further, a second peak in the H_α radial profile has been observed at $\rho(r/a)$ ~ +/- 0.3 -- +/- 0.5 in majority of discharges irrespective of the plasma column position. This observation suggests a considerable accumulation of neutrals in the region of $\rho(r/a)$ ~ +/- 0.3 -- +/- 0.5. CV to CIII line ratio variations at the same location also suggest a substantial presence of neutrals explained by the charge-exchange, involving collisions between H-like carbon ions and neutral hydrogen atoms.

Keywords: tokamak, Abel-like matrix inversion, Balmer alpha, neutral transport.

1. Introduction

Neutral atom transport properties play an important role in tokamak plasma confinement [1]. Therefore, it is necessary to measure the neutral atom density profile in a tokamak. Direct measurements of the neutral (hydrogen) density n_0, in tokamak plasmas are almost lacking. Except for few attempts with LIF [2], often indirect information via charge exchange spectroscopy (CX) of sensible intensity ratios of impurity (carbon) ions is used [3,4].

Several investigations of spectral line ratios in both VUV and X-ray regions of the spectra often required substantial presence of neutral atoms in the hotter central regions of the tokamak to resolve the observed anomalies. In this paper we measured the neutral atom density profile by monitoring the hydrogen Balmer alpha (λ = 656.28 nm) emission from the Aditya tokamak. This radiation results from the collisional excitation of a neutral hydrogen atom from the device wall or limiter surface enters into the main plasma. It is generally assumed that the neutral hydrogen atoms can penetrate to the hot central plasma by diffusion from the edges through successive charge transfers with the working gas ions [1].

Section 2 briefly describes the experimental setup. In section 3 an overview of the calibration of the spectroscopic instruments has been given. Finally, in section 4 the obtained results are discussed.

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2. Experimental setup

Up to eight simultaneous chords or lines-of-sight (LOS) can be set up from a top port window on Aditya along a poloidal diameter from the inboard to outboard edge. The 1 mm core diameter of fibers and collimating lenses (diameter = 11 mm, focal length = 19 mm) yield a spatial resolution of 25 mm at the mid-plane (increasing to 42 mm at the bottom edge of the plasma). Figure 1A shows a schematic of the viewing geometry. The back ends of these (~20 m long) fibers couple to eight 400 μm core diameter input fibers on the spectrograph entrance slit with a center-to-center separation of 700 μm. The slit height can accommodate up to nine of these 400 μm core fibers. The ninth fiber is used as a reference track for recording spectrum from a neon lamp during discharges [5].

The Multi-track Spetrometer system consists of a 1.0 m long Czerny–Turner spectrometer fitted with a 2D CCD (charge-coupled device) camera with 1024 × 256 pixels (1 pixel = 26 × 26 μm).

A normal incidence spectrometer was used to record the spectrum in the wavelength region 110 – 300 nm, which views plasma from a radial port. The view chord can be chosen vertically from the midplane to 20 cm above the midplane, by tilting a silver mirror in the transmission path as shown in the figure 1B. The detector attached to the exit slit of the spectrometer is an Intensified Charge Coupled Device (ICCD) camera.

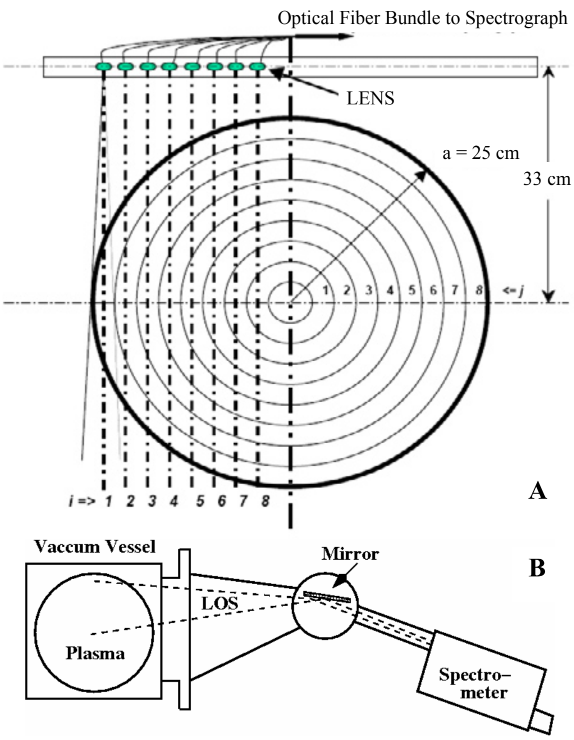

Figure1: Schematic of the viewing geometries of Multi-track Spectrometer (A) and Normal Incidence Spectrometer (B) systems respectively

3. Calibration

We first established a relative calibration among all nine tracks. Light from a fluorescent lamp was diffused over an area of 50cm×10cm using a milky white plastic diffuser plate in transmission. The uniformity of the diffused light over this area was ensured using the same fiber across the length and the width of the region. Then all of the nine input fibers were illuminated with this extended uniform source and the nine tracks of spectra were recorded at different wavelengths from 350 to 800 nm. The spectrum consisted of both mercury lines and a background continuum. Relative calibration factors do not show any wavelength dependence over the entire visible range. A statistical variation of less than 1% for each frame was observed by acquiring a number of these nine track frames at a single wavelength. Further, A standard tungsten lamp (NIST, USA) was used to calibrate the fiber–spectrometer–detector system for absolute intensity measurements. One of the nine channels was calibrated using the lamp. The calibration was transferred to the other fibers using the relative calibrations obtained above [5].

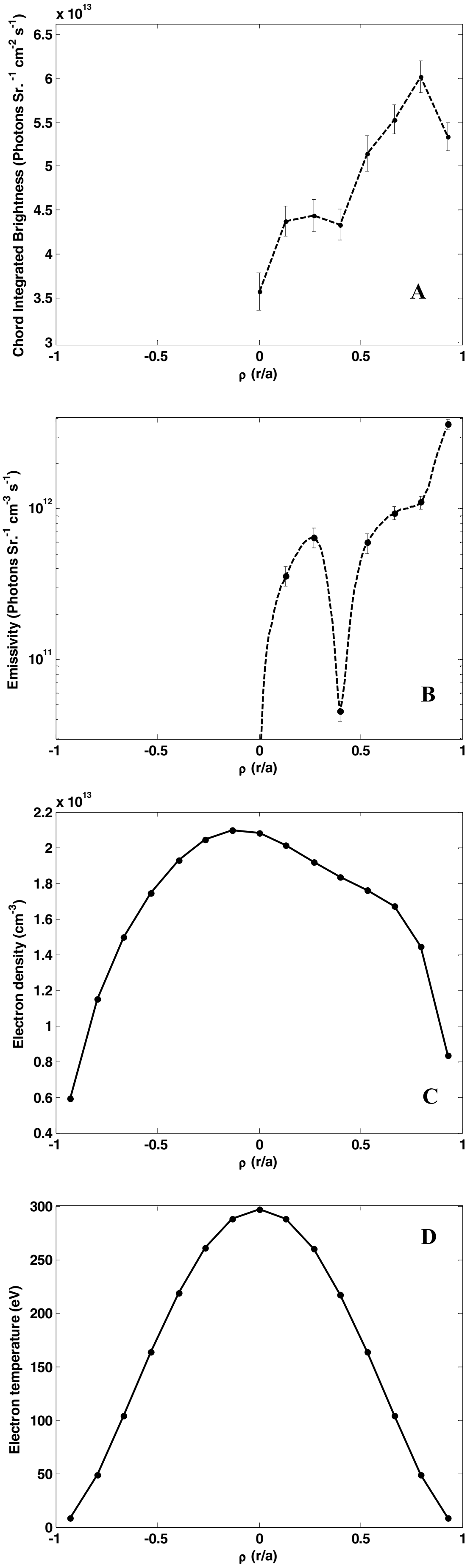

Figure 2: From A to D: Chord integrated and absolute calibrated brightness profile of Hydrogen Balmer α emission, Emissivity profile of the same obtained from Abel-like matrix inversion of the chord integrated signal, Electron density and temperature profiles in one of the characteristic discharges in Aditya tokamak.

4. Results and Discussion

The Aditya tokamak [6] is an air-core machine with B_T = 0.75 T. The plasma with major radius R = 0.75 m, minor radius a = 0.25 m is limited by a poloidal graphite limiter of circular cross-section. For the shot data used here, the typical discharge parameters were: plasma current, I_P = 60– 70 kA, average electron density, $n_e = 1\times10^{13}\ \mathrm{cm}^{-3}$ and plasma discharge duration = 100 – 120 ms.

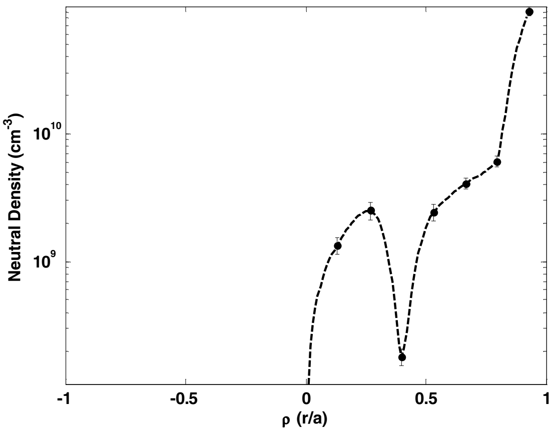

Figure 3: Neutral hydrogen density profile obtained from the Hα emissivity profile, electron density and temperature profiles and atomic reaction rate coefficients from ADAS

From the multi-track chord-integrated measurements, recorded with a 200 μm entrance slit width of the spectrometer (Figure 2A) radial emission profiles (Figure 2B) are obtained using an Abel-like matrix inversion technique [7-9]. The plasma volume is partitioned into radial zones with constant emission, E_j, constant temperature and constant velocity, with the radial extent of each zone being the coverage of a particular chord. The brightness, B_i, of a chord i is given by $B_i = L_{ij} E_j$, where L_{ij} is the path length of the ith cord through the jth zone. The emission, E_j, can be obtained by inverting the above equation. The inversion algorithm was tested by generating synthetic chord-line integrated profiles of emission. Different amounts of Gaussian white noise has been incorporated in the simulated brightness profile to ascertain the sensitivity of the inversion algorithm. The observed spectra are fitted with Gaussian profiles using the least squares fitting routines and the brightness is calculated for each chord by integrating the Gaussian curve used in the fit. The standard errors in the amplitude from a Gaussian fit are calculated assuming a normal distribution of detector noise, which depends mainly on the signal-to-noise ratio in the brightness observed. Uncertainty in the fitting procedure is less than 1%. The error propagation in the inversion was calculated considering that $\sigma_b^2 = [M^2]\ \sigma_a^2$, where b and a are vectors operated by matrix $[M]$, $b = [M]\ a$, and σ_a and σ_b are the standard deviations of vectors a and b. The error in $[M]$ is considered negligible. Furthermore, the statistical errors present in the relative and absolute calibration of the collection optics are incorporated. Owing to the excellent signal to noise ratio for H_α, the uncertainty in the recorded chord integrated brightness is less than 5%, inclusive of all the contributing factors. For an average noise in the brightness of 5%, uncertainty introduced by inversion in the obtained emissivities is less than 15%. Neutral atom density profile is now calculated form the emission profile along with the electron density and temperature profiles and the electron impact excitation and recombination rate coefficients from ADAS [10]. Electron density profile and central electron temperature are obtained experimentally from the microwave interferometry and soft x-ray diagnostics respectively. It has been found that the neutral atom density decreases up to 1.81×10^8 at $\rho\ (r/a)$ = 0.4 from its value of 9.04×10^{10} near the limiter location and then peaks up again to a value of 2.5×10^9. Simple calculation for neutral penetration shows that the neutral density should decay exponentially with minor radius. These results are repeated in many shots and the dip in the neutral density profile seems to be real as it is quite above the experimental error bars.

Furthermore, investigation of line ratio of CV (C^{4+}), the He like carbon lines are identified at wavelengths 227.1 and 227.7 nm (two of the lines are merged), to CIII (C^{2+}), Be like carbon seen at 229.7 nm, also shows an anomaly at the location $\rho\ (r/a)$ = 0.3 which suggests a substantial presence of neutral at that location for charge exchange to take place and resolving the anomaly (figure 4, top panel). Since neutral beam has not been used in Aditya, charge exchange involving slow collisions between the recycling hydrogen neutrals and the CVI (H-like Carbon ions) are of interest as shown in equation (1).

$$C^{5+} + H \rightarrow C^{4+} + H^{+} + \Delta E \qquad (1)$$

However, at the location where the neutral density goes down there is no anomaly observed in spite of presence of

CVI ions as shown in figure 4, bottom panel, calculated from STRAHL code [11,12]. If the neutral density remains large at that point, which is not the case (figure 3) then we should have observed the anomaly there too. This has been reported earlier in similar tokamaks [4]. Hence, the neutral density profile observed seems to be correct with a second peak coming at ρ = 0.3. The reason for the observed increase in the neutral density and thereby enhancing charge exchange with CVI at ρ = 0.3 is still not clear and further investigation and analysis are underway to understand the accumulation of neutrals at ρ = 0.3.

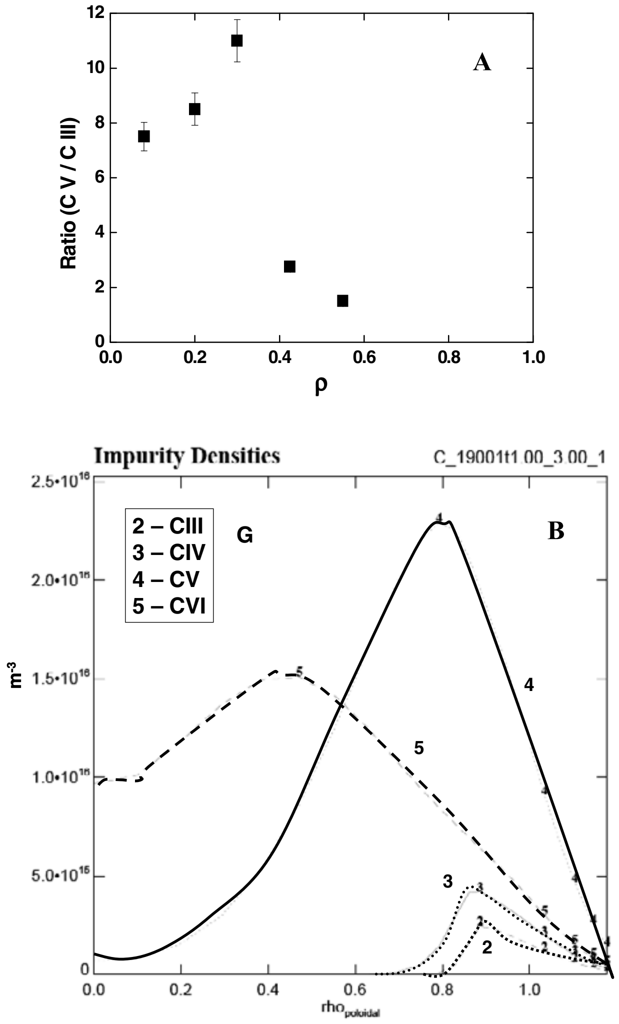

Figure 4: 4A shows the ratio of CV to CIII as a function of ρ (r/a) measured with the normal incidence spectrometer; 4B shows the density distribution for different charge states of Carbon as estimated from the STRAHL impurity transport code.

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References

[1] P C Stangeby, J. Phys. D: Appl. Phys. **36** 2784–2797, (2003)

[2] M. M. Larionovl., S**.** Leviny, U. V. Petrovg, . T. Razdobarin, V. V. Semenov, and G. A. Serebreny, Plasma Physics and Controlled Fusion, **30**. 1637, (1988)

[3] W.R. Hess, C. De Michelis, M. Mattioli, R. Guirlet, M. Druetta, Nuclear Instruments and Methods in Physics Research B **98** 95 (1995)

[4] K. J. McCarthy, B. Zurro, C. Burgos, J. Vega, and A. Portas, Physical Review E, V **52**, 6671 (1995)

[5] Santanu Banerjee, Vinay Kumar, M.B. Chowdhuri, J. Ghosh, R. Manchanda, Ketan M. Patel and P. Vasu, Meas. Sci. Technol. **19** 045603 (2008)

[6] S.B. Bhatt, D. Bora, B.N. Buch, C.N. Gupta, K.K. Jain, R. Jha, P.I. John, P.K. Kaw, Ajay Kumar, S.K. Mattoo, C. Natarajan, R. Pal, H.A. Pathak, H.R. Prabhakara, H.D. Pujara, V.N. Rai, C.V.S. Rao, M.V.V.S. Rao, K. Sathyanarayana, Y.C. Saxena, G.C. Sethia, A. Vardharajalu, P. Vasu and N. Venkataramani, Ind. J. Pure Appl. Phys. **27** 710 (1989)

[7] Ghosh J, Griem H R, Elton R C, Terry J L, Marmar E, Lipschultz B, LaBombard B, Rice J E and Weaver J L *Phys. Plasmas* **11,** 1033 (2004).

[8] Bell R E, *Rev. Sci. Instrum.* **66,** 558 (1995)

[9] Ghosh J, Elton R C, Griem H R, Case A, DeSilva A W, Ellis R F, Hassam A, Lunsford R and Teodorescu C, *Phys. Plasmas* **13,** 022503 (2006)

[10] H.P. Summers, The ADAS (Atomic Data and Analysis Structure) User Manual, JET-IR 06 (1994)

[11] R. Dux, Technical Report No. 10/30, IPP, Garching, Germany (2006)

[12] R. Dey, N. Ramasubramanian, R.Manchanda, Santanu Banerjee, J. Ghosh, P. Vasu, Vinay Kumar and Aditya Team, *Proc. of IAEA International Workshop on Challenges in Plasma Spectroscopy for Future Fusion Research Machines, Jaipur, India,* (2008)