

Determination of local temporal electron density and temperature using visible spectroscopy of carbon emissions

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Introduction

The development of diagnostic tools and methods for measurements of plasma parameters, like temperatures, densities and confinement times, is an important matter in plasma physics. In a previous work [1] we have used hydrogen spectral line emissions and the concept of particle time confinement uniqueness to develop a diagnostic for the measurements of electron density (n_e) and temperature (T_e) at the edge of NOVA-UNICAMP tokamak plasma [2]. That work established the basic ideas to start the studies on the use of impurity spectral line emissions for measurements of T_e and n_e . Now we present a diagnostic method used to determine the local T_e and n_e in the NOVA-UNICAMP tokamak plasma, using visible spectroscopy of carbon emission lines. This method is based on a well known relationship between the particle flux (Γ_{ion}) and the photon flux (ϕ_{ion}) emitted by an ion, at a fixed wavelength, combined with ionizations per photon atomic data provided by ADAS [3].

In the experiment we measured simultaneously the photon fluxes of three different C¹⁺ (CII) spectral line emissions. The experimental spectroscopic data was taken during one shot tokamak discharge using three absolutely intensity calibrated spectrometers equipped with photomultipliers. In this experimental setup the light from the plasma is collimated with a telescope ($f = 100$ mm) that was installed in the equatorial port and transmitted to the entrance slit of the monochromators through an optical fibre of 0.8 mm diameter.

Using this method was possible to determine temporal evolution of electron density and temperature during the flat top phase of tokamak discharges. These results are in good agreement with the expected values for the plasma region where occurs the larger probability of CII emissions.

Theoretical model

The relationship between the particle flux (Γ_{ion}) and the photon flux emitted by an ion ($\phi_{ion}^{[2]}$), at a fixed wavelength is given by [4]:

$$\Gamma_{ion} = \left(\frac{S}{XB} \right) \phi_{ion}^{[\lambda]} \quad (1)$$

where the (S/XB) factor is known as ionization per photon coefficient, and it depends on local T_e and n_e . In a plasma in the equilibrium condition and with some impurities, we can assume that the particle flux of a given ion specie, at a fixed ionization stage, is constant. Then, for an ion emitting in various different wavelengths we have [5]:

$$\Gamma_{ion}[\lambda_1] = \Gamma_{ion}[\lambda_2] = \dots = \Gamma_{ion}[\lambda_n] = \dots \quad (2)$$

Taking the ratios between particle fluxes measured at different wavelengths we can write:

$$\frac{\Gamma_{ion}[\lambda_1]}{\Gamma_{ion}[\lambda_2]} = \frac{\Gamma_{ion}[\lambda_2]}{\Gamma_{ion}[\lambda_3]} = \dots = \frac{\Gamma_{ion}[\lambda_{n-1}]}{\Gamma_{ion}[\lambda_n]} = 1 \quad (3)$$

Combining equations (1) and (3) with measurements of photon fluxes emitted by three $C\,II$ lines, we have a system with two equations and two undetermined parameters, which allows us to perform an interactive method in order to find correct values of T_e and n_e that satisfy the Γ_{ion} constancy.

Analysis method

The ADAS database provides S/XB coefficients of CII transitions listed in Table 1 for a wide range of electron temperatures and densities. The ADAS data were interpolated in a finest way in order to improve the precision of our measurements.

Table1. List of CII transitions used with their respective wavelengths (information given by [6])

Label	Wavelength (Å)	Transition (Configuration, Term, J)
CII1	4267.26	$2s^24f, ^2F^0, 7/2 \rightarrow 2s^23d, ^2D, 5/2$
CII2	5132.95	$2s2p(^3P^0)3p, ^4P, 3/2 \rightarrow 2s2p(^3P^0)3s, ^4P^0, 1/2$
CII3	6578.05	$2s^23p, ^2P^0, 3/2 \rightarrow 2s^23s, ^2S, 1/2$

With the measured fluxes of CII emission lines and their respective S/XB coefficients, we made numerical calculations of flux ratios in function of electron density, for various fixed electron temperature values. As we can see in Figure 1, the ratios between particle fluxes have a cross point at some density value. The ratio values at cross point (RVCP) are, in general, different for each T_e value, and the same occurs for the electron density values at cross points (n_{eCP}). The next step is to study the behavior of $RVCP$ and n_{eCP} in function of T_e . Figures 2-(a, b) show these behaviors.

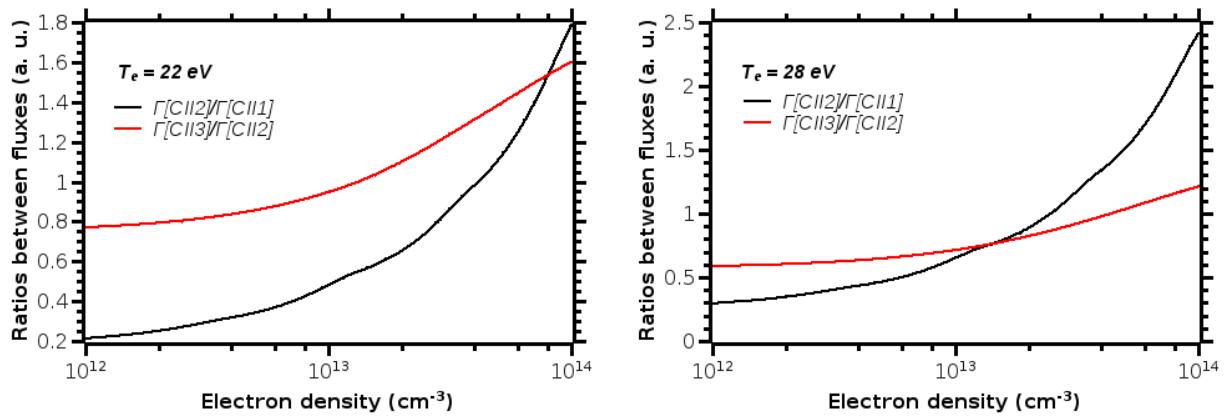


Figure 1. Plot of ratios between particle fluxes versus n_e , for electron temperatures of 22 eV (left) and 28 eV (right).

In the $RVCP$ vs T_e curve we can observe that $RVCP$ is equal to 1.0 for $T_e = 25.8$ eV. This T_e value satisfies the Γ_{ion} constancy (equation 2), and is used in the n_{eCP} vs T_e curve to obtain the n_e value that also satisfy Eq. (2). And from Fig. 2-b we get $n_e \approx 2.9 \times 10^{13}$ cm⁻³.

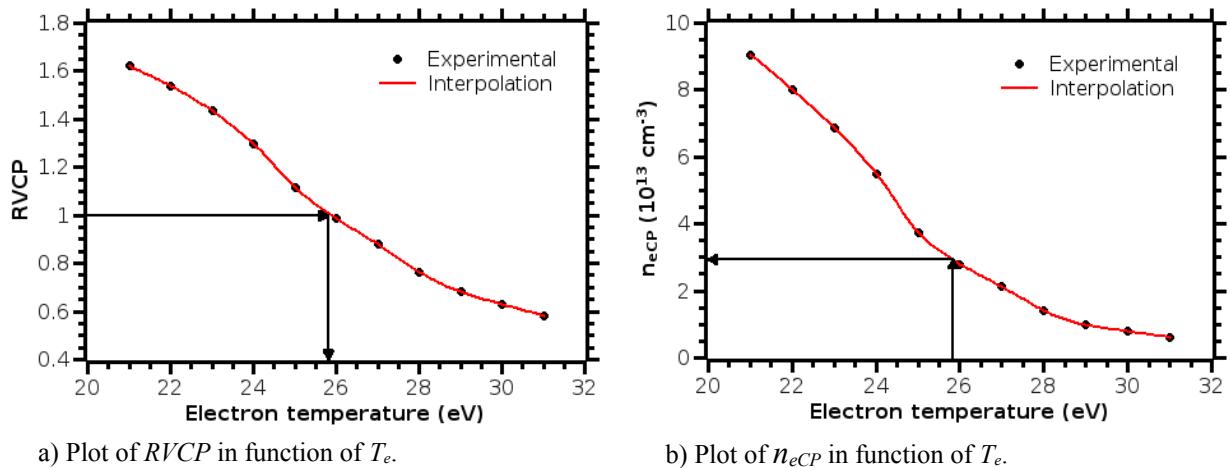


Figure 2. Last steps of the method for determination of T_e and n_e that satisfy Eq. (2).

The procedure described above must be performed for each time instant of the plasma discharge in order to get the temporal evolution of T_e and n_e .

Results and conclusions

Using the method previously described, we have determined the temporal evolution of the electron temperature and density at the edge of NOVA-UNICAMP tokamak plasma. The T_e and n_e results, shown in figure 3-a, was obtained in a 8.5 ms tokamak discharge with a plasma current of 12 kA.

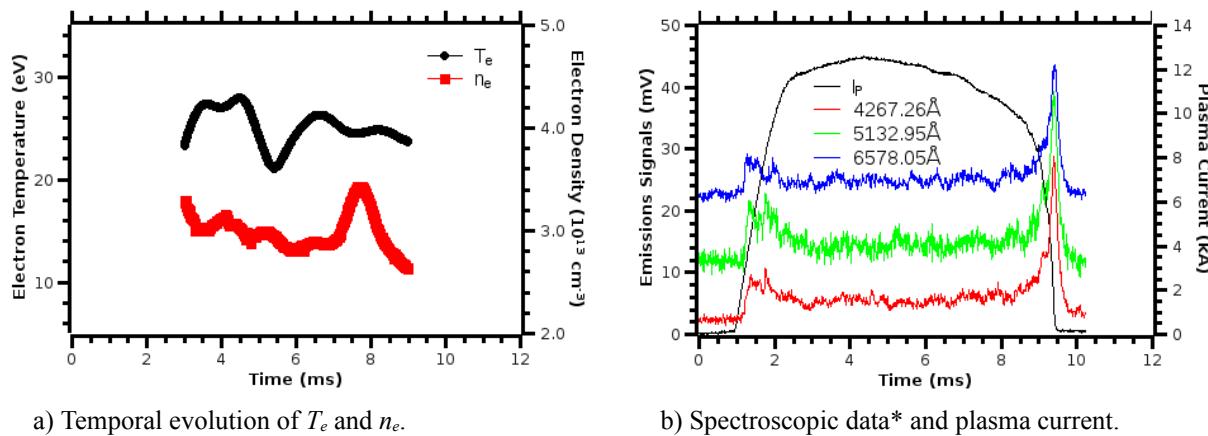


Figure 3. Results of T_e and n_e (a) obtained for a tokamak discharge with a work pressure of approximately 1.2×10^{-4} Torr and their respective experimental data (b). *The the values of emission signals used in the calculations are taken from a baseline where the signals must be zero.

The electron temperature obtained in this discharge oscillates around 25 eV. This result is in good agreement with the predicted in [2] and [7] for the plasma region where occurs the larger probability of *CII* emissions in the NOVA-UNICAMP tokamak. The electron density oscillates around $3 \times 10^{13} \text{ cm}^{-3}$. This value is a little bit higher than expected for the plasma edge of NOVA-UNICAMP tokamak, but agree in the magnitude order of measurements made in [2]. This indicates that the proposed diagnostic method can be used to monitor the electron densities and temperatures at the edge of tokamak plasmas, or inner radial positions, according to the impurity ionization level and provided that at least three independent line emissions for each ion species can be measured.

Acknowledgments

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