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Impurity transport studies in TORE SUPRA with He-like spectroscopy

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Introduction

The He-like spectra of iron, chromium and other elements are measured routinely at the tokamak TORE SUPRA [1]. The aim of this work is the determination of the diffusion coefficients and the density of the neutrals in the plasma core using the He-like spectra of iron. The approach consists of two parts. In the first, theoretical part, the one-dimensional impurity transport code [2] is applied to calculate the radial profiles of H-, He- and Li-like ions. In the second part we reconstruct the synthetic spectrum of He-like iron on the basis of calculated radial profiles and atomic processes. Finally, the density of the ionized stages in the core is determined by least-square fitting of the synthetic to the measured He-like spectrum.

He-like spectra

The He-like spectrum of iron, measured at the tokamak TORE SUPRA is given in the Fig.1.

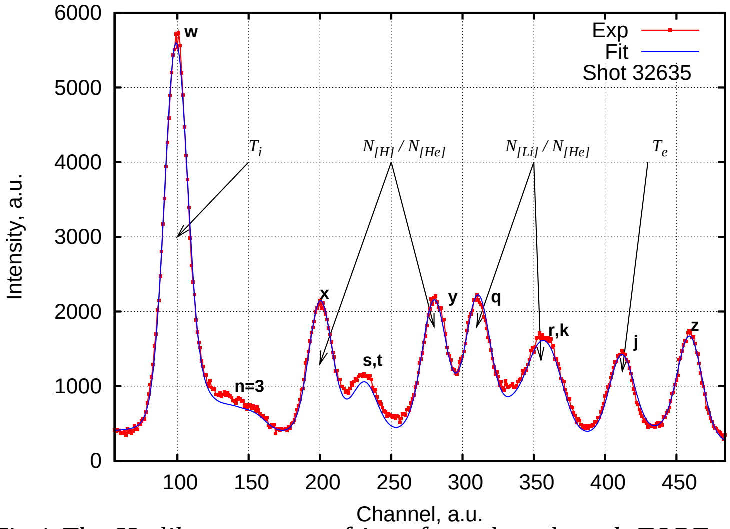

Fig.1 The He-like spectrum of iron from the tokamak TORE SUPRA, t = 4..10s. The measured spectrum is fitted with the plasma parameters: T_e, T_i, $N_{[Li]}/N_{[He]}$, $N_{[H]}/N_{[He]}$.

The spectra were analyzed at the steady-state plasma conditions. The spectrum consists of the He-like singlet line **w** and the lines in the triplet system **x**, **y**, and **z**. Additional to the He-like lines the strong Li-like satellite lines **q**, **r**, **s** and **t** contribute to the spectra through the processes of the inner-shell excitation and dielectronic capture. The less intensive Li- and Be-like dielectronic satellites form the quasi-continuum background of the spectra. The precise

*partner in the Trilateral Euregio Cluster theoretical description of the He-like spectra and detailed information about the spectrometer can be obtained from Ref. [3,4].

The ratio between the intensities of the collisional satellites (**q** and **r**) and the **w** line is proportional to the ratio between the density of the Li- and He-like ions. The recombination part of the triplet lines **x**, **y** and **z** is used for the determination the abundance of the H-like ions in the plasma. We should note that the **z** line is positioned in the shadow of the vessel of the spectrometer and so the measured intensity of this line is weaker relative to the other lines. The calculated intensity of the **z** line was scaled by the factor 0.53 to describe the measured one.

Modeling of the spectra

The model of the He-like spectra depends on the plasma information as well as on the atomic data. The intensity of any spectral line is determined as:

$$I(\lambda) = \int_{-a}^{a} N_e(r) \sum_q N^{q+}(r) \sum_{\lambda_i} < \sigma v >^{q+}_{\lambda_i} (r) V(\lambda_i, \lambda; r) dr, \quad (1)$$

where I(λ)- is the observed intensity at the wavelength λ; λ_i- is the wavelength of the specific transition; q - is the ionization stage; $< \sigma v >^{q+}_{\lambda_i}$ - is the corresponding rate coefficient; $V(\lambda_i, \lambda; r)$ - is the Voigt function, reflecting the Doppler and the Lorentzian width of the wavelength λ_i at λ. As follows from (1), the emission of the spectral lines depends on the radial profiles of the plasma parameters. The assumed profiles are given in the Fig. 2.

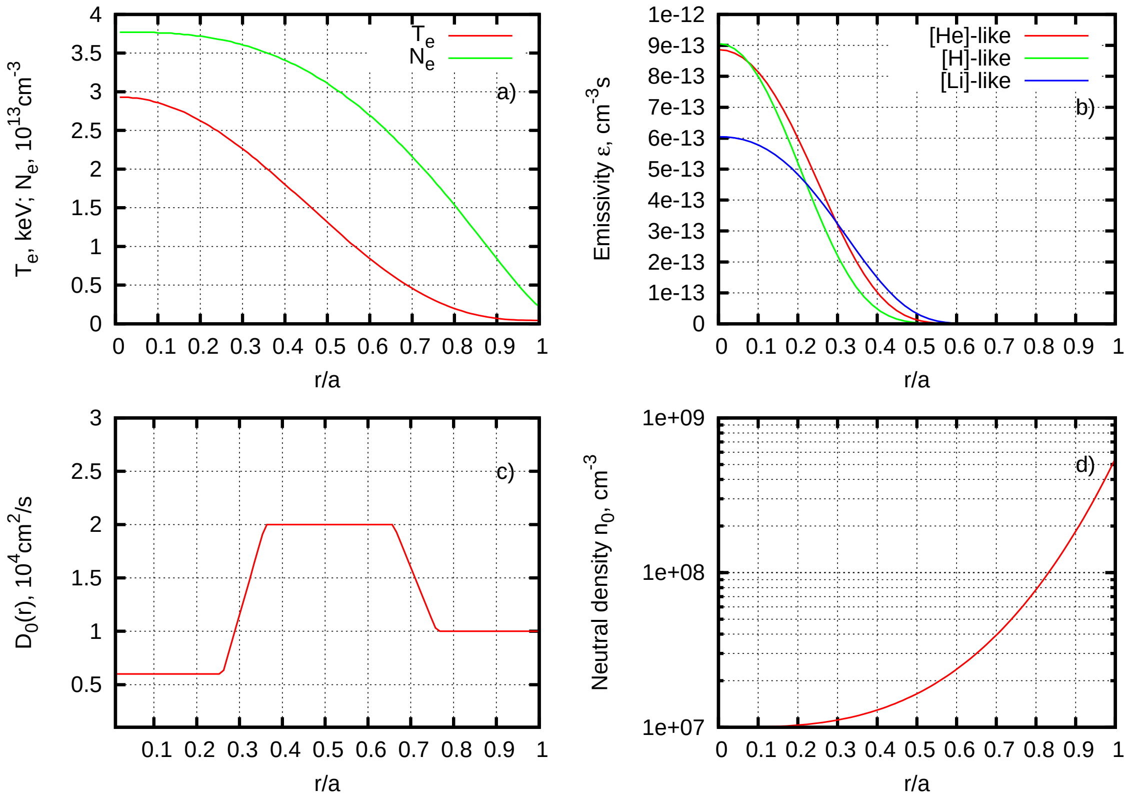

Fig.2 Radial profiles used in the model. [a] -electron temperature and density; [b] -emissivity of the ionization stages;[c] - diffusion coefficient;[d] - neutral density.

The profiles of electron temperature and density were obtained by fitting the experimental data of Thomson scattering and interferometry. Previous impurity transport studies in the tokamak TORE SUPRA [2] and TEXTOR [5] showed the suppression of the diffusion in the plasma core. In this paper we assume the same profile of the diffusion coefficient as in the previous works. The radial profile of the neutral density was taken close to the RITM code calculations [6]. From (Fig. 2, b) and (1) follows that the emission of the spectral lines occurs mostly in the hot core region, within the normalized plasma radius $r/a < 0.5$. The radial distributions of the ionized stages were obtained using the impurity transport code. For their calculation the profiles of the diffusion coefficient and the neutral density were normalized with the coefficients k_n and k_D, so that $D(r) = k_D D_0(r)$ and $n(r) = k_n n_0(r)$. The Fig. 3 shows examples of the profiles.

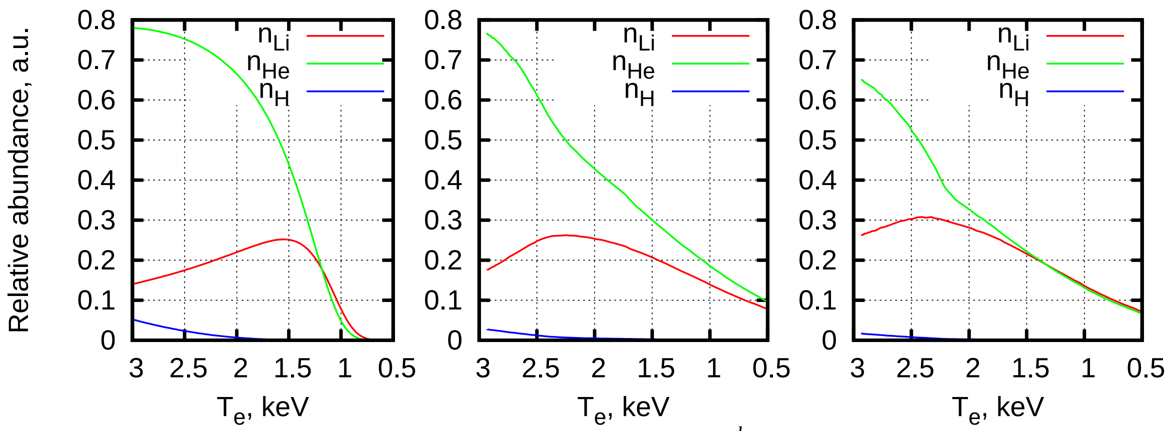

Fig.3 Ionization balance. [a] *-$k_D = k_n = 0$ (coronal equilibrium);* [b] *-$k_n = 0$, $k_D = 1$;*[c] *- $k_n = 5$, $k_D = 1$.*

The radial profiles were used in (1) to simulate the theoretical intensities of the lines. The plasma paremeters (Fig.1), including the density of the ionized stages, were obtained by least-squares fitting of the experimental spectra to the theoretical one.

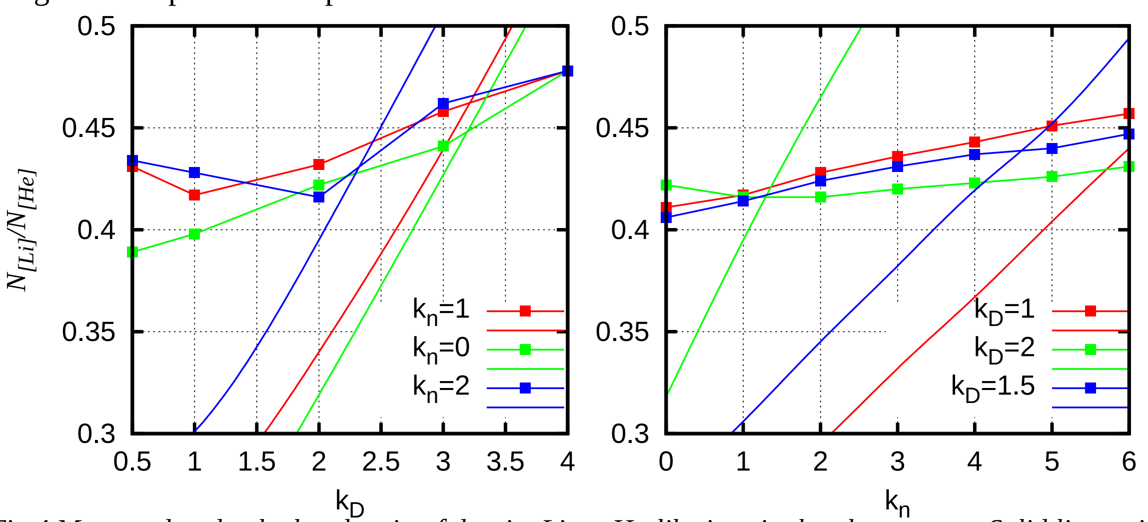

Fig.4 Measured and calculated ratio of density Li- to He-like iron in the plasma core. Solid lines with blacksquares - measured values, solid lines - calculated with the transport code.

The ratio $N_{[Li]}/N_{[He]}$, obtained on the basis of the He-like spectra, was compared with the theoretical calculations from the impurity transport code. We iterated between the impurity transport code calculation and least-square problem for the spectrum until the convergence for the ratio $N_{[Li]}/N_{[He]}$ is achieved. The results of the iterations are shown in Fig. 4. Here, the dependence of the measured and calculated ratio on the parameters k_D and k_n is given.

Results and Conclusions

The measured ratio ($N_{[Li]}/N_{[He]}$) proved to has a weak dependence on the radial distribution profiles and is mostly determined by the atomic processes. Its variation is found to be within 20% at different radial profiles of the ionization stages. We found the set of values of the coefficients k_D and k_n when the measured and predicted quantity coincides. The estimated density of the neutrals is of the order of $2 \cdot 10^7 - 6 \cdot 10^7 cm^{-3}$. It is important to note the process of the charge exchange recombination and its influence on the total ionization balance [7,8]. Obviously it is not possible to determine both parameters k_D and k_n from the measurements of Li- and He-like ions alone. The measurements of the H-likes ions should be also included in the model. Unfortunately, up to now, the He-like spectra of iron show extremely high concentration of the H-like ions, exceeding the coronal limit by factor 8-10. The reason of such a deviation, reported also in the previous works, is still under discussion. In our modeling we did not take into account the direct contribution of the charge-exchange recombination to the intensities of the He-like lines. This process should partly diminish the observed deviation.

Acknowledgments

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References

[1] S. Assas, C. Fenzi-Bonizek, L.-G. Eriksson, and G.T. Hoang, Proc. 30th EPS Conference on Controlled Fusion and Plasma Physics **27A** (2003).

[2] M. Mattioli, C.De Michelis, A.L. Pecquet Nucl. Fusion **38**, 1629 (1998).

[3] F. Bely-Dubau, et al. Phys. Rev. A **26**, 3459 (1982).

[4] P. Platz, Y.Margerit, J.-F. Artaud, M. Mattioli, and B. Moulin Rev. Sci. Instr. **70**, 308 (1999).

[5] W. Biel, et al., Proc. 28th EPS Conference on Controlled Fusion and Plasma Physics **25A**, 1389 (2001).

[6] M.Z. Tokar Plasma Phys. Controlled Fusion **36**, 1819 (1994).

[7] F.B. Rosmej, et al., Plasma Phys. Control. Fusion **41** 191 (1999).

[8] G. Bertschinger, O. Marchuk, "High-Temperature Plasmas Diagnostics by X-ray Spectroscopy in the Low Density Limit", R.E.H. Clark, D.H. Reiter (Eds.), "Nuclear Fusion Research, Understanding Plasma-Surface Interactions", Springer Verlag, 2004, p. 183.