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BROADENING OF LITHIUM-LIKE CARBON SPECTRAL LINES EMITTED IN TOKAMAK PLASMAS

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Abstract.

Calculations of profiles of C IV n=5-6 (λ=4658 Å) and n=6-7 (λ =7726 Å) lines, broadened by Stark and Doppler effects, are presented for plasma conditions relevant to Tokamak divertors (Te=1-10 eV, Ne=10^{21}-10^{19} m^{-3}). The calculations show that for the above conditions, Stark and Doppler broadenings may have comparable effects on the C IV line profiles and that both the electron density and the C^{+3} temperature can be deduced from the fit of experimental C IV line spectra.

1. Introduction.

Spectral line emission from ionic impurities like Li-like carbon ions C^{+3} is routinely used in tokamaks and stellarators for plasma diagnostic purposes. For instance the plasma ion temperature is inferred from the comparison of line widths or from fitting of observed spectra with theoretical line shapes calculated assuming the Doppler effect as the dominant broadening mechanism. In JT-60U, the n=6-7 (λ=7726 Å) line emitted by C^{3+} ions have been used for ionic temperature diagnostics of the divertor region [1] assuming Doppler effect as the dominant broadening mechanism. However, for transitions from highly excited energy levels, Stark effect affects the width and shape of the emitted lines especially at high electron densities. In this paper, we propose to investigate plasma conditions for which Stark broadening competes with the Doppler broadening. The main assumptions made here, are the homogeneity of the plasma emissive region (no density or temperature gradients) and the weakness of Zeeman effect, which is neglected although it can affect the lines under strong magnetic fields. The profiles calculated ignoring Zeeman effect can be compared to experimental spectra obtained with a polarizer allowing the transmission of the π components as suggested in [1] for another reason: to reduce experimental errors in the determination of the plasma parameters. Comparing calculated profiles of C^{3+} lines, a convolution of Doppler and Stark broadenings, to experimental spectra should allow the simultaneous determination of the impurity temperature and the electron density of the plasma emissive zone.

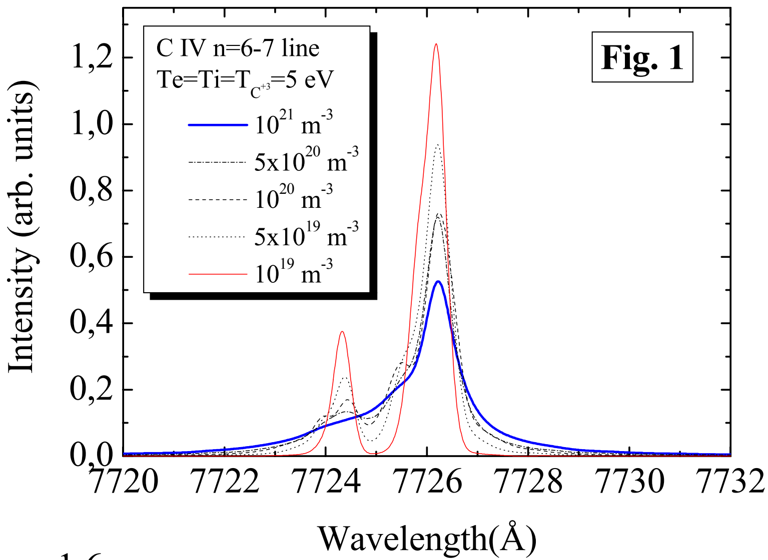
2. Stark lineshape code and Atomic physics data. The line profiles presented here have been obtained using the PPP [2] lineshape code which is based on the Standard model of Stark broadening [3], i.e. the interactions of the emitter with the plasma electrons and ions are treated respectively with the impact and quasi-static approximations. Ion dynamics effect, that the PPP code allows to include through the FFM model, is not important for the lines and plasma conditions considered here. The PPP input file consists in an atomic data basis containing mainly the energies and populations of the atomic levels and all dipole transition matrix elements connecting the levels. To build the atomic data basis we have on the one hand used the Cowan's code [4] for levels with principal quantum numbers n=4-8 to calculate all the reduced matrix elements of dipolar transitions. On the other hand, we have adopted as level energies, the values of P. Quinet [5] and the ASD database of NIST [6]. However, for the transitions considered here, we have slightly modified the energies such that the line wavelengths coincide with the corresponding experimental values given in [1] (see Table 1). For the 5 ^{2}F-6 ^{2}G and 5 ^{2}G-6 ^{2}H transitions, these experimental wavelengths are 4657.75 Å and 4658.62 Å respectively. The remaining other values are 7724.38 Å, 7725.95 Å and 7726.26 Å, they correspond to the 6 ^{2}F-7 ^{2}G, 6 ^{2}G-7 ^{2}H, and 6 ^{2}H-7 ^{2}I lines respectively. As mentioned in [1], the fine structure splitting of the above *l*-levels is negligible and hence is not included here. Note also that the level populations have been assumed to satisfy a statistical equilibrium. For all transitions between the different atomic *l*-levels, the used dipole matrix elements calculated with the RCN/RCG Cowan's atomic package code are in good agreement with the corresponding ones extracted from the ASD database [6]: $g_k A_{ki}$ values (statistical weight $g_k=(2s+1)\,(2l+1)$ of the upper *l*-level k of a transition k→i times the spontaneous transition probability A_{ki}) were converted to line strength S_{ki} using the following formula: $A_{ki} = 2.0261 \times 10^{18} S_{ki} / \lambda_{ki}\, g_k$, where the wavelength λ_{ki} of the transition in Å, A_{ki} in s^{-1} and S_{ki} in atomic units. The square root of S_{ki} gives the reduced matrix element of the transition.

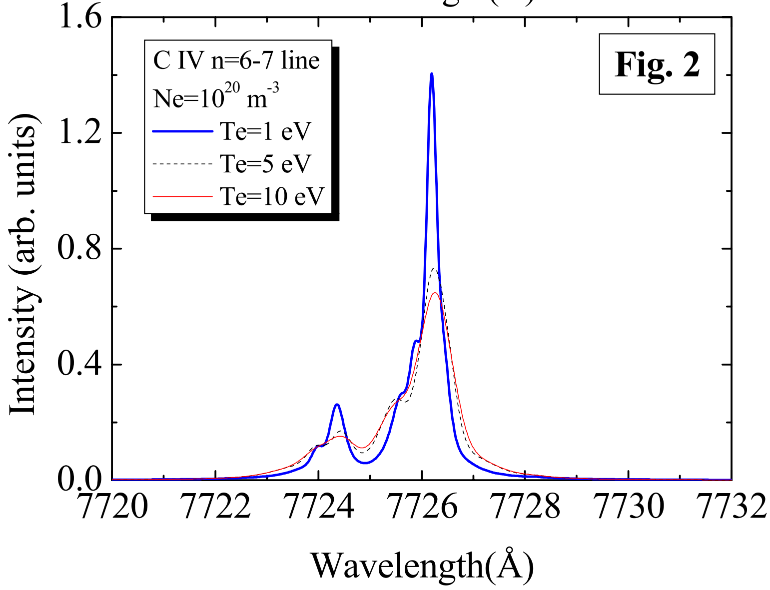
Level	5 ^{2}D	5 ^{2}F	5 ^{2}G	6 ^{2}D	6 ^{2}F	6 ^{2}G
Theoretical energy (cm^{-1})	449 889.0 (a)	449 941.3	449 945.2	471 371.0 (a)	471 402.4	471 405.8
Adopted Energy (cm^{-1})	449 882.25	449 934.5	449 939.4	471 369.6	471 401.0	471 404.1
Level	6 ^{2}H	7 ^{2}F	7 ^{2}G	7 ^{2}H	7 ^{2}I	
Theoretical energy (cm^{-1})	471 406.8	484 341.9	484 345.6	484 345.8	484 346.0	
Adopted Energy (cm^{-1})	471 405.0	484 340.5	484 347.0	484 347.5	484 347.8	

Table 1. (a) From [6]: mean value of the fine levels $^2D_{3/2}$ and $^2D_{5/2}$. All other theoretical energies are taken from [5] which reports experimental values of Bashkin and Stoner [7]

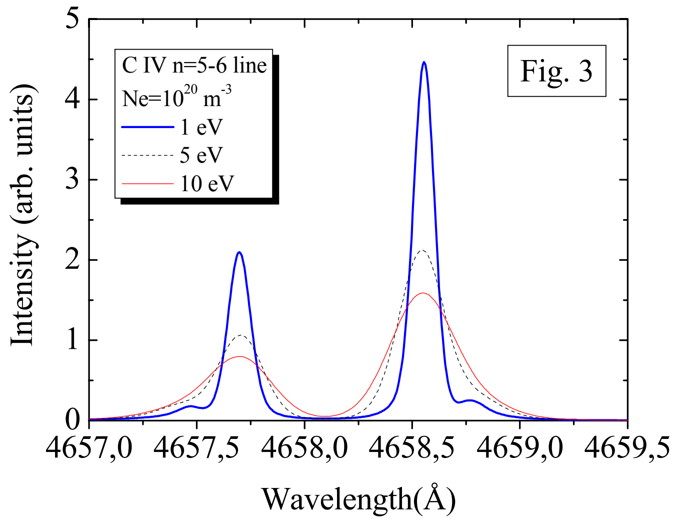
3. Results and discussion. As already stated for the considered plasma conditions (Ne=10^{19}-10^{21} m^{-3}, Te=10-1 eV), Doppler effect competes with Stark effect for the broadening of the C IV n=5-6 and n=6-7 lines. It's known that Stark broadening depends strongly on the electron density and weakly on the electron temperature while Doppler broadening depends only the emitter temperature. Increasing the temperature has opposite effects on Doppler and Stark broadening if the emitter (C^{+3}) and the electron temperatures are equals. To illustrate this we present in **Figs 1-2**, profiles of the C IV n=6-7 line calculated for a variety of electron densities and temperatures of a deuterium plasma with Te=T_{D+}=T_{C+3}.

Fig. 1 shows C IV n=6-7 line profiles calculated for a fixed temperature Te=T_{D+}=T_{C+3}=5 eV but for electron densities between 10^{19} and 10^{21} m^{-3}. It can clearly be seen from **Fig. 1** the increase of line broadening due to Stark effect and the decrease of the dip between the peaks with increasing electron density **Fig. 2** represents calculated profiles of the same line at a fixed density of 10^{20} m^{-3} and temperatures of 1, 5 and 10 eV. The features accompanying the two main peaks are due to the forbidden components owing to Stark effect which couples energy levels. Increasing the temperature leads to the attenuation of these features which become masked by Doppler effect.





For the C IV n=5-6, we show only the effect of the temperature on the line profile for a fixed density of 10^{20} m^{-3} (**Fig. 3**). Again, features appear on the sides of the two peaks at the lowest value of 1 eV and disappear with increasing temperature hence increasing Doppler broadening. The complex shapes of both the C IV n=5-6 and n=6-7 can be exploited, by comparison to experimental spectra, for the simultaneous determination of the electron density Ne, the C^{+3} ion temperature T_{C+3} and even the electron temperature Te if different from T_{C+3}. The results that can be obtained with such a spectroscopic method can be confronted to those obtained with other independent methods such that based on line intensities.



4. Conclusion .

We have presented calculations of Stark-Doppler profiles of the C IV n=5-6 and n=6-7 lines for plasma conditions where these broadening mechanisms are such that a simultaneous spectroscopic determination of the electron density and the C^{+3} and electron temperatures is possible. These calculations will be compared to experimental data from JT-60 U and other fusion oriented devices in the near future.

References

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