§83. Ion Temperature Measurement for Edge/divertor Plasmas Using Helium Line Emission

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The spectral line shape of He I is governed by the electron temperature and electron density via Stark broadening and by the temperature of the excited state via Doppler broadening. Stark broadening is described by a Lorentzian function, whereas Doppler broadening is described by a Gaussian function. The convolution of these two functions is called a Voigt function, which is represented by an integral equation. A convenient formula for the Voigt spectral line profile as a function of wavelength λ normalized to the peak at λ_0 has been proposed in ref.[1] as

$$\frac{I(\lambda)}{I(\lambda_0)} = \left(1-\frac{W_\mathrm{L}}{W_\mathrm{V}}\right)\exp\left(-\left(\frac{\lambda-\lambda_0}{W_\mathrm{V}/(2\sqrt{\ln 2})}\right)^2\right)+\frac{W_\mathrm{L}}{W_\mathrm{V}}\left(1+\left(\frac{\lambda-\lambda_0}{W_\mathrm{V}/2}\right)^2\right)^{-1}$$

$$+0.0016\left(1-\frac{W_\mathrm{L}}{W_\mathrm{V}}\right)\frac{W_\mathrm{L}}{W_\mathrm{V}}\left(\exp\left(-0.4\left(\frac{\lambda-\lambda_0}{W_\mathrm{V}}\right)^{2.25}\right)-\left(1+0.1\left(\frac{\lambda-\lambda_0}{W_\mathrm{V}}\right)^{2.25}\right)^{-1}\right)$$

where W_V is the width of the Voigt function determined by

$$W_\mathrm{V} = \frac{W_\mathrm{L}}{2}+\sqrt{\frac{W_\mathrm{L}^2}{4}+W_\mathrm{G}} \equiv W_\mathrm{L}[+]W_\mathrm{G}$$

where W_L and W_G denote the full width at half maximum (FWHM) of the Lorentzian and the Gaussian functions, respectively. We simply describe the convolution in terms of these broadenings by using [+] for our convenience. The departure of this empirical formula from the exact formula is estimated in ref. [1] to be within -5 % and +2.5 %.

The last fiscal year, we proposed that the ion temperature, the neutral temperature and the electron density can be determined from the spectral line shape of the following three atomic helium lines of the upper states, (a) 3^1P (501.567 nm), (b) 7^1P(335.455 nm), and (c) 7^3D(370.500 nm), where the lower terms with principal quantum number $n = 2$ (visible region) of each transition are uniquely determined due to the selection rule. The method can be summarized by the following three equations[2]:

$W_\mathrm{V}(3^1\mathrm{P}) = W_\mathrm{G}(3^1\mathrm{P}) = W_\mathrm{G}(\mathrm{T}(\mathrm{He}^0))$,

$W_\mathrm{V}(7^1\mathrm{P}) = W_\mathrm{G}(\mathrm{T}(3^1\mathrm{P}))\ [+]\ W_\mathrm{L}(7^1\mathrm{P})$,

$W_\mathrm{V}(7^3\mathrm{D}) = W_\mathrm{G}(7^3\mathrm{D})\ [+]\ W_\mathrm{L}(\mathrm{n_e}(7^1\mathrm{P}))$,

where G, L, and V denote the broadening of Gaussian, Lorentzian and Voigt profiles, respectively.

In this report we justify the principle of the method from the view point of the collisional-radiative (CR) model.

Figure 1 shows the comparison of the line width (FWHM) of the ^{3}D states between Doppler and Stark broadening for $n = 3$ to 8. For Doppler components typical ion or neutral temperature range for the detached recombining plasma were taken into consideration.

One can see that in the low-n state, the contribution of the Stark broadening is negligible even in considerably high electron density.

However, as n increases, the Stark broadening becomes comparative to the Doppler broadening. It suggests the possibility of resolving these components by observing both low and high n components.

Next we evaluated the contribution of the population influx to each state, since the influx caries the information of the thermal motion of the previous state.

Figure 2 shows the ratio of the atomic component of the population influx to specific states to those of the ionic component calculated based on the CR-model including the radiation trapping [3]. The evaluation was conducted for the brightest point (denoted the label 3) of the detached recombining plasma in MAP-II divertor simulator [4].

The main populating process is the excitation from the ground atomic state for low-n states and ^{1}P states (due to the strong optical coupling to the ground state, namely the radiation trapping) while, that of high-n (≥ 7) ^{3}D states are the recombination from the ionic state.

On the other hand, the ionic component has been found to be less effective even for higher n states for ionizing plasma. Therefore, this method not only offers these diagnosing method for recombining plasmas, but also contains the possibility of investigating the population dynamics between the exited states.

[1] E. E. Whiting, J. Quant. Spec. Rad. Trans. **8**, 1379-1384 (1968).
[2] S. Kado et al., J. Nucl. Matter. **415**, S1174 (2011).
[3] Y. Iida, S. Kado, A. Okamoto *et al.*, J. Plasma Fusion Res. SERIES, **7**, 123(2006).
[4] S. Kado *et al.*, J. Plasma Fusion Res. **81**, 810 (2005).

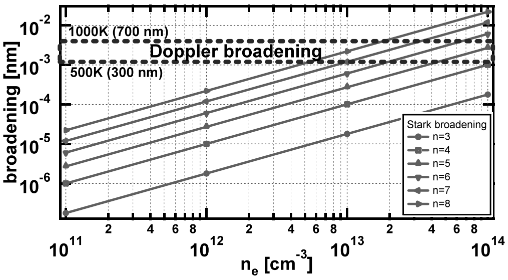

Fig. 1 Comparison between Doppler and Stark broadening for the transition from ^{3}D states (n ≥ 3) to $n = 2$ states in He I spectra.

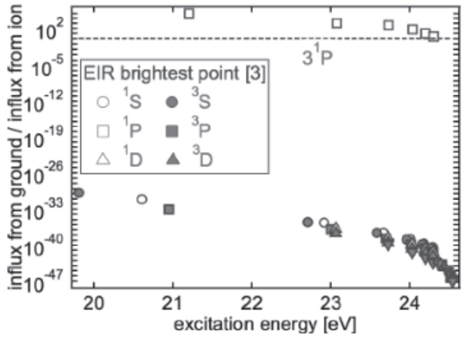

Fig. 2 Contribution ratio of the population influx between atomic and ionic states.