# §67. LHD Plasma Diagnostics Using Optically Thick Helium Collisional-Radiative Model

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Understanding of the reactions of atomic and molecular hydrogen in LHD edge plasmas is essential to improve the performance of the main plasmas and to reduce the heat flux to the divtertor wall. In order to investigate the reactions, we have been developing collisional-radiative models and neutral transport code for the hydrogen species. In the models, the electron temperature $T_\mathrm{e}$ and density $n_\mathrm{e}$ are input parameters. Determining them from visible emission line intensities of helium atoms with a collisional-radiative model is one of widely used methods [1)]. However, the radiation trapping effect is neglected in many cases.

We have recently proposed a simple and precise method to include the radiation trapping effect in the collisional-radiative model [2)], where the photo-excitation rate from the ground state is included as fitting parameter in addition to $T_\mathrm{e}$ and $n_\mathrm{e}$ to reproduce measured line intensities. The method was applied to RF plasmas ($n_\mathrm{e} \sim 10^{16}$ m$^{-3}$) at Shinshu University in Japan. Measured intensities of the helium emission lines were well reproduced by the model, and $T_\mathrm{e}, n_\mathrm{e}$ and the photo-excitation rate were successfully determined. However, because of the low $n_\mathrm{e}$, the contribution of the photo-excitation to the population density except for the singlet $p$ states was small.

The purpose of this study is to test the method for high $n_\mathrm{e}$ LHD plasmas where the contribution of the radiation trapping to the population density distribution is expected to be not negligible. We have analyzed visible helium line intensities emitted from gas puffed helium atoms in hydrogen plasmas. Figure 1(a) shows measured spectra (Shot No. 98898). Figure 1(b) shows the population densities of the excited states derived from the intensities.

We have estimated the relaxation times of the metastable states $2^1S$ and $2^3S$, and have adopted the quasi-steady-state approximation [1, 2)] to $2^1S$ and $2^3S$. Then the population density of the excited state $p$, $n(p)$, is given by,

$$\begin{aligned} n(p) &= r_1(p) n_{\mathrm{He}} n_e + r_{2^1P}(p) n_{\mathrm{He}} I_{2^1P} \\ &\quad + r_{3^1P}(p) n_{\mathrm{He}} I_{3^1P} + \cdots \end{aligned} \qquad (1)$$

where $n_{\mathrm{He}}$ is the ground state atom density. The first term on the right hand side of eq.(1) is the conventional ionizing plasma component. The second and third terms originate from the photo-excitation to $2^1P$ and $3^1P$, respectively. $I_{2^1P}$ and $I_{3^1P}$ denote the excitation rates to $2^1P$ and $3^1P$ from the ground state by the photo-excitation per atom.

Figure 1(b) shows the result of the fitting by eq.(1). The experimental population densities are well reproduced. Obtained $T_\mathrm{e}$ and $n_\mathrm{e}$ are 12.7 eV and $5 \times 10^{18}$ m$^{-3}$, respectively. We can understand that these values reflect $T_\mathrm{e}$ and $n_\mathrm{e}$ of a position where emission intensity is maximum along the line of sight. The population of $3^1P$ is dominantly produced by the photo-excitation from the ground state. For the population of $3^1D$, the contribution of the electron impact transition from the photo-excited $3^1P$ to $3^1D$ is nearly the same as the direct electron impact excitation from the ground state. For the other excited states, the contribution of the photo-excitation is small. We could not determine $I_{4^1P}$ in eq.(1) due to the low intensity of $4^1P - 2^1S$ emission line. However, transitions from $4^1P$ to other states by electron impact is expected to be small because the population densities of $4^1S$ and $4^1D$ are well reproduced by the model. The excitation from the photo-excited $2^1P$ to other states is negligible for $n_\mathrm{e}$ in this plasma.

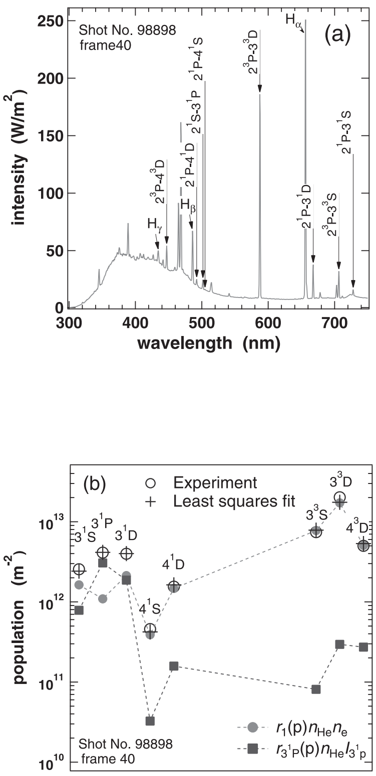


Fig. 1: (a) Spectra observed in LHD plasma (Shot No. 98898). (b) Population distribution. Open circles: spectroscopic measurement; plus signs: result of the least-squares fit calculated using eq. (1) with optimized values of $n_e$, $T_e$, $I_{3^1P}$ and $n_{\mathrm{He}}$.

1) Goto, M.,: JQSRT **76**(2003)331.

2) Sawada, K. et al.: Plasma and Fusion Research **5**(2010)001.