§5. Significant Reabsorption Effect in Formation of Helium Level Populations

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The population distribution over the excited levels of neutral helium can be obtained with the collisional-radiative (CR) model for a given set of the electron temperature T_e and the electron density n_e. The CR model for neutral helium has been extended so as to include the reabsorption effect in the resonance lines[1].

If the plasma considered is in the ionizing phase and the quasi-steady-state (QSS) approximation is applied to the two metastable states as well as the ground state, any excited level population is expressed as

$$N(p) = R_1(p)N(1^1\mathrm{S})n_e + \sum_n R_{n^1\mathrm{P}}(p)I(n^1\mathrm{P})N(1^1\mathrm{S}), \quad (1)$$

where $N(1^1\mathrm{S})$ is the ground state population, $I(n^1\mathrm{P})$ is the photoexcitation rate coefficient for the transition from the ground state to $n^1\mathrm{P}$, and $R_1(p)$ and $R_{n^1\mathrm{P}}(p)$ are called the population coefficients and functions of T_e and n_e. The first term in Eq. (1) is the conventional ionizing plasma component and the remaining terms are due to the reabsorption effect. Here, $3^1\mathrm{P}$ is only considered as the upper level of the photoexcitation process and all the other photoexcitation processes in Eq. (1) are omitted.

We can calculate with this extended CR-model the population distribution in absolute units when T_e, n_e, $I(3^1\mathrm{P})$, and $N(1^1\mathrm{S})$ are known. Here, we attempt to solve a reverse problem, namely, those parameters are determined so that a merit function

$$f(T_\mathrm{e}, n_\mathrm{e}, N(1^1\mathrm{S}), I(3^1\mathrm{P})) = \sum_p \left(\frac{N^{\exp}(p) - N(p)}{N^{\exp}(p)} \right)^2 \quad (2)$$

takes the minimum, where $N^{\exp}(p)$ is the measured population of level p and the summation is conducted over the all excited levels for which the population is measured.

The observation of emission lines in the visible wavelength range is made for a discharge shown in Fig. 1, where the line-averaged electron density $\overline{n}_\mathrm{e}$ is increased with the steady helium gas-puff, while the central electron temperature T_e0 is lowered correspondingly.

Nine emission lines of neutral helium are identified in the observed spectra and used for determining T_e and n_e. The results are shown with the filled squares (T_e) and circles (n_e) in Fig. 1. It is known that the line emission of neutral helium is localized at the plasma edge, so that the derived T_e and n_e are regarded as those at the plasma edge though the measurement is line-integrated.

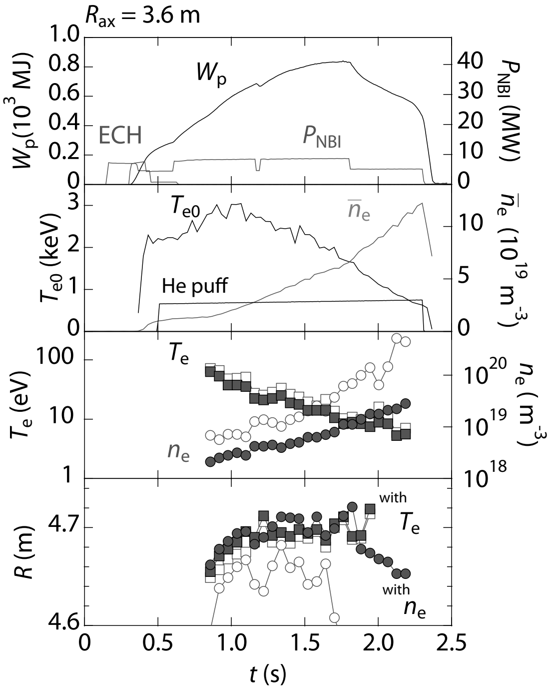

Fig. 1: Temporal development of the discharge for the present analysis. The deduced T_e and n_e and the emission locations from those parameters are also shown. The filled and open symbols show the results with and without the reabsorption effect, respectively.

For examining the significance of the reabsorption effect in the present measurement, we have made a similar analysis in which no photoexcitation process is taken into account. The open symbols show the results and it is clear that the derived n_e is systematically larger than that with the reabsorption effect, while the difference in T_e is small.

It is not possible to judge at this moment which result gives the actual parameters. We attempt to determine the emission locations by comparing the derived T_e and n_e values with their spatial profiles measured by the Thomson scattering method. It is found that the locations determined from T_e and n_e by the CR model with the reabsorption effect show good agreement with each other, while those by the model without the reabsorption effect gives significant discrepancy. These results suggest that the present model describes the actual population distribution better than the conventional model and has arrived at the state available for a practical use in the actual T_e and n_e measurements.

1) K. Sawada et al.: Plasma and Fusion Res. **5** (2010) 001.