§1. Atomic and Molecular Hydrogen Spectroscopy in LHD Plasma

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In the LHD visible spectroscopic measurements, a lot of emission lines which seem to be originated from molecular hydrogen are observed. However, the identification of them was not done. If the upper and lower levels of the transitions of the molecular emissions are identified, their intensities can be used to determine the electron temperature T_e and density n_e, the molecular density n_{H2}, vibrational temperature T_v and rotational temperature T_{rot} in the ground electronic state.

We have already constructed a collisional-radiative model of molecular hydrogen in which the electronic and vibrational states are resolved, where the main concern is to produce the effective reaction rate coefficients of molecular hydrogen which are used in neutral transport codes. In order to calculate the intensity of molecular emission lines in the visible wavelength region, we have improved the model to include the rotational state in addition. In the revised model, assuming Hund's (b) case, the levels are labeled by the principal quantum number n, and Λ, N, and J. The number of 4133 levels for $n \leq 6$ are included. Level energies of $EF^1\Sigma_g^+$, $GK^1\Sigma_g^+$, $H^1\Sigma_g^+$, $B^1\Sigma_u^+$, $C^1\Pi_u$, $B'^1\Sigma_u^+$, $D^1\Pi_u$, $I^1\Pi_g$, $J^1\Delta_g$ are taken from Ref.1. For other $n \leq 4$ states, level energies are taken from Ref.2. We calculated those for $n = 5, 6$ from electronic potentials. Spontaneous transition probabilities $e^3\Sigma_u^+ \to a^3\Sigma_g^+$, $d^3\Pi_u \to a^3\Sigma_g^+$, $i^3\Pi_g \to c^3\Pi_u$, $j^3\Delta_g \to c^3\Pi_u$, $I^1\Pi_g \to C^1\Pi_u$, and $J^1\Delta_g \to C^1\Pi_u$ in Ref.3 are included in the model. The values for other transitions are calculated according to Ref.4. Transition probabilities to continuum of $X^1\Sigma_g^+$ and $b^3\Sigma_u^+$ are also calculated. The vibrationally resolved excitation cross section from $X^1\Sigma_g^+$ to $B^1\Sigma_u^+$, $B'^1\Sigma_u^+$, $B''^1\Sigma_u^+$, $C^1\Pi_u$, $D^1\Pi_u$, $D'^1\Pi_u$ in Ref.5 are included in the model. For the excitation to other states, data in Refs.6 and 7 are used. We assume that the rate coefficients are proportional to Franck-Condon factor. In the rotational excitation, $\Delta N = 0$ or $\Delta N = \pm 1$ are assumed, considering the conservation of a and s symmetry. Excitation cross sections between excited states are estimated from united atom helium cross sections.

For the test of the model, we applied the collisional-radiative model to an RF plasma in Shinshu University. In order to determine T_e and n_e from intensities of helium emission lines, 35 sccm helium gas was introduced with 15 sccm hydrogen gas. T_e = 8.5 eV and $n_e = 1.3 \times 10^{10}\text{cm}^{-3}$ was obtained from the helium line intensities measured by an echelle spectrometer, which covers the range of 380 nm-800 nm. From the Fulcher band intensity, T_v and T_{rot} were determined to be 4200 K and 350 K, respectively. Calculated emission lines in 380 nm-800 nm using these parameters are compared with the observed emission lines. With the help of the calculated wavelength and intensity of the emission lines, we identified the observed emission lines. Figure 1(a) is an example of the identification.

Next, we applied the model to the LHD plasmas. Wavelength range of 400 nm-860 nm was observed with 24 shot by shot measurements. The calculation roughly reproduced molecular emission lines in the ranges of 470-490 nm and 607-630 nm (Fig. 1(b)). However, the other observed lines were not reproduced well. To start with, we will improve the wavelength calibration of the LHD spectrometer.

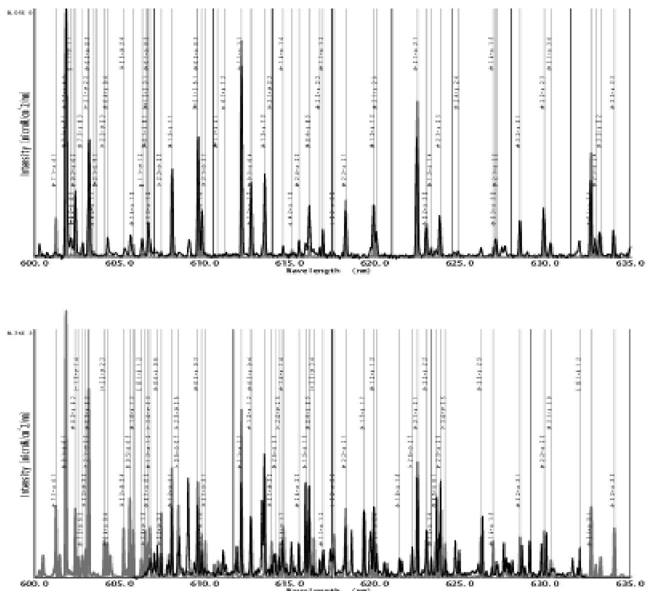

Fig. 1: Spectra of (a) RF plasma (upper) and (b) LHD (lower). Calculation (thick, gray) and Experiment (thin).

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