§9. Spectroscopic Diagnostics in Boundary Plasmas

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The objectives of this workshop are to understand and interpret spectroscopic data, and to obtain the knowledge required to control peripheral plasmas such as divertor plasmas. Compared with core plasmas, these plasmas have lower temperature and higher density, and their properties depend on the collective phenomena of atoms, molecules and their ions. Hence, understanding the collective phenomena is directly linked to controlling these plasmas. These years, the influences of the collective phenomena have been quantitatively estimated. It is certain that the quantitative estimation owes much of the progress to collection and compilation of atomic and molecular data, modeling using the compiled data, and improved technique of spectroscopic measurement. In the workshop, the researchers in these fields, that is, data-producers, modelists and experimentalists, reported the present status of their progress and the issues from their respective points of view.

From a viewpoint of the data-producers, problems on theoretical calculation of cross-sections were reported. For vibrational and rotational transition, dissociative recombination, and dissociative excitation of H_2^+ by collision with low energy electron, several problems were pointed out: only under limited conditions, that is, collision energy of < 2 eV and vibrational quantum number (v) of ≤ 2, the contribution from highly and doubly excited electronic state can be neglected. Under another conditions, that is, one electron in the first excitation orbit, the other in a highly excitation orbit, and collision energy of < 13 eV, the cross-sections can be calculated beyond the limit of v. But another problem, high order effects in the configuration-interaction, arises. The first order perturbation theory has been still used for this case. Non-adiabatic effects at high collision energy of > 3 eV were considered to be small. However, it was found that this is the case for D_2^+ and that this is not necessarily the case for H_2^+. The excitation cross-section from the ground state to the *d*-state of H_2 by electron collision was calculated using the Gryzinski method. The vibrational temperature of the ground state estimated by a coronal model using this cross-section was found to be different by ~ 10% from that using the Franck-Condon principle. This difference is equivalent to overestimation by the latter model (Franck-Condon) for the population density of $v \geq 4$ by more than 30%.

As for modeling, it was reported that integration of a collisional-radiative model code and transport codes had progressed and that comparison of code prediction and experimental data was performed. For three-dimensional transport analyses on LHD plasmas, the integrated codes for neutral hydrogen and helium have been extended from the original one-dimensional ones. In these codes, not only ground state but also vibrationally excited H_2 and metastable He are tracked as an individual particle by the Monte Carlo technique because they can affect the spatial distribution of the emission. The spatial distribution of density and temperature of hydrogen and helium predicted by the integrated code was compared with that determined experimentally using Zeeman and Doppler effects, resulting in good agreement. From this agreement, it was found that the spatial distribution of the emission from neutral hydrogen and helium indicated the spatial distribution of the particle recycling flux. Hence observation of the different spatial distribution of the emission between two magnetic configurations of $R_{ax} = 3.6$ m and $R_{ax} = 3.75$ m was found to be due to different spatial distribution of particle flux to the divertor plates.

For JT-60U divertor plasmas, similar analyses were performed. The decay lengths of H_2 line intensity were ~ 1 cm and ~ 4 cm from the divertor plates along the separatrix, respectively in the attached and the detached divertor plasma. The prediction of the integrated code was in agreement for both the attached and the detached case. However, there is still difference in absolute intensity for the detached case. The reason is not known yet. Another integrated code was developed for impurity transport analyses. The integrated code predicted that there were two predominant emission zones of C^{3+} line along a spectroscopic viewing chord: a common flux region and a private flux region. This prediction gave reasonable interpretation on the double Doppler profile of the C^{3+} line, which was measured as line integral along the viewing chord. The prediction also indicated that C^{3+} temperature was close to D^+ temperature in the inner divertor plasma because of short energy relaxation time between C^{3+} and D^+ due to low temperature and high density. It was therefore concluded that D^+ temperature could be measured from the Doppler broadening of the C^{3+} line. But this result was not the case for the outer divertor plasmas because of long energy relaxation time.

It was reported that a new recombination process of plasmas, assisted by hydrocarbons (Molecular Assisted Recombination), was identified in a divertor plasma simulator. When CH_4 was injected, the ion flux along magnetic field lines decreased due to the charge exchange ionization followed by dissociative recombination of CH_4:

$$CH_4 + H^+ \rightarrow CH_4^+ + H \qquad (1)$$

$$CH_4^+ + e \rightarrow CH_3 + H \qquad (2)$$

The efficiency of the decrease of the ion flux becomes high with an increase of the number of H of the injected hydrocarbon, i.e., CH_4, C_2H_6 and C_3H_8, in that order. This order can be interpreted as the number of cycles for a hydrocarbon to work like a catalyst as understood from eqs. (1) and (2).

As described above, these research activities are linked with each other from an academic point of view. We believe that this workshop gave a meaningful opportunity to exchange information and make a summary on the present status of these research fields.