§9. Atomic and Molecular Processes in Divertor Plasmas

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Several problems, which relate each other, have been addressed. They are:

i) What is the temperature of the divertor plasmas ?

ii) Whether does the Molecular Assisted Recombination (MAR) really control the recombination of the divertor plasmas ?

iii) Do we really understand MAR quantitatively ?

iv) How much does the plasma detachment reduce the heat load to the divertor plate ?

v) How far do we know about the processes concerning molecular hydrogen and its isotopes ?

We have investigated the above problems, and our tentative conclusions are given below.

i) On the NAGDIS-II divertor simulator, probe measurements were done. From the probe characteristics the electron temperatures between 3 and 10 eV were obtained. From the Balmer continuum spectra, electron temperatures close to 0.1 eV were obtained. The plasma fluctuation was examined carefully. Fluctuations of several MHz with the amplitude of about 10 V were found as well as a sawtooth-like oscillation of period of 5 ms with similar amplitude. In the peripheral region, when the probe data was corrected for the fluctuation the original electron temperature of 37 eV changed to 0.7 eV.

ii) Several year ago, MAR was proposed as a new recombination mechanism which may enhance recombination of rather high temperature plasmas. One factor which was overlooked at that time was: Even if MAR takes place, very fast ionization due to the conventional collisional-radiative ionization offsets easily the MAR recombination, effectively reducing the effect of MAR. This would be the reason why MAR is not confirmed in real divertor plasmas yet.

iii) Two groups conducted the collisional-radiative model calculations including molecular hydrogen, in which vibrationally excited levels are treated independently. Detailed comparison was made between the results with the independent vibrational levels and those on the assumption of the quasi-steady-state (QSS) for the vibrationally excited levels depending on the ground level. The latter simplified model gives results substantially different from the former more accurate method. For example, the temporal developments of the level populations are quite different even for sufficiently late time, and the ion conversion rate and the dissociative attachment rate in the latter model are higher than the accurate treatment. For electron densities above 10^{20} m^{-3} the QSS assumption becomes good.

A detailed collisional-radiative model calculation including all the vibrational levels revealed that the MAR rate coefficient originally proposed coincided with the present calculation in which the hydrogen molecules start as the ground vibrational level molecules $v = 0$. When they start as vibrationally excited molecules, *e.g.*, $v = 4 - 6$, the MAR rate coefficient becomes larger by about one order. This finding indicates that, in order to understand the recombination process in divertor plasmas, it is essential to have knowledge of what is the vibrational state the recyling molecules are in.

iv) On the JT-60U divertor plasma atomic and molecular spectroscopy of hydrogen were performed under the Marfe conditions. It was concluded that the ratio of the volume recombination rate to the wall recombination rate is 1:2. Just in front of the divertor plate the Fulcher band of molecular hydrogen was observed. It was found that the rotational temperature is quite low, *i.e.*, 0.05 eV, while the vibrational level populations are 1:0.85:0.55 for $v = 0$, 1 and 2, respectively. The source of the hydrogen molecules is not known.

v) For molecular hydrogen and its ions, electron collision cross sections are well established up to the energy above which doubly excited molecules are formed. In molecular ion electron collisions dissociative recombination has a resonance at the energy between atomic n=4 and 5, and H^- can be produced by $H_2^+ + e \rightarrow H^+ + H^-$. For electron collision processes for H_2^+, HD^+, and D_2^+ the cross section data are available, but data are not yet ready for T_2^+. For H_3^+ cross section data is available for energy higher than 1 eV, while for lower energies no data is available. For HeH^+ and CH^+ data is available for energies lower than 1 eV. In general, the rate coefficient for molecular processes depends strongly whether a particular process involves a potential curve corssing. In the case with a level crossing the rate coefficient is typically 10^{-7} cm^3s^{-1}, which is compared to 10^{-10} cm^3s^{-1} for processes without a crossing.