## §4. Catalytic Mechanism of Divertor Plasma Recombination Based on Hydrocarbon Impurities

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The characteristic features of recently observed detached divertor plasmas provide a strong indication that the plasma detachment phenomenon is closely related to the volume recombination of cold divertor plasma[1]. The theoretical analysis of a hydrogen divertor plasma recombination [2] shows that for temperatures 0.2 - 0.3 eV, the radiative and the three-body recombination processes are dominant recombination mechanisms, while in the temperature range 0.3 - 2 eV, the volume recombination is dominated by the negative ion assisted[3] and ion-conversion assisted[4] molecular recombination mechanisms. In these two mechanisms it is assumed that the hydrogen molecule is vibrationally excited; only then the initial reactions in these mechanisms (the electron dissociative attachment and the atomic to molecular ion conversion processes, respectively) have sufficiently large rate coefficients for the mechanisms to be effective.

In the present work we provide arguments that in divertor plasmas containing even a small concentration of hydrocarbon impurities, $C_x H_y$, there is another powerful mechanism which drives the volume plasma recombination. This mechanism is based on the reactions

$$H^+ + C_x H_y \longrightarrow H + C_x H_y^+$$
$$e + C_x H_y^+ \longrightarrow \Sigma C_{x'} H_{y'} + H'$$
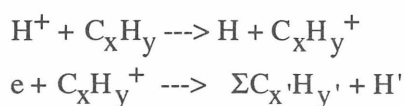
where H' is an atomic product representing the recombined (e, H(+)) pair, and the summation runs over all possible fragmentation channels. A characteristic of this recombination scheme is that most of the products of the dissociative recombination step are again hydrocarbon molecules which can initiate new charge exchange - recombination cycles similar to the one given above. Thus, the $C_x H_y$ molecule exerts a catalytic effect on the volume divertor plasma recombination. The number of charge exchange-recombination cycles of the above type provided by a given $C_x H_y$ molecule increases with increasing complexity of the molecule, and also depends on the fragmentation pattern of the second step of the reaction cycle. For instance, for $C_2 H_4$ the number of cycles is 40 before the fragmentation chain comes to the chain-terminating cycle

$$H^+ + CH \longrightarrow H + CH^+$$
$$e + CH^+ \longrightarrow C + H .$$

The efficiency of the catalytic $C_x H_y$ molecule assisted recombination (MAR) mechanism is based not only on the large number of recombination cycles, but also on the, generally, large cross sections of the two reactions involved in each of the cycles. These cross sections also (generally) increase with increasing the complexity of the $C_x H_y$ molecule (and its ion). This follows from the fact that the charge exchange reactions between protons and any hydrocarbon molecule are exothermic (contrary to the case of hydrogen molecule, for which the reaction is endothermic for all vibrational states bellow the vibrational state v=4), and that, owing to the multitude of internal degrees of freedom in $C_x H_y$, the reaction exothermicity can easily be expended to vibrational and rotational excitation of the $C_x H_y^+$ reaction product, thus creating the conditions for a (quasi-)resonant electron transfer process. Vibrational excitation of the $C_x H_y^+$ ions may significantly enhance the cross section for the dissociative recombination reaction, the second reaction step of the cycle. (For the case of hydrogen molecular ion this enhancement is an order of magnitude.)

In order to appreciate the efficiency of the catalytic $C_x H_y$ MAR mechanism, we shall compare it with the efficiency of the ion - conversion MAR based on the molecular hydrogen. A detailed analysis of the efficiencies of the two mechanisms is given elsewhere[5]. The concentration of $C_x H_y$ molecules in the molecular hydrogen divertor gas, required to obtain the same number of recombined electron -ion pairs as the entire hydrogen gas at the plasma temperature of 1 eV, is: 0.09(for CH_4), 0.07(for $C_2 H_4$), 0.04(for $C_2 H_6$), 0.036(for $C_3 H_6$) and 0.025(for $C_3 H_8$).

It should also be mentioned that the catalytic $C_x H_y$ MAR mechanism is operative in a much broader plasma temperature range (than the pure ion conversion mechanism in H_2), extending up to 8 - 10 eV[5].

References
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