§2. Charge Transfer Processes in Collisions of Ground State C^+ Ions with H_2, D_2, CO and CO_2 Molecules in the Energy Range from 0.15 keV to 4.5 keV

Kusakabe, T., Hosomi, K., Nakanishi, H. (Kinki Univ.),
Kimura, M. (Yamaguchi Univ.), Kato, T.

An understanding of charge transfer processes at low collision energies has become increasingly important in a number of applications such as plasma science and material science where low-temperature plasmas play a key role in determining characteristics of plasma behavior and of target materials. Although many investigations have been performed on charge transfer of various ions in collisions with various gas atoms and molecules, data are still limited and fragmentary, in particular at energies less than 10 keV. Furthermore, they often contradict each other.

In the present work, we have carried out a joint experimental and theoretical study for understanding collision dynamics for charge transfer processes of the ground state $C^+(^2P)$ ions, which are typical impurity ions in most laboratory plasmas. Charge transfer cross sections have been determined over the kinetic energy of 0.15 keV to 4.5 keV in collisions with H_2, D_2, CO and CO_2 molecules. The specific processes we have studied are collisions of the ground state $C^+(^2P)$ ion with the various molecules :

$C^+(^2P) + H_2,D_2(v = 0) \text{-->} C + H_2^+,D_2^+(v = 0)$ (1)

$C^+(^2P) + CO(v = 0) \text{--->} C + CO^+(v = 0)$ (2)

$C^+(^2P) + CO_2(v = 0) \text{-->} C + CO_2^+ (v = 0)$ (3)

where v describes the vibrational quantum number.

These collision processes, which are all endothermic with appreciable energy defects (as shown above), are important to low temperature edge plasmas such as those in the thermonuclear fusion devices with carbon-coated or graphite-lined walls as plasma facing material. Also collisions of low charged ions with the excited molecules are critical in understanding features in plasma-based material and thin film production. In addition, these collision systems are very important for understanding the dynamics for the cancer therapy, which employs accelerated ion-beams, and also constitute an essential part of the interstellar cloud formation in astronomy .

In the present experiments, the ionizing electron energy in ion source is carefully controlled to avoid the production of the metastable-state ions so that the cross section values for the ground state ions are more accurately determined. However, there is always a possibility that a small amount of metastables exists in the ion beam, therefore it is important to assess the contribution from the $C^{+*}(^4P)$ metastable state to the total charge transfer processes. We examine the effect both experimentally and theoretically. We have carried out a joint experimental and theoretical study on charge transfer processes in collisions of C^+ ions with H_2, D_2, CO and CO_2 molecules in the energy region from 0.15 keV to 4.5 keV. The measured and theoretical results agree reasonably well above 1 keV, while a discrepancy begins to show up at lower energies. The present experimental cross sections for charge transfer by the ground state C^+ ion impact on H_2, D_2, CO and CO_2 targets at 2 keV are approximately 1 x 10^{-16} cm^2, 2.2 x 10^{-16} cm^2 and 2.0 x 10^{-16} cm^2, respectively. The observed cross sections decrease rather slowly with the decreasing collision energy, in disagreement with the present theoretical trend which predicts a much more significant decrease. These results are significant for application in fusion research. For CO and CO_2, the present results are significantly smaller than those earlier measurements. There is found no sizable difference in the cross sections between H_2, and D_2 targets. These processes are important for the better understanding of the plasma diagnostics at the divertor edge. Though we have carefully chosen the ionizing electron energy far below the production threshold of the metastable C^+ ions, there is a slight chance that the present ion beam may not be completely free from the metastable ions. To some degree, vibrationally excited molecules may contribute to the experimental overestimation of all the cross sections at lower energies. Further experiments employing high-purity electronic ground state ions and vibrational ground state molecular targets would be highly desirable to verify our results.