§6. Cross Sections of Charge Transfer by Slow Helium Ions in Collisions with Water Molecules

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Water molecule (H_2O) is main components of comets and one of the typical impurities in almost all laboratory plasmas. Recent observations of X-ray emission from comets have been modeled using the charge transfer processes. The fully and partially striped solar wind ions capture electrons from cometary gases into the excited state, and emit photons.[1)] In the large thermonuclear fusion devices, adsorbed H_2O molecules are released from the inner wall of the vacuum vessel and some electrodes. It is considered to have affected the character of plasma through various collision processes. On the other hand, a helium atom is one of the common elements in the solar wind plasmas and the fusion product in the next day large fusion devices. It is important, therefore, to measure the cross sections for charge transfer of slow He^+ and He^{2+} ions colliding with H_2O molecules. But the previous cross section measurements in these collision partners are scarce. To obtain precise and reliable cross section data and a detailed understanding of the collision dynamics, therefore, we have carried out a joint experimental and theoretical study for charge transfer of He^+ and He^{2+} ions colliding with H_2O molecules at low keV energies.

In the present experiment, He^+ and He^{2+} ions were extracted from an electron impact ion source and introduced into a 4 cm long collision cell filled with high purity water molecules. After collisions, fast ions and product fast neutral particles were detected with a position sensitive micro-channel plate detector. The cross sections of charge transfer were determined by an initial growth rate method. In order to extract high pure ground state He^+ ions, they were produced from ^4He atoms by 30.5 eV electron impact. On the other hand, He^{2+} ions were generated by 270 eV electron impact from the isotope ^3He atoms to prevent mixing of the H_2^+ ions. The introducing system of water vapor with water reservoir was constituted, which can be cooled by liquid nitrogen in order to remove the air absorbed into water.

As a first step of this study, the cross sections for charge transfer by H^+ ions colliding with H_2O molecules have been measured in the collision energy range between 0.2 and 4.0 keV. As shown in Fig. 1, the present cross section data gradually decrease with increasing collision energy, and are found to be in good agreement with previous experimental data of Greenwood *et al.*,[1)] Lindsay *et al.*,[2)] and Dagnac *et al.*[3)] Recent theoretical calculations of Mada *et al.*[4)] are in fairly good agreement with the experimental data in the energy range of above 1 keV, while they are apart from the measured cross sections at energies below 1 keV.

The present cross sections for charge transfer by He^+ ions colliding with H_2O molecules have been measured in the collision energy range between 0.2 and 4.0 keV. The present data increase with increasing collision energy and can be connected smoothly with the data of Rudd *et al.* measured at higher energy region.[5)] The previous experimental data of Greenwood *et al.* measured in the energy range of 1.2 to 6.6 keV[1)] are almost constant, and are larger by a factor of two at 1.2 keV in energy than the present results. Recent theoretical calculations of Cabrera-Trujillo *et al.*[6)] are found to be in good agreement with the present data.

In He^{2+} + H_2O collisions, only two data sets are available till now. Rudd *et al.* measured both single- and double-charge transfer cross sections (σ_{21}, σ_{20}) at above 5 keV/u in energy.[5)] Greenwood *et al.* have presented two articles concerning the cross section data at energies below 7 keV/u.[1,7)] The present measurements for He^{2+} ions colliding with H_2O molecules have been carried out in the collision energy range between 0.6 and 8.0 keV. The present σ_{21} results are in excellent agreement with the previous data of Greenwood *et al.*[1,7)] However, the present σ_{20} data are found to gradually increase with increasing collision energy, while the previous data of Greenwood *et al.*[7)] decrease. Theoretical calculations of Cabrera-Trujillo *et al.*[6)] are supporting the present results.

The theoretical calculations using the molecular-orbital close-coupling method (MOCC) will be applied to these specific processes considered with the molecular vibrational effects.

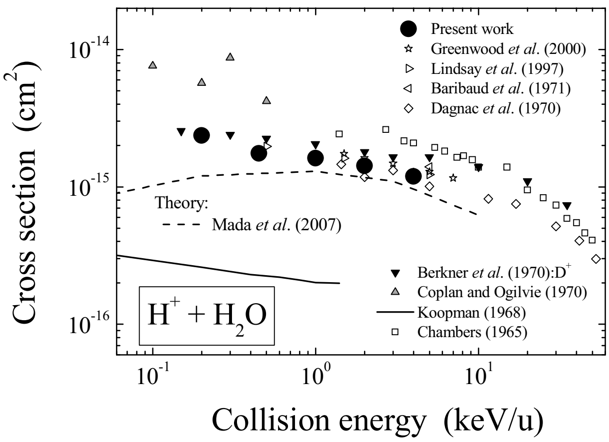

Fig. 1. Charge-transfer cross sections for H^+ ions in collisions with H_2O molecules.

1) Greenwood, J.B. *et al.*: Astrophys. J., **529** (2000) 605.
2) Lindsay, B.G. *et al.*: Phys. Rev. A, **55** (1997) 3945.
3) Dagnac, R. *et al.*: Compt. Rend., Ser. B, **268** (1969) 676.
4) Mada, S. *et al.*: Phys. Rev. A, *75* (2007) 022706.
5) Rudd, M. *et al.*: Phys. Rev. A, **32** (1985) 2128.
6) Cabrera, R. *et al.*: Phys. Rev. A, *75* (2007) 052702.
7) Greenwood, J.B. *et al.*: Phys. Scripta, **T110** (2004) 358.