Experiments on hydrogenation and deuteration of C_2H_2 and C_2H_4 on low temperature surfaces : formation mechanism of C_2H_6 with astronomical interest

H. Kobayashi,[1,2] H. Hidaka,[3] T. Hama,[3] H. Kawakita,[1] and N. Watanabe[3]

[1]*Koyama Astronomical Observatory, Kyoto Sangyo University, Japan*
[2]*Kyoto Nijikoubou, LLP, Japan*
[3]*Institute of Low temperature Science, Hokkaido University, Japan*

Simple hydrocarbons, acetylene (C_2H_2), ethylene (C_2H_4) and ethane (C_2H_6) widely exist in various circumstances in space. Although the gas phase C_2H_2 and C_2H_4 are detected in limited objects of interstellar medium (ISM, e.g., [1,2]), C_2H_6 was not detected in the ISM yet. Observational bias might be a reason for this difference because the bands of these species in infrared region are greatly affected by severe telluric absorptions. Alternatively the observational results may reflect the result of chemical evolution in ISM. Thus we performed quantitative experiments providing a precious clue for understanding the evolution of these hydrocarbons. As previously proposed, one of most important processes to form C_2H_6 is hydrogenation of C_2H_2 on low temperature surface (C_2H_2 -> C_2H_3 -> C_2H_4 -> C_2H_5 -> C_2H_6) [3, 4]. We conducted hydrogenation experiments of pure C_2H_2 and C_2H_4 solids (to compare our results with the previous studies [3, 4]) and those on amorphous solid water (ASW, to reproduce the ISM condition) at 10K and 20K, respectively. Deuteration experiments of C_2H_2 and C_2H_4 on ASW were also performed. All experiments were conducted by using laboratory setup for surface reaction in interstellar environment (LASSIE) at Institute of Low Temperature Science, Hokkaido University [5].
Obtained effective reaction rate constants, which are defined by a reaction rate constant times a number density of atomic hydrogen/deuterium adsorbed on the surface, are shown in Figure 1 with a result of CO hydrogenation on ASW reported by Hidaka et al. [6]. At 10K, the difference in the effective hydrogenation reaction rate constants between C_2H_2 and C_2H_4 was found to be a factor of ~3 on both pure solids and ASW samples, whereas previous experimental studies [3, 4] reported that the hydrogenation rate of C_2H_4 is larger than that of C_2H_2 by orders of magnitude. The kinetic isotope effects of hydrogenation/deuteration are found to be very small in both C_2H_2 and C_2H_4 reactions at 10 K. This significantly small kinetic isotope effect for tunneling reactions can be explained as "diffusive reaction" where the reaction process is dominated by diffusion of H and D atoms on the surface. At 20 K, the effective rate constants of deuteration became larger than those of the hydrogenation. This unusual behavior would be attributable to the difference of the number densities of H and D atoms on the surface.

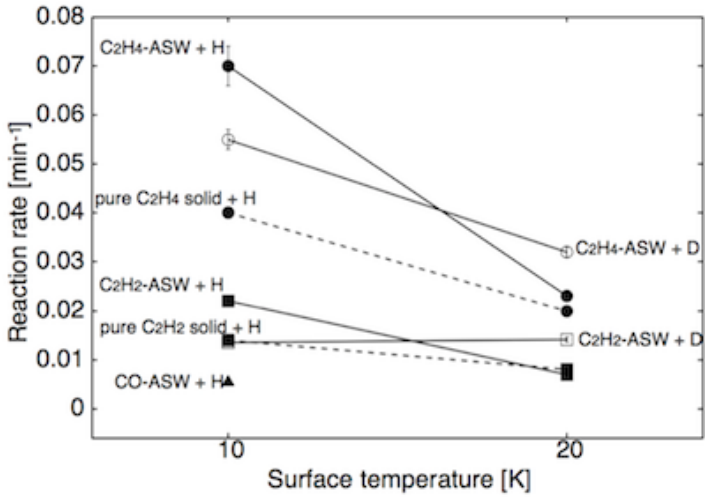

Figure 1: Temperature dependences of the effective reaction rate constants for the H and D atom exposure for each sample (filled square with solid line; C_2H_2-ASW + H, filled square with dashed line; pure-C_2H_2 solid + H, filled circle with solid line; C_2H_4-ASW + H, filled circle with dashed line; pure C_2H_4 solid + H, open square with solid line; C_2H_2-ASW + D, open circle with solid line; C_2H_4-ASW + H, triangle; CO-ASW + H).

References

[1] Bast, J. E., Lahuis, F., van Dishoeck, E. F., Tielens, A. G. G. M. 2013, A&A, 551, 118
[2] Hinkle, K. H., Wallace, L., Richter, M. J., Cernicharo, J. 2008, Proc. IAU symp. 251, 2008
[3] Hiraoka, K., Takayama, T., Euchi, A., Handa, H., Sato, T. 2000, ApJ, 532, 1029
[4] Bennet, J. E., and Mile, B. 1973, J.Chem.Soc, Faraday Trans. 1, 69, 1398
[5] Watanabe, N and Kouchi, A. 2002, ApJ, 571, L173
[6] Hidaka, H., Watanabe, N., Shiraki, T., Nagaoka, A., Kouchi, A. 2004, ApJ, 614, 1124