Experimental studies on the behavior of hydrogen on bare grain surfaces and within icy grains

Tsuge, M.,[1,*] Kouchi, A.,[1] Watanabe, N.[1]
[1] tsuge@lowtem.hokudai.ac.jp, Institute of Low Temperature Science, Hokkaido University, Japan

In contrast to numerous experimental and theoretical investigations on the physicochemical processes involving hydrogen atoms and/or molecules on cosmic ice dust surfaces (especially on amorphous solid water, ASW), experimental studies on bare grain surfaces (i.e., silicate or carbonaceous materials) have been scarcely performed partly because it is difficult to prepare model surfaces. In our group, a laser ablation system was developed for in situ preparation of silicate and carbon films. Using an amorphous diamond-like carbon (DLC) film, we investigated the diffusion of physisorbed H atoms (H_2 formation) and desorption energetics of H_2.[1] We found that H_2 recombination reaction on a DLC surface efficiently occurs even at 20 K. Another important hydrogen process occurring on grain surfaces is ortho-to-para nuclear spin conversion (NSC) of H_2, since the ortho-to-para ratio not only affect chemical evolution but also affect the gas dynamics of core formation in star-forming regions. We determined, for the first time, the NSC-rates on an amorphous silicate (Mg_2SiO_4), DLC, and graphite surfaces in a temperature range 10–18 K.[2,3] The NSC process on the silicate surface is very rapid; e.g., 980 s at 10 K and 260 s at 18 K. Numerical simulations indicated that ortho-to-para ratio of H_2 in molecular clouds changes even on a bare silicate surface within an astronomically meaningful timescale. On the other hand, the NSC process on DLC and graphite surfaces are found to be several times slower than that on amorphous silicate surface.

H_2O, HCHO, and CH_3OH molecules have been found abundantly as solids in ice mantles that cover the cosmic dust. It has been demonstrated that the formation of these molecules involves the surface reaction of H atoms, which are accreted from the gas phase. For example, CH_3OH molecule is efficiently produced on ASW surface via a successive hydrogenation of carbon monoxide: $CO \xrightarrow{H} HCO \xrightarrow{H} HCHO \xrightarrow{H} H_3CO/H_2COH \xrightarrow{H} CH_3OH$. Such hydrogen reactions are thought to be active only at temperatures below ~20 K because the sticking probability of H atoms and their residence time on the dust surface are significantly reduced at elevated temperatures. However, we found that reaction of non-energetic hydrogen atoms with CO molecule can occur even in ice mantles and at temperatures as high as 70 K: the diffusive hydrogenation process.[4] In this process, hydrogen atom colliding ASW surface penetrates into ice and diffuse within the ice to induce hydrogenation reactions. Recently, we investigated the diffusive hydrogenation processes of aromatic species (benzene and naphthalene) embedded in ASW and found that a part of molecules (up to 30%) can be fully hydrogenated by an H-atom fluence relevant to molecular cloud conditions.[5]

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