Diffusive hydrogenation of CO embedded in amorphous solid water at temperature up to 70 K

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Surface processes on interstellar dust grains have an important role in the chemical evolution in molecular clouds. Hydrogenation reactions on ice surfaces have been extensively studied and are known to occur at low temperatures mostly below 20 K [1,2]. In contrast, information about the chemical processes of molecules within an ice mantle is lacking. In this work, we investigated diffusive hydrogenation reactions of carbon monoxide (CO) embedded in amorphous solid water (ASW) as a model case and discovered that the hydrogenation of CO efficiently proceeds to yield H_2CO and CH_3OH even above 20 K when CO is buried beneath ASW [3].

In our experiments, layered ice samples were prepared by depositing water molecules over solid CO (~5 monolayers, MLs), in which the thickness of ASW layer was varied from 1 to 80 MLs. The temperature of layered ice sample was set within the range 10–70 K for H-atom irradiation. Depletion of CO and formation of H_2CO and CH_3OH were monitored by the reflection absorption infrared spectrometry.

Figure 1 shows the experimental result for a layered ice at 20 K; in the IR spectrum (left panel), depletion of CO and formation of H_2CO and CH_3OH are clearly seen, and time variation of column densities are plotted on the right panel. For the ASW layer with 20 MLs, temperature dependence was investigated, and it was found that CO hydrogenation efficiency is enhanced by elevating temperatures from 10 to 20 K and that CO hydrogenation occurred even at temperatures up to ~70 K. Another series of experiments performed by varying the thickness of the ASW layer (at 20 K) revealed that hydrogenation of CO occurs when CO is fully buried under the ASW layer. The experimental results suggest that H atoms diffuse through the cracks of ASW and have a sufficient residence time to react with embedded CO. Cracks collapse at elevated temperatures but the occurrence of hydrogenation reactions means that the cracks would not completely disappear and remain large enough for penetration by hydrogen atoms. Considering the H-atom fluence in the laboratory and molecular clouds, we suggest that the penetration of H atom and its reactions within the ice mantle occur in astrophysical environments.

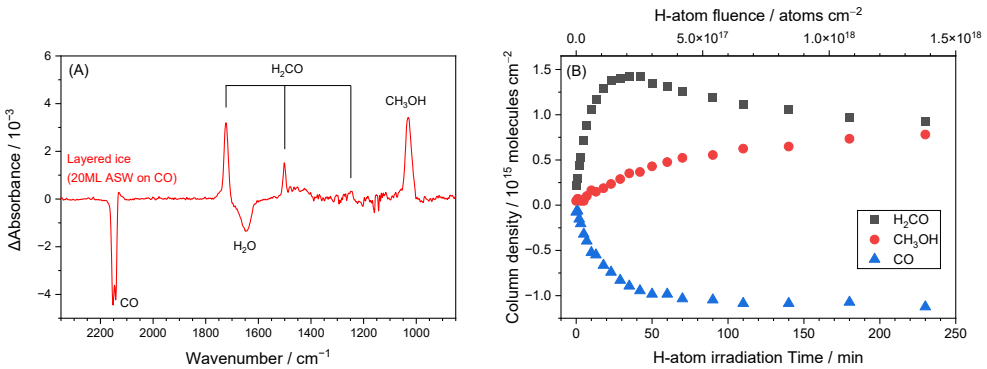

Figure 1: (A) Infrared difference spectrum after 180 min H-atom irradiation on a layered sample with 20 MLs ASW on 5 MLs CO. (B) Variations in column densities with H-atom irradiation time.

References

[1] Watanabe, N., Shiraki, T., & Kouchi, A. 2003, ApJL, 588, L121
[2] Fuchs, G. W., Cuppen, H. M., Ioppolo, S., et al. 2009, A&A, 505, 629
[3] Tsuge, M., Hidaka, H., Kouchi, A., Watanabe, N. 2020, ApJ, 900, 187