Reactions via irradiation of an ice surface with low-energy ions at low temperature conditions

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In molecular clouds, various chemical species have been observed in spite of their very low temperature environment. To reveal why the chemical diversity appears, many investigations have been carried out theoretically and experimentally. Ion-molecule reactions in gas phase have been always indispensable for understanding of molecular evolution in molecular clouds. Experimental efforts in these decades have also shown that hydrogenation on icy grain is crucial for productions of abundant molecules such as hydrogen, water, methanol, and so on.[1] Besides these reactions, it is inferred that interactions of gas-phase ions with an ice mantle play some roles. Indeed, recent theoretical studies have predicted new pathways of molecular formation through reactions between low-energy ions in gas phase and ice surface.[2] Nevertheless, few experiments have been performed because of experimental difficulties, especially for detecting trace amounts of adsorbates on ice. We have developed a new experimental apparatus using an ion pick-up method[3] [4] for detecting reaction products on ice surface.

We recently reported the experiment for the reaction between low-energy CH_3^+ ions and a water ice surface.[5] The CH_3^+ ions in the energy range of several electron volts impinged on the surface of amorphous solid water in the temperature range of 12–60 K. After CH_3^+ irradiation, the production of methanol molecules was observed as quantum chemical calculations suggested.[2] We are now also conducting experiments for the reaction of low-energy CH_3^+ ions with a methanol solid surface at low temperatures. We will report the reaction of low-energy CH_3^+ with a water ice and will also touch our recent progress.

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[1] Watanabe, N.; Kouchi, A. Ice surface reactions: A key to chemical evolution in space. *Prog. Surf. Sci.* **2008**, *83*, 439.
[2] Woon, D. E. Ion-ice astrochemistry: barrierless low-energy deposition pathways to HCOOH, CH_3OH, and CO_2 on icy grain mantles from precursor cations. *Astrophys. J.* **2011**, *728*, 44.
[3] Kang, H. Reactive ion scattering of low energy Cs^+ from surfaces. A technique for surface molecular analysis. *Bull. Korean Chem. Soc.*. **2011**, *32*, 389.
[4] Ishibashi, A. et. al. Efficient formation pathway of methyl formate: the role of OH radicals on ice dust. *Astrophys. J. Lett.*. **2021**, *921*, L13.
[5] Nakai, Y. et. al. Methanol formation through reaction of low-energy CH_3^+ ions with an amorphous solid water surface at low temperature. *Astrophys. J.* **2023**, *953*, 162.