

Physicochemical Processes on Cosmic Ice Dust

Naoki Watanabe

Institute of Low Temperature Science, Hokkaido University, Japan,

Physicochemical processes on cosmic ice dust are indispensable for chemical evolution at each stage of star formation. The chemical evolution begins in molecular clouds where temperature is as low as 10 K. In molecular clouds, the hydrogenation of primordial atomic and molecular species plays an important role because hydrogen atoms can migrate and encounter reaction partners on the grain surface even at ~ 10 K. The formation of abundant interstellar species like H_2O , NH_3 , H_2CO , and CH_3OH by reactions often through quantum tunneling on the cryogenic ice surface was experimentally confirmed [1, 2]. Furthermore, hydrogen-deuterium substitution reactions on ice dust were found to promote deuterium enrichments of interstellar molecules. Apart from these chemical processes, nuclear spin, in other words ortho-to-para state, conversion of H_2 molecules on dust is a big issue of discussion. In molecular clouds, the ortho-to-para ratios of H_2 is crucial for not only chemical evolution but also gas dynamics toward star formation because H_2 in the ortho-ground state ($J=1$) is more energetic and thus reactive than that in the para-ground state ($J=0$) by approximately 14.6 meV corresponding to 170 K. The radiative transformation of molecular nuclear spins is forbidden in the gas phase but not on the dust surfaces. We experimentally observed the nuclear spin conversion of H_2 on various types of dust analogues [3].

Recently, significant progress in astronomical observations has enabled us to discover many kinds of complex organic molecules (COMs), in particular, towards star-forming regions. During temperature elevation in star-forming regions, heavier species can diffuse on the ice dust and subsequently many COMs would be produced through reactions among heavier species, especially radicals. It is thus important to investigate experimentally the behavior of radicals on the ice surface for understanding formation pathways of COMs. However, conventional methods for detecting OH radicals on ice, such as Raman, infrared, and electron spin resonance spectroscopies, are not applicable because of their low detection sensitivities and non-surface selectivity. We recently developed a new method, a combination of photostimulated desorption (PSD) and resonance-enhanced multiphoton ionization (REMPI), for directly detecting radicals on ice at low temperatures [4]. Using the PSD-REMPI method, the activation energies for diffusion of OH [5] and C radicals on ice were determined.

In about two decades, our group at ILTS has revealed various physicochemical processes related to above mentioned phenomena. In my talk, some of our experiments including their astronomical backgrounds will be presented.

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