論文内容の要旨

The role of organic haze in the hydrogen cycle on Titan

(タイタンの水素循環における有機物ヘイズの役割)

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Titan, the largest moon of Saturn, has a thick atmosphere composed primary of nitrogen and methane. More than 10 organic molecules and dense haze layers also have been detected in Titan's atmosphere. The goal of this thesis is to understand why Titan's atmospheric composition is the current one and how the atmosphere has evolved during the age of solar system. In this study, we focused on the heterogeneous reactions on the surface of organic aerosol, which forms haze layers in Titan's atmosphere. We experimentally investigated the heterogeneous reactions in a laboratory and determined the reaction probabilities of the heterogeneous reactions quantitatively. By incorporating the reaction probabilities into a photochemical model of Titan's atmosphere, we evaluated the role of organic haze both in the chemical composition of the atmosphere and the hydrogen cycle on Titan. The possible impacts of the heterogeneous reactions on the evolution of Titan's atmosphere were also discussed.

In order to determine the most plausible laboratory analog for Titan's organic aerosol, we first conducted pyrolysis analysis of Titan aerosol analogs, termed tholins, formed by cold plasma irradiations and ultraviolet (UV) light at long wavelengths. By comparing the experimental results with the new observational data obtained by Huygens probe, we suggest that the aerosol production takes place in the upper atmosphere (> 500 km in altitude) through chemical reactions driven by charged particles from Saturn's magnetosphere and solar UV irradiation at short wavelengths.

The aerosols formed in the upper atmosphere fall down and form dense haze layers in the mesosphere and stratosphere. A large amount of atomic hydrogen is considered to be produced by photochemical reactions in Titan's atmosphere. The H atoms formed in the atmosphere are considered to be consumed by the reactions with other molecules and to modify the chemical composition of the atmosphere. The previous theoretical studies suggested that atomic hydrogen reacts with aerosol in Titan's atmosphere. However, there are no qualitative or quantitative laboratory experiments about the heterogeneous reactions. In order to investigate the mechanisms and kinetics of the heterogeneous reactions, we irradiated atomic deuterium onto the Titan tholin and analyzed both the gas products and the changes in infrared spectra and chemical composition of the Titan tholin. Our experimental results indicate that the heterogeneous reactions are composed of three reaction processes; hydrogenation (addition of H atom into aerosol), H_2 recombination (abstraction of H contained in aerosol by forming H_2), and etching (removal of carbon and/or nitrogen). The hydrogenation proceeds at reaction probability of P_{hydro} = 2.08 × exp (-1000/T), while the H_2 recombination proceeds at reaction probability of P_{abst} = 0.0019 × exp (-300/T). Under the conditions of Titan's atmosphere, the etching of aerosols proceeds very inefficiently.

Then, we incorporated the reaction probabilities determined in the experiments into a photochemical model of Titan's atmosphere. The calculation results show that the heterogeneous reactions mainly contribute to the removal of atomic hydrogen throughout the mesosphere and stratosphere. Low concentration of atomic hydrogen enhances the concentrations of unsaturated complex organics and reduces the concentrations of saturated hydrocarbons. These results show that Titan's aerosols act as an efficient sink of atomic hydrogen. Such behavior of aerosol may keep the chemical composition of the Titan's atmosphere to the current one, which is suitable for synthesis of complex organic molecules. Furthermore, our results also suggest that the increase in haze production induces further increase in the haze production in the atmosphere. By taking into account this positive feedback, the frozen state of Titan might have been maintained longer in the past than the prediction by previous radiative models.