クライオプラズマ環境下における天文関連赤色物質の生成消失レートの温度依存性
Temperature dependence of production and disappearance rates of astronomy-related reddish compounds synthesized with cryoplasma

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[Background] Icy bodies in the outer solar system such as Pluto and Kuiper belt objects can be characterized by their color diversity, which ranges from neutral to ultra-red [1]. The red colors are thought to be caused by materials produced by energetic irradiation such as cosmic rays [1]. To study the chemical processing of molecules in astronomical environments, laboratory experiments have been conducted that simulate such irradiation induced chemistry using energetic sources such as ion beams and discharge plasma [2]. While laboratory experiments have suggested that these reddish materials could be complex refractory organic compounds such as tholins [3], such complex organic compounds are non-volatile even at room temperature. In contrast to this, our group established a reddish coloration on ice that was sustained only at cryogenic temperatures [4]. This was done by using cryoplasma, where the gas temperature can be controlled continuously between 273–5 K [5], as an energetic activation source to irradiate a CH_3OH/H_2O ice sample. To gain further insight into the conditions at which reddish coloration can be sustained and contribute to a better understanding of the causes of the color diversity of icy bodies in the outer solar system, in this study, we quantified the production and disappearance rates of the astronomy-related reddish compounds synthesized with cryoplasma at various temperatures.

[Methods] He-3% N_2 cryoplasma was generated in a dielectric barrier discharge configuration, with 1.83–1.93 kV_{pp} sinusoidal A.C. voltage applied at 10 kHz. The dielectric barrier was CH_3OH/H_2O ice and the gap length was 0.5 mm. The ice sample was irradiated by cryoplasma for 8.5–9 hours at ambient temperatures between 100–120 K. Optical emission spectroscopy was used to monitor the transmittance of the ice sample at regular time intervals.

[Results and discussion] Qualitatively, the reddish coloration on the ice was observed to decrease in intensity as the ambient temperature during irradiation increased between 100–120 K. Quantitatively, the absorbance, which is proportional to concentration, in the blue wavelength region after 8.5–9 hours of irradiation was 0.45 at 100 K and 0.28 at 120 K. This trend of decreasing absorbance is in agreement with the visual appearance of the ice.

The absorbance vs irradiation time data was fitted to a first-order kinetics, as an initial analysis. The rate constant for the forward reaction of the product formation and the nominal rate constant for the disappearance reaction of the product destruction were found to be functions of temperature. This implies that the concentration of the reddish compounds is likely defined by the equilibrium between its formation and destruction, which varies within a narrow temperature range. It also indicates that a steady-state concentration of the reddish compounds depends on temperature.

While it has been demonstrated that irradiation of nitrogen-containing plasma is needed for the production of reddish compounds [4], the temperature-dependent production rate may indicate that under the current experimental conditions, the supply of nitrogen radicals is not the rate-determining process. Therefore, both ambient temperature and energetic irradiation sources need to be considered when examining the conditions at which reddish coloration can be sustained on icy bodies in the outer solar system.

References

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