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Electron irradiation and thermal driven chemistry on H_2S-CH_3OH-NH_3-H_2O and CH_3OH-NH_3-H_2O ices: application to Jupiter Trojans

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Abstract

In this work we investigate chemical reactions driven by irradiation and thermal processing of outer solar system simulants and the resultant products. The main goal of this laboratory simulation work is testing migration hypotheses predicted by solar system formation models [1]. The ice samples are chosen to simulate the differences between chemistry in objects initially located inside and outside the stability line of H_2S. CH_3OH-NH_3-H_2O (3-ice) and H_2S-CH_3OH-NH_3-H_2O (4-ice) ice films was irradiated under ultrahigh vacuum conditions. Mid-IR analysis of the ice composition and mass spectrometry monitoring of the released volatiles during the heating of the irradiated mixtures show a rich chemistry for both mixtures. Our experimental work suggests that S-bearing molecules like OCS and SO_2 could be formed under conditions expected for objects that initially contained near-surface frozen H_2S and were then exposed to space weathering, particularly heating and irradiation while migrating to a position close to Jupiter's orbit.

1. Introduction

Jupiter Trojan asteroids are a population of small bodies captured around the L4 and L5 Lagrangian points of the Sun-Jupiter system. This family of asteroids can be categorized into two classes according to their Visible and Near-IR spectra: red Trojans and less red Trojans. The issue of how objects belonging to the same dynamical group have such diversity in their Vis-NIR spectra is tentatively linked to the origin and evolution of the Trojans asteroids. One hypothesis postulates that these objects were formed in the Kuiper Belt region and then migrated to their present position [1,2]. Space weathering factors, such as energetic particles and photon irradiation, are believed to be responsible for the growth of an organic refractory mantle covering the surfaces of these icy, airless objects. Energy released by irradiation of the organic ices drives a complex chemistry leading to the production of red crust. The surface chemical composition of icy bodies between 5 and 20 A.U. is expected to be dependent on their orbital distance as well as their size. A strong gradient in starting surface composition, followed by UV and particle irradiation, would lead to bimodal surface colors as seen today [3]. Space weathering alteration of the surface and the chemistry engaged in the development of such an organic layer has been investigated by very few laboratory simulation studies. While one experiment [4] shows that the irradiation of carbon containing molecules leads to a reddening of the initial ice, no laboratory studies have tested whether the addition of N or S containing molecules have an effect on the observed reddening.

2. Experimental Methodology

Electron irradiation experiments were carried out using the Icy World Simulation Laboratory at the Jet Propulsion Laboratory. The experimental setup used consisted of a high vacuum stainless steel chamber (base pressure ~ 1×10^{-8} torr). The ices were grown on a gold coated glass substrate attached to the cold finger of a closed-cycle helium cryostat. The ice films were grown by leaking gas mixture into the chamber directly onto the 50 K gold mirror.

An electron gun is mounted on the chamber, perpendicular to the substrate. High energy electrons (10 keV) impact the sample with a typical beam current of 0.5 µA. All studied ices were submitted to the same fluence of electron energy ~ 2×10^{21} eV cm^{-2}. After irradiation, samples were warmed to 120 K at 0.5 K/min while continuing electron irradiation. Samples were then irradiated 1 hour at 120 K, the electron beam turned off, and then warmed at 0.5 K/min to 150 K. This experimental procedure simulated the irradiation and heating history of an icy surface scattered from the Kuiper Belt region (50 K) to Jupiter Trojans region (120 K). Chemical changes in the constituents of the ice were monitored with a Midac Fourier transform infrared spectrometer covering a wavenumber range 400-7000 cm^{-1} at 2 cm^{-1} resolution. A quadrupole mass spectrometer was also used to monitor the gaseous species released when the irradiated ices were warmed.

3. Results

Figure 1 presents mid-IR spectra of the 4-ice mixture as deposited and after electron irradiation at T= 50 K. We observe a significant decrease in absorbance of the initial ice components, and new products appear in the spectrum of the irradiated sample. In the 3-ice mixture and the 4-ice mixture, we observe CO, CO_2, OCN^-, HCOOH, CH_2OH and CH_4. In the 4-ice mixture we also observe, after irradiation, an intense band at 2040 cm^{-1}. This band is assigned to the C=O stretching mode of OCS. OCS can be a product of reactions between a CO (which is produced from the dissociation of methanol) and an S atom or HS radical produced by photo-dissociation of H_2S.

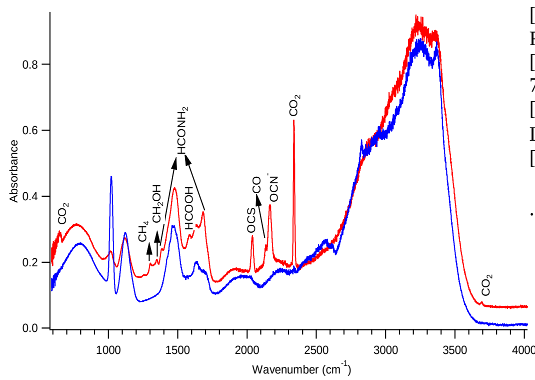

Figure 1: mid-IR spectra of H_2S-CH_3OH-NH_3-H_2O (3:3:3:1) deposited on a cold substrate (50 K) before (blue) and after (red) electron irradiation.

The heating of the irradiated 4-ice mixture to temperatures above 120 K leads to the appearance of new products. We tentatively assign these bands to SO_2 and CS.

4. Summary and Conclusions

Irradiation and heating of laboratory analogues of the icy surface with and without H_2S results in a rich chemistry that varies, depending on whether S-bearing species are present in the initial ice mixture. The generation of molecules like OCS, OCN^-, and $HCONH_2$, and their stability under irradiation and heating (simulating the migration of an object from the Kuiper belt region to Jupiter's orbital distance) can be helpful for choosing target molecules for potential future missions to the Jupiter-Trojan asteroids.

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