SUBLIMATION, DEPOSITION AND UV PHOTOCHEMISTRY OF ENCELADUS PLUME MIXTURES.

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Introduction: The south polar region of Enceladus is the source for a plume of gas and water ice particles that are a source for Saturn's E ring [1]. The plume emanates from multiple locations on the surface that correspond to the fractures referred to as the "tiger stripes" [2]. INMS data show the plume is composed of 91 ± 3% H_2O, 3.2 ± 0.6% CO_2, 4 ± 1% N_2 or CO, and 1.6 ± 0.4% CH_4 [3]. Temperatures on Enceladus range from ~37 K in the north polar night to a diurnal range of 50-75 K at low latitudes to perhaps 145 K or more in the warmest surface area of the tiger stripes [4]. Within this large temperature range, water ice undergoes significant structural reorganizations which influence the inclusion, mobility, and escape of trapped gases [5; 6].

We have conducted preliminary experiments with ices similar in composition to the plume gases in order to assess the contribution of phase change and sublimation related gas release in the formation of Enceladus' plume. While this behavior may not completely explain the presence of the plume, it undoubtedly contributes to its formation.

Regardless, some portion of the plume will be deposited on the surface of Encladus. Remote sensing of surface composion will, at least in part, reflect the temperature dependent depostion efficiency of the plume constituent species in combination with subsequent chemistry driven by ultraviolet (UV) solar photons. We have therefore begun an investigation into the depostion efficiency of the plume materials as a function of temperature, as well as the UV photochemistry of the subsequent ices.

Experimental: We performed temperature programmed desorption experiments on ice films deposited from a gas sample of composition 1.6% CH_4, 3.1% CO_2, 3.8% N_2, and 91.5% H_2O. The thickness of the ice film was approximately 0.15 μm, deposited at a rate of approximately 0.5 μm/hr. Samples were deposited at 20 K and 70 K and were warmed at a rate of 1 K/min. These deposition temperatures were selected to bracket the range of insolation driven temperatures on Enceladus.

An Ar-mini arc discharge lamp was used to provide a broadband UV spectrum, roughly analogous to the solar spectrum. Photochemical products were monitored via Fourier transform infrared (FTIR) spectroscopy.

Results: Figure 1 shows the results of our TPD studies. A number of desorption features are common to both the 20K and 70 K depositions. Desorption of N_2, CH_4 and CO_2 is seen at 42 K, 55 K, and 85 K, respectively. These desorptions correspond to the sublimation of these species from the surface of the highly porous, amorphous water ice film [7; 8].

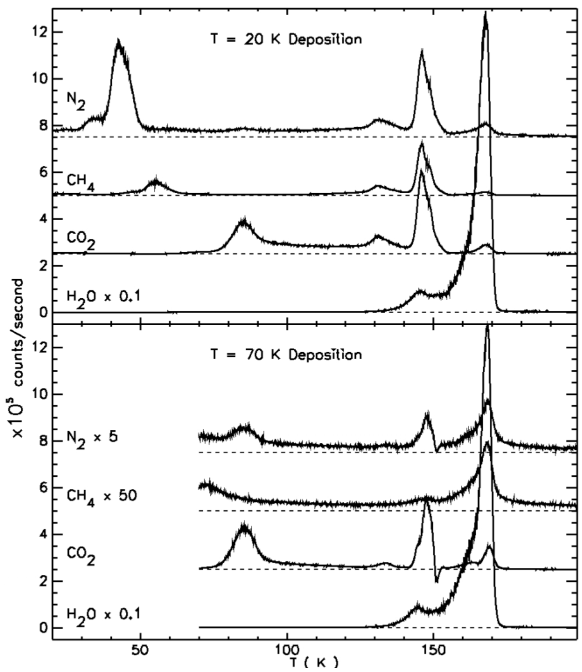

Figure 1. Measured mass spectrometer signal *S* vs. temperature for each of the 4 ice component molecules for ices deposited at T=20 K (top) and T=70 K (bottom). Traces are offset vertically for clarity.

Significant N_2, CH_4 and CO_2 desorption features are also seen at 131 K and ~145 K. These are probably caused by phase changes within the water ice matrix from an amorphous solid to a third amorphous phase or a 'strong viscous liquid.' [9] and during crystallization to the hexagonal form, respectively. Water also begins to desorb significantly in the latter temperature range. Some of the more volatile gases are also released along with water as the rate of water sublimation reaches its peak.

Consider the temperature range 135 to 155 K in the "instantaneous outgassing" plot Fig. 2. This is where the H_2O is just beginning to desorb while the other gases are still trapped in significant amounts. This initial burst of outgassing results in a high fraction of H_2O plus significant quantities of CO_2, N_2 and CH_4. The T=20 K deposited ice could easily produce a plume-like mixture of gases if it were warmed to 135

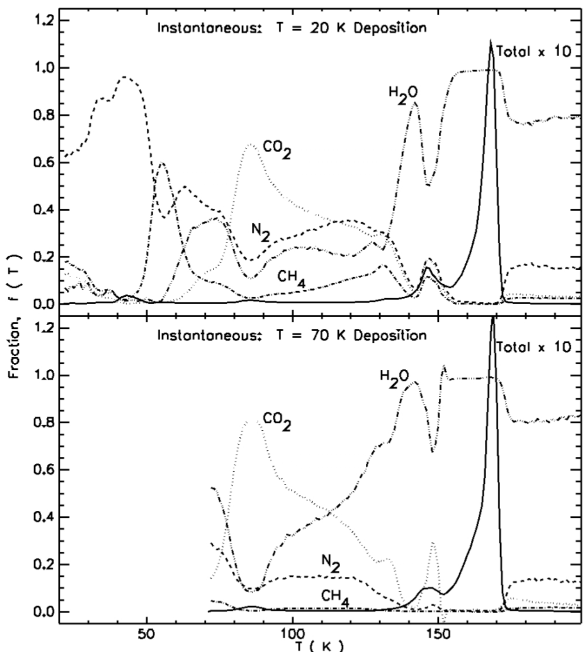

Figure 2. The "instantaneous outgassing" for ices deposited at T=20 K (top) and T=70 K (bottom). The ordinate value where a vertical line drawn at any T intercepts the $f_i(T)$ curves gives the instantaneous fraction of each component gas escaping during a $\Delta T = 1$ K interval. The solid lines labeled "Total" denote the fraction of all gas release that occurs within the $\Delta T =$ 1 K interval.

to 155 K. The T=70 K deposited ice would be depleted in CH_4 and CO_2 would be enriched over N_2. Fig. 2 also shows that if ice deposited at either T=20 K or 70 K were warmed to T>155 K, then the escaping gas will be essentially pure H_2O because nearly all of the other trapped gases escape in the range from 135 to 155 K.

This 135 to 155 K temperature range is also precisely the temperature range that includes the CIRS measured temperatures of Enceladus South pole and Tiger stripes [4], which strongly suggests that the gas escape phenomena that we measure in our experiments are an important process for similar composition and temperature ices on Enceladus. Our results show that plume-like composition ices heated to the 135 to 155 K temperatures measured by CIRS will result in gases escaping with composition similar to the INMS plume composition. In contrast, similar ices heated to higher or lower T will not reproduce the measured plume composition.

Photolysis of ices depostited from the plume-like gas mixtures are difficult to analyze given the low concentrations of the non-water species, and subsequent photolytic products. Therefore we are examining a series of binary and tertiary mixtures at proportions that enable product detection in our FTIR spectra. Figure 3 shows a preliminary FTIR spectrum of a UV photolyzed, 10% mixture of CH_4 in water. In this case, the deposition was performed at 20K to ensure the ratio of CH_3 in the gas mix was representative of the depositied ice. Clear evidence for the production of CO_2, CH_3OH, and C_2H_6 is seen in the figure. Other species such as CO are produced, but are not visible at the scale displayed. The photolytic chemistry seems to be dominated by the reaction of OH radicals with CH_4 and its subsequent products. This is similar to the result of proton irradiation of similar ice mixtures

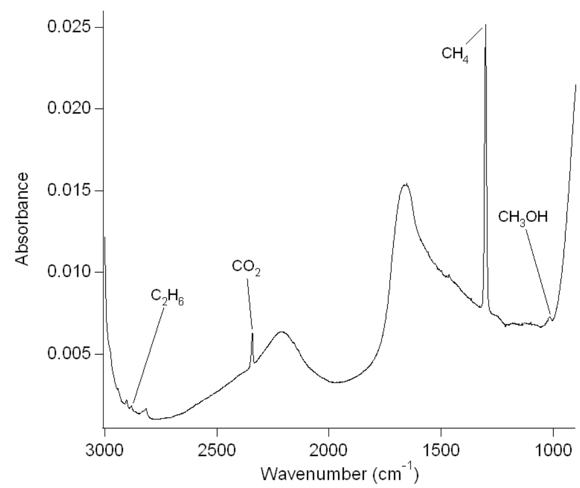

Figure 3. FTIR spectrum of 10% CH_4 in H_2O at 20K photolyzed for 30 minutes.

Acknowledgements: This work was performed at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA). Financial support through JPL's Research and Technology Development program is gratefully acknowledged.

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