

Trapping of volatiles in amorphous water ice. R. M. E. Mastrapa¹, R. H. Brown¹, B. A. Cohen¹, V. G. Anicich², W. Dai¹, and J. I. Lunine¹, ¹(University of Arizona, 1629 E. University Blvd., Tucson, AZ 85721-0092), ²(Jet Propulsion Lab, Building 183, Room 126, 4800 Oak Grove Drive, Pasadena, CA 91109-8099).

Introduction: The composition of objects in the Kuiper Belt is an important question in Planetary Science. They are assumed to have remained where they formed and are most likely to consist of the original material that the planets formed from. Experiments and modeling of the temperature and pressure conditions present during Kuiper Belt formation can lead to estimates of composition. To that end, this project looks at the amount of volatiles trapped in amorphous water at low temperatures.

Experimental Procedure: In this study, CO, CH₄, and CO₂ were trapped in H₂O at temperatures as low as 20 K and pressures between 10⁻⁵ and 10⁻⁸ Torr (~10⁻⁸ – ~10⁻¹¹ bars). These experiments were conducted at the Extraterrestrial Ice Simulator (EIS) at JPL. The gases were released into a chamber cooled by a Helium refrigerator and were deposited on a sapphire window. An infrared transmission spectrum was taken of each sample before sublimation to confirm the presence of volatiles. The samples were then heated at rates from 0.25 K/min to 1 K/min. During heating, a mass spectrometer was used to measure the amount of degassed volatiles and water. The flux was then integrated to get the total number of molecules that were deposited on the window.

Results and Conclusions: The volatiles escaped from the ice mixtures in temperature ranges similar to those found in previous work [1, 2, 3], namely 48-52 K, 145-160 K, 170-185 K. H₂O is released from 150 K to 185 K. However, the temperature range of escape is strongly dependent on the deposition temperature. If the deposition temperature is below the point where the solid volatile rapidly sublimates in the ambient environment of our experiment, from now on referred to as the solid point, then the first range of volatile escape is centered around its solid point, and there is little of the volatile remaining from 170-185 K. In this experimental setup, the solid points of CH₄, CO, and CO₂ are, respectively, 45 K, 40 K, and 80 K.

The results of the trapping experiments are presented in Figure 1 and Table 1. All of the results have been normalized to a ratio between the number of water molecules and the number of volatile molecules. Note that the ratio of water to volatile increases with temperature of deposition. However there is still a significant number of volatile molecules still present at higher deposition temperatures. Volatiles such as CH₄ and CO can be trapped in amorphous ice and temperatures above their solid point.

In our data, the infrared spectrum of CO trapped in water ice shows a splitting of the 4.662 μm solid CO line into two bands at 4.677 μm and a shoulder out to 4.648 μm as shown in Figure 2. These shifts are similar to those seen by Sandford, et al [4]. However, these shifts are seen in the depositions made below the solid point of CO (20 K marked in blue). The deposition made above the solid point of CO is shifted to slightly longer wavelengths, 4.688 μm , and has no shoulder (43 K, marked in pink).

Future experiments will include measurements with different volatiles. Also, since the volatiles were released into the sample chamber at the same pressure as the water, measurements will be taken with a solar system composition gas with the proper ratios of water to volatile.

References: [1] Bar-Nun, A., G. Herman, D. Laufer, and M. L. Rappaport, (1985), *Icarus*, **63**, 317-332. [2] Bar-Nun, A., J. Dror, E. Kochavi, and D. Laufer, (1987), *Physical Review B*, **35**, no. 5, 2427-2435. [3] Hudson, R. L., and B. Donn, (1991), *Icarus*, **94**, 326-332. [4] Sandford, S. A., L. J. Allamandola, A. G. G. M. Tielens, and G. J. Valero, (1988), *Astrophysical Journal*, **329**, 498-510.

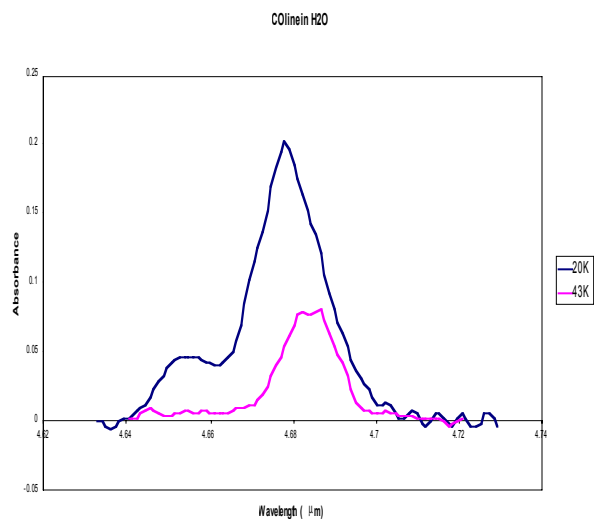


Figure 2. Absorbance Spectrum of CO in water ice. The x axis is wavelength in microns (μm) and the y axis is Absorbance. Blue – 20 K deposition. Pink – 43 K deposition.

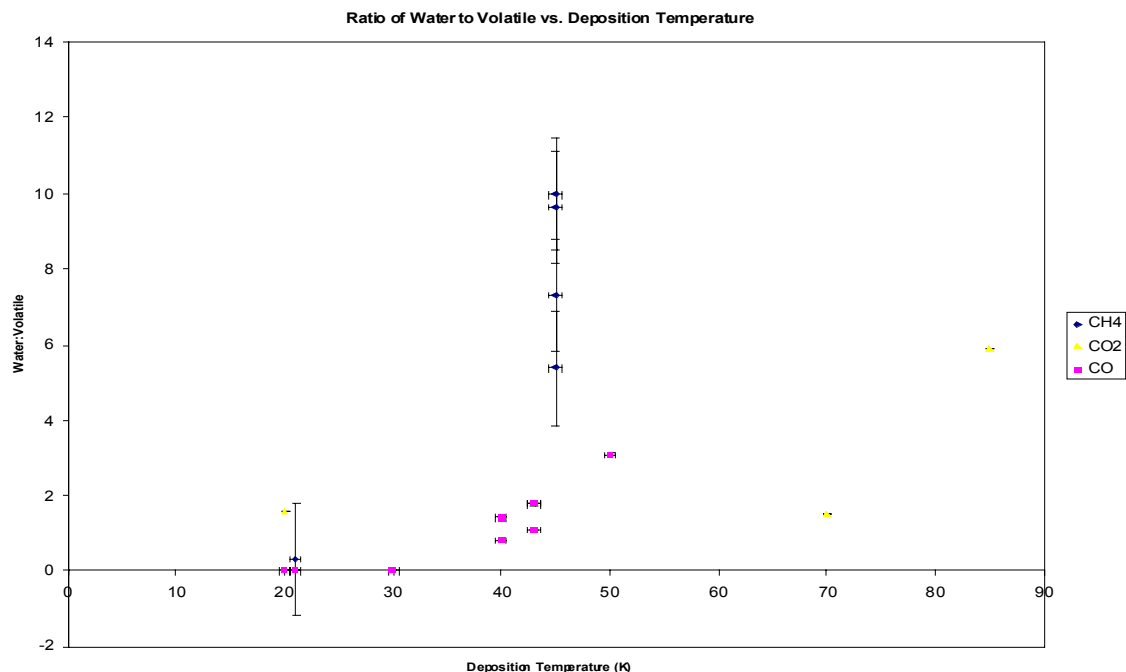


Figure 1. Results from trapping experiments for CH₄ (blue) CO₂ (yellow triangles) and CO (pink squares). The x axis is deposition temperature in K. The y axis is the ratio of water molecule to volatile molecule. The data is averaged over calibrations. The error bars reflect the averaging of different calibrations and an average value for all experiments conducted with the same volatile. Table 1 includes values for each experiment.

Volatile	Deposition Temperature (K)	Ratio of Water molecules to Volatile molecules	Ratio Standard Deviation
CH ₄	45	5.37	1.14
CH ₄	45	9.64	1.48
CH ₄	45	7.32	1.89
CH ₄	45	9.99	4.37
CH ₄	21	0.32	0.01
CO	40	1.40	0.04
CO	40	0.80	0.02
CO	21	3.28E05	1.14E06
CO	43	1.08	0.15
CO	43	1.79	0.06
CO	43	1.76	0.08
CO	20	2.09E04	5.59E06
CO	30	1.61E03	4.44E05
CO	50	3.09	0.09
CO ₂	85	5.87	0.36
CO ₂	70	1.51	0.09
CO ₂	20	1.57	0.06
CO ₂	40	1.45	0.04

Table 1. Results from trapping experiments for CH₄ (5 experiments), CO (9 experiments), and CO₂ (4 experiments). Ratio values were averaged over multiple calibrations except for CO₂, where only one calibration was performed. The standard deviation of the ratio is based on the response of the mass spectrometer.