Pressure-dependent trace gas trapping in amorphous water ice at 77 K: Implications for determining conditions of comet formation. R. Yokochi[1,2], U. Marboeuf[2], E. Quirico[2] and B Schmitt[2], [1]Department of Geophysical Sciences, The University of Chicago (5734 S. Ellis Avenue, Chicago, IL 60637, USA), yokochi@uchicago.edu, [2]UJF-Grenoble 1/CNRS-INSU, Institut de Planétologie et d'Astrophysique de Grenoble [IPAG] (UMR 5274, Grenoble F-38041, France).

Introduction: Previous experimental studies reported that amorphous water can efficiently encapsulates ambient gases during its condensation at low temperature and high deposition rates [1,2], reflecting the physical and chemical conditions of the surrounding environment. Assuming that cometary ice at least partially formed by condensation of nebula gas at low temperature in a form of amorphous ice, the experimental data was applied for determining the formation condition of the cometary ice and volatile budget of terrestrial planets [2,3,4]. In this work, we conducted new, simple and reliable, experiments at 77 K in order to understand the physical mechanism controlling the trapping efficiency of trace gases in amorphous water ice [5].

Method: Amorphous water ice was deposited by transferring water vapor from a volume at ambient temperature (R1) to another (R2) containing inert gas at 77 K (submerged in liquid nitrogen). The two volumes were equipped with pressure sensors allowing quantification of water ice deposition and gas trapped (Figure 1). Heating tape was installed on the top surface of the cylindrical deposition reservoir (R2) immediately above the liquid nitrogen surface in order to minimize the thermal gradient zone where ice deposition at various intermediate temperatures could disturb the experimental results.

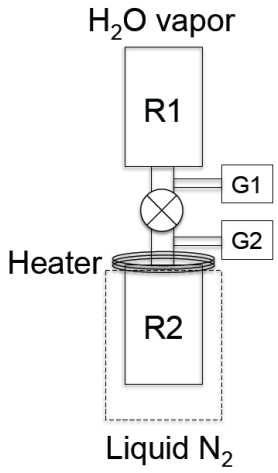

Figure 1: Schematic diagram of the experimental system. Pumping systems and an external liquid water reservoir are omitted in this figure to illustrate the simplicity of the experiment. Heating tape was installed on the top surface of the cylindrical deposition reservoir immediately above the liquid nitrogen surface in order to minimize the thermal gradient zone.

In most experiments, the gas pressure of R2 decreased after water ice deposition, which was interpreted as a trapping of gas into the deposited water ice. The quantity of ice deposition and gas trapping was determined by the pressure decrease in R1 and R2, respectively. Water ice formed was assumed to be amor-phous since the flux of water is higher by several orders of magnitude than the rates given by Kouchi et al. [6] and clathrate formation is kinetically unfavorable.

Results and Discussion: Amorphous water ice quantitatively trapped gases at 77 K. The concentration of trapped gas and the partial pressure of gas during water condensation show a clear positive correlation at low trace gas pressures (< about 20 μbar, Figure 2) for all gas species, independent of the water vapor pressure during ice formation (i.e. deposition rate). This suggests that the efficiency of gas trapping in water ice is primarily controlled by the partial pressure of gas present with the depositing ice.

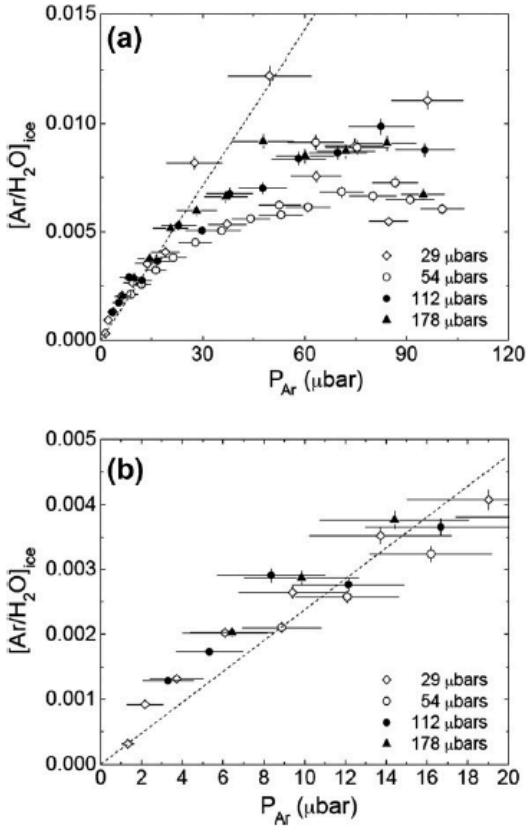

Figure 2: Concentration of Ar in water ice as a function of Ar partial pressure. Different symbols represent different water vapor pressure (thus ice deposition rate) during ice deposition.

The trapping efficiencies of gas species decrease in the order of Kr>CH_4>CO>Ar>N_2 at 77 K, in agreement with previous studies [1,2,3]. The slope of this correlation, when assumed to be linear, is $(1.8 – 8.8) \times 10^{-4}$ μbar^{-1}.

The data depart from this general correlation at higher gas pressures and plot below the linear correlation, indicating a somewhat lower gas trapping efficiency [5]. During the experiments, the rate of water ice deposition was primarily proportional to the partial pressure of water vapor (as was the case for pure water vapor), but the presence of inert gases resulted in up to tens of % of enhancement in the rate of water ice deposition at a given water vapor pressure (Figure 3), independent of the gas species. Because the mean free path of gases at 77 K is a few mm at the higher pressure range of the experiments, water molecules entering R2 at ambient temperature can collide against inert gas atoms/molecules at 77 K tens of times before reaching the pyrex glass surface at 77 K. This process may cool the water molecules, resulting in crystallizing ice particles at higher temperature than 77 K before they reach the pyrex wall. As crystalline ice has much lower gas trapping efficiency than amorphous ice [1], formation of partially crystalline ice during high gas pressure experiments explains the deviation of gas trapping efficiency from the the correlation. Hence we suggest that the experimental results at low pressure best represent trapping efficiencies of gases in amorphous ice.

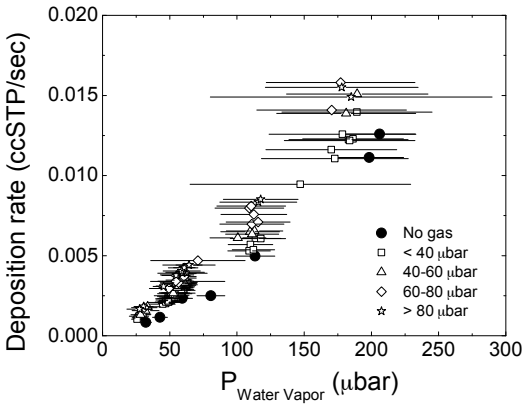

Figure 3: Rate of ice deposition as a function of water vapor pressure at the presence of Ne: The ice deposition rate is greater in the presence of Ne (26–108 μbar, open symbols) than in the presence of only the condensing water vapor (filled circle). The higher the partial pressure of Ne, the greater the degree of enhancement in deposition rate.

Astrophysical Implications: Based on the observation that the trapping efficiency of gas is independent of (i) ice deposition rate and (ii) gas/H_2O ratio in the vapor phase, we suggest that the efficiency of gas trapping is governed by equilibrium adsorption, rather than condensation kinetics or limited gas diffusivity. This contrasts with previous studies where it has been assumed that the quantity of trapped gas scales with the ratio of the trace gas to water vapor [1,2,3]. An astrophysical implication of this result, at places in the solar nebula where amorphous ice forms, is that the partial pressure of the trace gas in ambient nebula gas would be an important controlling factor of noble gas concentration in depositing amorphous water ice, aside from temperature.

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