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Laboratory investigations of cloud particle formation and sublimation on Titan, Mars, and Earth

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Abstract

Microphysical modeling of cloud formation and growth relies on fundamental measurements of the properties of condensable gases which form cloud particles. NASA's Ames Chemistry Laboratory has the capability to measure vapor pressures and heterogeneous nucleation conditions for a variety of gases found in the atmo-spheres of solar system bodies. Highlights from work for Earth, Mars, and Titan demonstrate the range of conditions and atmospheres studied to date.

1. Introduction

Any condensable gas can form cloud particles when conditions favor nucleation and growth of the liquid or solid phase. Accurate reference data are needed to predict existence conditions for these particles, but not all values of interest have been measured for the wide variety of temperatures appropriate to planetary atmospheres. Furthermore, formation of any new phase must overcome a nucleation energy barrier, which can result in relative humidities (RH) above 100% before particle onset, and the degree of super-saturation required has been shown to be temperature dependent [2, 4]. Laboratory studies which provide the required nucleation and equilibrium information can improve the accuracy of microphysical modeling of cloud particles.

2. Laboratory capabilities

The cloud nucleation and growth chamber of the Ames Chemistry Laboratory (ACL) was designed to allow studies of condensable gases over ranges of temperature (145 – 200 K) and partial pressure (5×10^{-8} – 5×10^{-4} hPa) that mimic portions of the atmospheres of Earth and Mars. Recently this facility has been modified to study benzene condensation and growth in Titan's atmosphere as well.

A silicon substrate is suspended in a stainless-steel chamber with KBr windows above and below to allow passage of an infrared beam. A liquid nitrogen cryostat allows the cooling of the substrate, and a kapton heater allows the temperature of the substrate to be adjusted via a temperature controller. Using a leak valve, gas phase molecular species can be introduced into the vacuum chamber. Temperature is measured with K-type thermocouples and pressure is measured with an ion gauge. Ice nucleation is monitored with a Fourier Transform Infrared (FTIR) spectrometer.

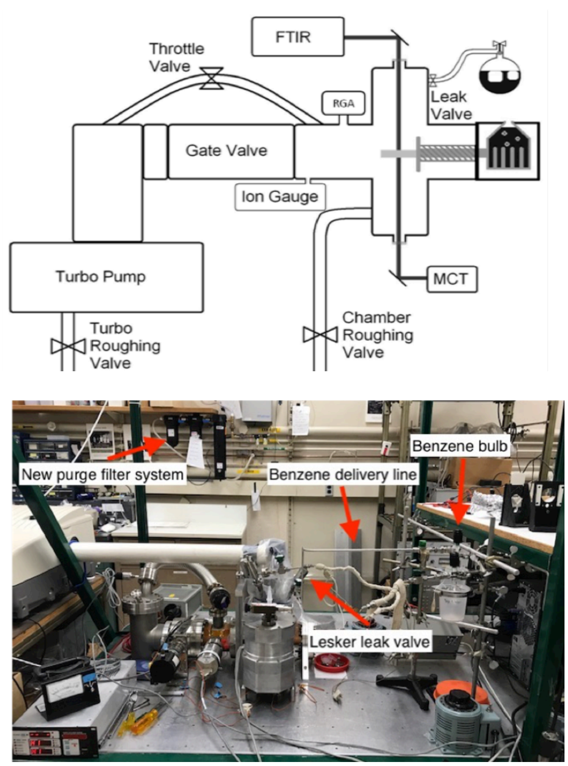

Figure 1: Schematic of cloud formation and growth chamber and photo showing implementation of gas delivery systems for Titan studies.

3. Current studies for Titan

Current efforts in the ACL cloud chamber focus on temperature-dependent measurements of the equilibrium vapor pressure of benzene as input parameters to the Titan CARMA microphysical model [1] to better understand the south polar cloud that appeared in autumn in 2012. These results are described in a companion abstract by Dubois et al.

4. Water cloud formation under Mars conditions

Observations of the Martian surface have indicated the presence of chlorine-bearing minerals, including perchlorates, which could be source material for dust lofted from the surface into the Martian atmosphere, providing potential nucleation sites for water ice clouds. Considering that salts play an important role in cloud formation on Earth, it is important to have a better understanding of how salt may affect nucleation processes under Mars-like conditions. We examined heterogeneous nucleation onto sodium chloride and sodium perchlorate substrates under Martian atmospheric conditions, in the range of 150 to 180 K and 4×10^{-7} to 5×10^{-5} hPa water partial pressure [5]. Sub-155 K data suggests an exponential model best describes the temperature dependence of nucleation onset of water ice for all substrates tested. Sodium perchlorate supports depositional nucleation at lower saturation levels than other substrates investigated and is comparable to smectite-rich clay in its ability to support cloud initiation. Perchlorates could nucleate water ice at partial pressures up to 40% lower than other substrates examined under Martian atmospheric conditions, suggesting that areas on Mars with uplifted salts such as perchlorates could form water ice clouds at lower atmospheric supersaturation than in areas absent of similar nucleators.

5. Water cloud formation in Earth's mesosphere

On Earth, polar mesospheric clouds (PMC) are observed in high latitude regions of both hemispheres in the summer months, when the mesosphere is coldest. We studied water ice nucleation on a standardized basalt dust from the Mojave desert. This surrogate was chosen for its low hygroscopicity, and vapor deposition of water ice was initiated over a temperature range of 147 – 181 K. The temperature dependence of ice onset was similar to our previous studies with water, and we report [3] that nucleation can require relative humidity above 400% at temperatures nearing 145 K.

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