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A novel experimental setup to study the nucleation of atmospheric vapours on small nanoparticles

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Abstract

We present a novel supersaturation chamber which allows us to expose nanoscale particles to supersaturated vapors in the wide range of temperatures occurring in planetary atmospheres. This chamber, the molecular flow ice cell (MICE), is integrated in the vacuum setup TRAPS and enables us to study adsorption, nucleation and growth processes of condensable vapours as for instance water vapour and carbon dioxide. We will present the experimental setup with focus on MICE. The general function principal of MICE and its limitations will be highlighted and we will elaborate that this new device is able to study adsorption, ice nucleation and growth processes exemplified with CO_2 nucleation experiments in the mesosphere of Mars.

1. Introduction

Heterogeneous nucleation on nanometer sized aerosol particles is able to initiate the formation of clouds in the atmosphere of planets. An example are ice clouds in the higher atmosphere of Earth, so called Noctilucent Clouds (NLCs). These clouds have been detected in the polar summer mesopause region of Earth at heights of 80-90 km [e.g. 3, 7]. They are believed to be caused by heterogeneous nucleation of H_2O on sub 2 nm meteoric smoke particles (MSPs). Surprisingly, similar clouds have been detected in the mesosphere of Mars as well [e.g. 1, 5, 6, 8]. In contrast to NLCs on Earth, they consist of CO_2 ice and occur at low latitudes mostly during pre- and post- aphelion season. Here, the main candidates acting as ice nuclei are MSPs and Martian Dust particles (MDPs). Scientists dealing with the formation of NLCs struggle with large uncertainties in describing the nucleation processes taking place due to a lack of experimental data at the extreme conditions of the mesosphere which states the need of laboratory measurements.

We recently designed a new supersaturation chamber which allows us to expose charged nanoscale particles to supersaturated vapors. Within the chamber we can control the particle temperature and vapor concentration of basically any condensable vapor. The chamber consists of a linear ion trap and is an integral part of the TRAPS Apparatus [4]. Among other things it allows to study nucleation and growth processes on nanoparticles at the very low temperatures in planetary atmospheres. Until now, we have studied nucleation and growth of H_2O and CO_2 on sub 4 nm radius iron oxide and silicon oxide particles as an analogue of MSPs. These measurements allow us to parameterize the growth and nucleation process of mesospheric CO_2 and H_2O clouds on Mars and on Earth. We will use this contribution to show our experimental setup and highlight the functioning of the molecular flow ice cell.

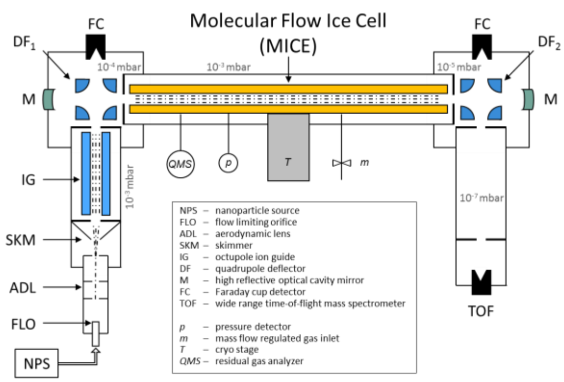

Figure 1: Schematic setup of the TRAPS apparatus including MICE [2].

2. Experimental Setup

Singly charged nanometer sized (2-4 nm in radius) MSP analogues are produced in a microwave plasma reactor and transferred via an aero-dynamic lens into the TRAPS chamber which is shown in Figure 1. Within the chamber the particles are further guided with an octupole ion guide. Particles of one polarity and a defined mass are selected into MICE using a quadrupole deflector DF_1. MICE is a combination of a linear ion trap with a supersaturation chamber working in the molecular regime: Temperature controlled surfaces are placed between the quadrupole electrodes. These surfaces are covered with a thin layer of the condensable vapour prior to an experiment. The vapour concentration is adjusted by controlling the temperature of the ice covered surfaces whereas the additional control of the electrode temperature allows us to control the particle temperature by collisions with the buffer gas helium. In MICE up to 10^8 particles are held under controlled particle temperature and vapor concentration. Heterogeneous ice nucleation and growth processes then can be examined by analyzing the mass distribution of the particles with a time-of-flight mass spectrometer (TOF) as function of the residence time under supersaturated conditions.

3. Results

We will show that the MICE is able to store sub 4 nm radius particles without significant loss in time. Homogeneous conditions are applied within the trap and we are able to produce saturations higher as 10^5. We will proof the functioning in the molecular regime and expound the operation regimes of MICE in terms of adjustable particle temperature and vapor concentration of CO_2 and H_2O. We will show exemplary that this new device is able to study adsorption, ice nucleation and growth processes exemplified with CO_2 nucleation experiments in the mesosphere of Mars.

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