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Heterogeneous CO_2 nucleation in the Martian mesosphere – laboratory experiments

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Abstract

We present measurements on heterogeneous CO_2 nucleation on sub 4 nm radius iron oxide and silicon oxide particles as analogues to naturally occurring Meteoric Smoke Particles (MSP). From the particle growth, we infer the particle surface desorption energy of CO_2. Additionally, evaluation of nucleation rates at controlled particle temperature and CO_2 concentration gives us the contact parameter of CO_2 on these particles, resulting in a full nucleation parameterization for MSPs in the Martian mesosphere. We find strong indications that the same parameterization can be used for upward propagated Martian Dust Particles (MDPs). We apply this nucleation parameterization to conditions of the Martian mesosphere which results in characteristic nucleation onset temperatures. Furthermore, the Sticking Coefficient of CO_2 on solid CO_2 is evaluated.

1. Introduction

CO_2 ice clouds have been detected in the Martian mesosphere [e.g. 1, 9, 10, 11]. These clouds mainly appear during pre- and post- aphelion season and are believed to be caused by heterogeneous nucleation on nanoparticles during supersaturated conditions induced by thermal tides and gravity waves [4, 12]. Although great progress has been made in the last century in monitoring and modeling mesospheric CO_2 clouds on Mars, large uncertainties especially in parameterizing the microphysical formation process of the ice particles remain. Main ice nucleation candidates are Meteoric Smoke Particles (MSPs) or upward propagated Martian Dust Particles (MDPs). Currently a single parameterization [5] is used to describe nucleation on either of these particle types in the mesosphere. It leads to CO_2 nucleation at temperatures only slightly below the saturation temperature. This result is in disagreement with night time observations of temperatures well below saturation temperature in absence of clouds [3, 8]. One possible explanation for the discrepancy between observation and theory is that the nucleation ability of MSPs and MDPs is actually lower than assumed.

We recently designed a novel experiment which allows us to investigate CO_2 nucleation and growth processes on MSP analogues under controlled conditions being reasonably close to conditions in the Martian mesosphere. This allows us to determine important surface properties of the MSP analogues such as CO_2 desorption energy, sticking coefficient, contact parameter and critical temperature for nucleation as a function of the particle size.

2. Experimental Method

We produce free sub 4 nm radius iron oxide and silicon oxide particles representing MSP analogues with a microwave plasma particle source. These particles are transferred into the vacuum setup TRAPS [7] in which we trap singly charged particles of selected mass in a supersaturation chamber called MICE [2]. In MICE, we can control the particle temperature and ambient CO_2 concentration. Heterogeneous nucleation and subsequent growth of CO_2 ice is observed by extracting a small sample from the trapped particle population at defined time steps and analyzing its mass distribution with a time of flight spectrometer.

3. Results and Discussion

Figure 1 shows an exemplary series of measurements of CO_2 deposition on silicon oxide particles having an initial radius of about 2.5 nm. The measured particle mass is shown as function of the residence time in MICE. The CO_2 concentration is set to a constant value, in this case to 5E15 m^{-3}.

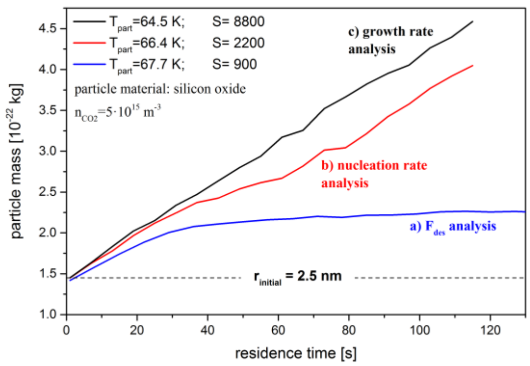

Figure 1: exemplary dataset with 2.5 nm silicon oxide particles used for desorption energy (a), nucleation rate (b), and growth rate (c) analysis.

The particle temperature and therefore saturation is varied and allows us to adjust conditions with and without nucleation taking place. The blue line (a) represents a condition at which no nucleation took place. The temporary increase of particle mass represents an adsorption process of CO_2 molecules on the particles surface allowing us to determine the desorption energy of CO_2 molecules on the investigated particle material. The red line (b) represents conditions which allow us to evaluate nucleation rates and determine the contact parameter *m*. Finally, at high saturations as represented by the black line (c) the growth rate can be evaluated to retrieve the sticking coefficient α of CO_2 on solid CO_2. The evaluation of such measurements allow us to determine a full parameterization of nucleation and growth of CO_2 on MSPs at conditions being reasonably close to conditions in the Martian mesosphere. We will present this new parameterization and show that it probably can be used for MDPs as well. We will discuss the results and highlight the consequences when applying this parameterization to the Martian mesosphere resulting in defined temperatures at which nucleation gets induced.

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References

[1] Clancy, R. T., Wolff, B. A., Whitney, B.A., et. al.: Mars equatorial mesospheric clouds: Global occurrence and physical properties from Mars Global Surveyor […], J. Geophys. Res.-Plantes, Vol. 112(E4), 2007.

[2] Duft, D., Nachbar, M., Eritt, M. and Leisner, T.: A linear ion trap for studying the interaction of nanoparticles with supersaturated vapors (submitted), Aerosol. Sci. technol., 2015

[3] Forget, F., et. al.: Density and temperatures of the upper Martian atmosphere measured by stellar occultations with Mars Express SPICAM, J. Geophys. Res. - Planets, Vol. 114, pp. E01004, 2009.

[4] Gonzalez-Galindo, F., Määttänen, A., Forget, F. and Spiga, A.: The Martian mesosphere as revealed by CO_2 cloud observations and General Circulation Modeling, Icarus, Vol. 216(1), pp. 10-22, 2011.

[5] Glandorf, D. L., Colaprete, A., Tolbert, M. A., Toon, O. B.: CO_2 snow on Mars and early Earth: Experimental Constraints, Icarus, Vol. 160(1), pp. 66-72, 2002.

[6] Määttänen, A., et. al.: Mapping the mesospheric CO_2 clouds on Mars: MEx/OMEGA and MEx/HRSC observations and challenges for atmospheric models, Icarus, Vol. 209(2), pp. 452-469, 2010.

[7] Meinen, J., Khasmiskaya, S., Rühl, E., Baumann, W. and Leisner, T.: The TRAPS Apparatus: Enhancing Target Density of Nanoparticle Beams in Vacuum for X-ray and Optical Spectroscopy, Aerosol. Sci. Technol., Vol. 44(4), pp. 316-328, 2010.

[8] Montmessin, F., Forget, F., Bertaux, F., Spiga, J.-L. and Määttänen, A.: Existence of Supercold Atmospheric Layers in the Martian Mesosphere, The Fourth International Workshop on the Mars Atmosphere: Modelling and observation, February 2011, Paris, France, pp. 404-405, 2011.

[9] Montmessin, F., Gondet, B., Bibring, J.P., et al.: Hyperspectral imaging of convective CO_2 ice clouds in the equatorial mesosphere of Mars, J. Geophys. Res. - Planets, Vol. 112, pp. E11S90, 2007.

[10] Montmessin, F., et al.: Subvisible CO_2 ice clouds detected in the mesosphere of Mars, Icarus, Vol. 183(2), pp. 403-410, 2006.

[11] Smith, P.H., et. al.: Results from the Mars Pathfinder Camera, Science, Vol. 278, pp. 1758-1765, 1997.

[12] Spiga, A., Gonzalez-Galindo, F., Lopez-Valverde, M. A. and Forget, F.: Gravity waves, cold pockets and CO_2 clouds in the Martian mesosphere, Geophys. Res. Lett., Vol. 39, pp. L02201, 2012.