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ADVANTAGES OF ICE CRYSTAL GROWTH EXPERIMENTS IN A LOW GRAVITY ENVIRONMENT

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ABSTRACT

The effects of convective fluid motions and mechanical supports on ice crystal growth in experiments conducted on earth can be inferred from studies conducted in their absence in a low-gravity environment. Current experimental results indicate the effects may be significant.

INTRODUCTION

Discussions on studies of crystal growth in low-gravity usually emphasize the absence of two variables in such an environment, convective fluid motions and a support for the growing crystal. Theoretical estimates of the magnitudes of these effects are difficult to obtain, primarily because of the primitive state of our knowledge of crystal growth mechanisms. However, the experimental results reported here and by other workers shed some light on the problem.

Convective Fluid Motion

Most experiments designed to study the effect of convective fluid motion on ice crystals growing from the vapor are conducted in a cold chamber in which a cloud of supercooled water droplets is artificially "seeded" to produce ice crystals which then grow and fall out of the cloud. As the crystals grow, they deplete the vapor supply and thus lower the ambient supersaturation. To maintain a constant ambient environment near water saturation, droplets must be added to the cloud. The simultaneous presence of droplets and ice crystals makes the "effective" supersaturation near the crystals difficult to determine and even more difficult to control. Although these studies may closely simulate the crystal growth conditions encountered in a natural cloud, they do not allow close observation of the growing crystals, long growth times (maximum of about 200 seconds), constant environmental growth conditions, or separation of the effects on crystal growth of droplets and ventilation velocity.

Recent studies were conducted in a dynamic thermal diffusion chamber to investigate the effect of ventilation on ice crystals grown from the vapor in the absence of water droplets. Partial results of this work were reported earlier; (Keller and Hallett, 1978) a complete description is in preparation. This experimental chamber employed two horizontal, ice coated, parallel plates, 1.2 m in length and separated by a distance of 2.5 cm. Air was circulated between the plates past ice crystals which nucleated and grew from a 250 micron diameter glass fiber suspended vertically between the two plates. This chamber allowed crystals to be closely observed for extended periods of time and to be grown at selected and well controlled ambient conditions of temperature, supersaturation, and ventilation velocity. However, neither the effect of the mechanical support on the nucleation and initial growth of the crystals nor the effect of natural convection on the subsequent crystal growth was fully known. Using the measurements from a large number of crystals grown in this chamber under a variety of ambient conditions, the composite effect of the ambient conditions of temperature, supersaturation, and ventilation velocity on the linear growth rates of ice crystals was compiled. Figure 1 shows isopleths of the ventilation velocity (cm s^{-1}) for an ambient temperature of -14.5°C.

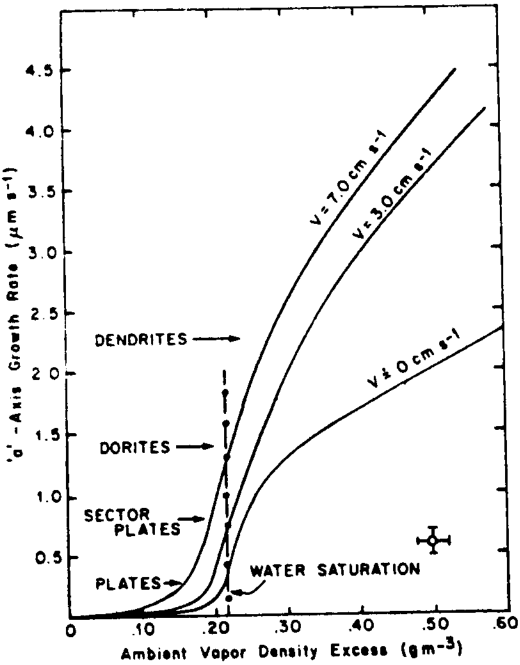

Figure 1. Isopleths of ventilation velocity (cm s^{-1}) for an ambient temperature -14.5°C show the relationship between the 'a'-axis growth rate and the ambient vapor density excess. Water saturation is indicated by a dot-dash line.

The various crystal shape regimes at this temperature are indicated by name. The shape regime boundaries as a function of 'a'-axis growth rate are not sharp, but can vary somewhat from one crystal to the next depending upon the crystal thickness. The most obvious effect shown by this figure is that the introduction of a ventilation velocity reduces the ambient supersaturation necessary to sustain the same linear growth rate. That is, increasing the ventilation velocity is roughly equivalent to increasing the ambient supersaturation. Other results show that for a fixed ambient temperature and ambient supersaturation, the linear 'a'-axis growth rate is directly proportional to the square root of the ventilation velocity provided that the crystal shape does not change significantly. Furthermore, the crystal shape transitions from plate to dendrite and column to needle occur at a lower ambient supersaturation as the ventilation velocity is increased.

It should be noted that the ventilation velocity specified in Fig. 1 as $v \doteq 0$ cm s^{-1} actually had a magnitude of a few mm s^{-1} due to the gravity induced natural convection associated with the release of latent heat from the growing crystals. The magnitude of this convection velocity increases with increasing growth rates. The effect of this small convection velocity on the growing crystals can not presently be quantitatively evaluated. When natural convection is greatly reduced, such as in the low gravity environment available on the Spacelab, Atmospheric Cloud Physics Laboratory (ACPL) flights, its effect on earth-based experiments can be inferred. It is anticipated that the effect of greatly reducing the natural convection velocity will be primarily observed on the habit transitions of ice rather than in terms of any substantial decreases in water vapor transfer. These habit transitions occur at -3, -8 and -25°C, where plate-like habit alternates with column-like habit as the temperature falls. Ice at supersaturations normally encountered in the atmosphere has been shown in recent laboratory studies to grow primarily by surface nucleation processes, one or another low index face being favored depending on the temperature. At somewhat lower supersaturations, there is an effect of emergent crystal dislocations on growth, and the laboratory studies strongly suggest that the transition is influenced by quite small local convective velocities. In other words, in the absence of convection, different crystal habits could occur. A knowledge of this transition, coupled with information on the relative mass fluxes, will yield information on surface molecular processes.

Mechanical Supports

The effects of a mechanical support on ice crystals growing from the vapor have also been difficult to ascertain. Most of the information on these effects is deduced indirectly from experiments such as the study of ice crystal growth reported by Schaefer and Cheng, 1968. In that study ice crystals were nucleated by six different mechanisms, under similar conditions in a supercooled water cloud at -20°C. Sometimes the crystals were nucleated on particulates such as silver iodide, lead iodide, or soil particles, and sometimes by rapid cooling from the injection of dry ice particles, or the expansion that occurs when a plastic bubble of packing material is compressed and "popped." In each case the crystals grew as they fell through the supercooled cloud. The structures of the resulting crystals apparently varied with the nucleating mechanism in a way that persisted to crystal sizes at least as large as 100 microns. Whereas, simple featureless plates were produced by adiabatic expansion and dry ice nucleation, complex and irregular crystals grew on volcanic dust and glacial clay particles.

These results suggest that the strain field produced by the nucleating particle (or by a mechanical support if one were introduced) could have a significant influence on the subsequent crystal growth. An indication of the magnitude of this effect can be obtained from recent studies of the epitaxial growth of ice on AgI and CuS single crystal substrates (Anderson and Hallett, 1979). These ice crystals were grown from the vapor in a precisely controlled temperature and vapor density environment and examined by photography through a microscope with a long working distance objective and vertical white light illumination. Under these circumstances the crystals grow as thin plates, the basal surface of the ice against the exposed basal surface of the substrate crystal. The crystals exhibit "thin film" white light interference patterns so that the thickness of a crystal can be determined from its color. Radial growth along the substrate usually predominates because the substrate forms an efficient heat sink for the growth interface. Frequently, crystals will grow radially only, without any discernible thickening.

Comparison of ice crystal growth on the two substrates, AgI and CuS, at the same environmental conditions, demonstrates the potential influence of a mechanical support. First, non-thickening crystals do not appear at warm temperatures (above -7°C) on either substrate. On CuS they form 10 to 20 percent of the crystal population as the temperature is lowered to -16°C; at and below -20°C the fraction may exceed 30 percent. These numbers are not precise because the flatness of the substrate also plays a role. On AgI, some crystals thicken very slowly at the warmer temperatures, but non-thickening plates do not begin to appear until about -15°C. The percentage of non-thickening crystals then increases rapidly with decreasing temperature and is comparable to the percentage for CuS below -20°C. A comparison of crystal growth rates at -15.2°C for non-thickening crystals on CuS and slowly thickening crystals on AgI shows that ice grows radially three times faster on AgI than on CuS (see Figure 2). This is interesting because examination of the radial growth rate of a non-thickening crystal, on either AgI or CuS, which subsequently begins to thicken shows that the thickening face adsorbs much of the available vapor and retards the radial growth. It must be noted that the quantitative information gained from these studies applies only to crystals less than 2 microns thick.

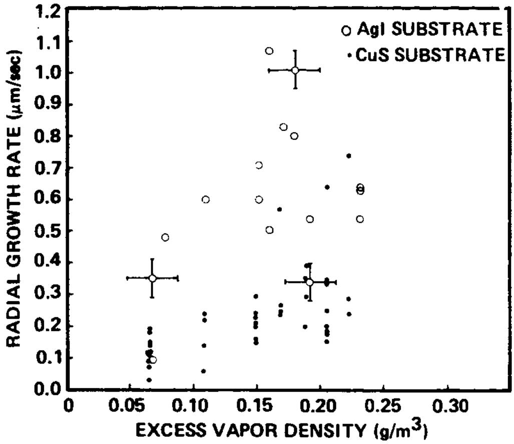

Figure 2. Ice crystal growth rates normal to the prism face on CuS and AgI (T = -15.2 C).

These results imply that the strain introduced into the epitaxially grown ice crystals is larger for CuS than for AgI. A comparison of crystallographic lattice dimensions in the basal plane shows that the lattice mismatch at the crystal-substrate interface is smaller between ice and AgI than between ice and CuS. This mismatch may be the primary source of the strain. Although comparisons such as these of radial growth rates for ice crystals growing epitaxially on different substrates give some assessment of the interface induced crystal strain, a thorough understanding of the effects introduced by a mechanical support on crystal growth must take into account such parameters as heat transfer along the support, trace contamination, asymmetric crystal growth, competition between adjacent crystals, and pertubations to the surrounding vapor and temperature fields.

Discussion

The initial ACPL ice crystal growth experiment is specifically designed to study the effect of greatly reduced natural convection. The utilization of a support fiber in this initial experiment simplifies the experiment but, more importantly, it allows the results to be more readily interpreted and compared to similar experiments conducted on earth. Later ACPL ice crystal growth experiments will study the combined effect of removing both natural convection and the mechanical support from the experimental system.

References

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