NOTES AND CORRESPONDENCE

The Growth of Small Ice Crystals in Gases of High and Low Pressures at -30 and -44°C **By Takehiko Gonda***Faculty of Science and Technology, Science University of Tokyo, Noda, Chiba, Japan**(Manuscript received 16 June 1976, in revised form 31 January 1977)***1. Introduction**

Many studies have shown that the habit of ice crystals grown at temperatures above -20°C varies with temperature in such a way as plate $\rightarrow$ column $\rightarrow$ plate. On the other hand, at temperatures below -20°C some studies have reported that columnar crystals are always predominantly

formed except polycrystalline snow crystals (Aufm Kampe *et al.*, 1951; Mason, 1953b; Hallett and Mason, 1958b; Kobayashi, 1961). In the present experiment the habit and the growth feature of small ice crystals which grow in helium and argon gases of high and low pressures at -30°C and about 4% over ice saturation and at -44°C and near ice saturation are investigated.

Fig. 1 Ice crystals predominantly formed in helium (left side) and argon (right side) at various pressures at -30°C and about 4% over ice saturation.

Fig. 2 The statistical frequency in occurrence of the growth feature among plates in helium at various pressures at -30°C and about 4% over ice saturation.

Fig. 3 Ice crystals predominantly formed in helium (left side) and argon (right side) at various pressures at -44°C and near ice saturation.

2. Experiment

The purpose of this experiment is to form small ice crystals under lower temperature and lower supersaturation over ice than those of a previous research (Gonda, 1976). The experimental apparatus is shown in a previous paper (Gonda, 1975). In order to form ice crystals at a constant vapor pressure at -30°C , the inner wall of the chamber was wholly covered with ice. Then, the water vapor supplier (5Ω) was heated (electric current = 2.5A) for about 10 minutes, and the silver iodide smoke supplier (1Ω) was operated for about 10 seconds. A dense fog was formed in the chamber at 30 seconds after the seeding and existed for about 2 minutes. By the use of an electric hygrometer the vapor pressure in the chamber was found to be about 104% with respect to ice. The experiment at -44°C was made by the similar way.

3. Variation of the growth feature of small ice crystals with the pressure

(a) Results at -30°C and about 4% over ice saturation

The small ice crystals formed by seeding silver iodide smoke in helium and argon at various pressures (1/5–15 atm) were almost plates. The frequency of the occurrence of columnar crystals was only below 1.4% of total single crystals through all pressures. Here, only single crystalline plates and single crystalline columns were selected and polycrystalline aggregates were excluded.

Ice crystals predominantly formed in helium and argon are shown in Fig. 1. The frequency of the occurrence of the growth feature in the case of plates formed in helium is shown in Fig. 2. As shown in these figures, solid plates were predominantly formed at pressures below 1/3 atm. Skeleton plates were predominantly formed at pressures between 1/2 and 5 atm. Dendrites were predominantly formed at pressures above 10 atm. The growth feature of small ice crystals in argon (figures are not shown) was different from that in helium in the following two aspects. One is that skeleton plates were formed at 1/5 atm in argon while not at all in helium and dendrites were formed at 1 atm in argon while not at all in helium. The other is that stellar crystals were predominantly formed at pressures above 5 atm in argon while in helium skeleton plates were predominant at 5 atm and dendrites were predominant at 10 and 15 atm.

(b) Results at -44°C and near ice saturation

The small ice crystals formed by seeding silver iodide smoke in helium and argon at various pressures (1/5–15 atm) were almost plates. The frequency of the occurrence of columnar crystals was below 18% of total single crystals through all pressures. The frequency of the occurrence of long prisms formed at pressures above 5 atm was below 15% of total single crystals. The frequency of the occurrence of long prisms formed at pressures below 1/2 atm was below 2.4% of total single crystals.

As shown in Fig. 3, small ice crystals in helium were predominantly skeleton plates at all pressures and small ice crystals in argon were predominantly skeleton plates at all pressures except 1/5 atm.

4. Variation of the habit of small ice crystals with the pressure

The mean values of the axial ratio c/a of plates in helium and argon at -30°C against the vapor diffusivity are shown in Fig. 4. As can be seen in the figure, the values of c/a in helium (open circles) are closer to unity with increasing vapor diffusivity. The values of c/a in argon (full circles) show the same tendency as that in helium. Meanwhile, under a constant vapor diffusivity the values in argon are closer to unity than those in helium. The variation of c/a at -44°C with the vapor diffusivity shows the same tendency as that at -30°C . These tendencies coincide with those at -7 and -15°C in the previous paper (Gonda, 1976).

Fig. 4 The mean values of the axial ratio c/a of small ice crystals formed in helium (open circles) and argon (full circles) at -30°C and about 4% over ice saturation versus the vapor diffusivity. Standard deviations of each mean value are illustrated.

5. Discussions

Small single crystals ($<30\mu\text{m}$) formed in free fall in helium and argon at various pressures (1/5–15 atm) at -30 and -44°C were almost plates. Kikuchi (1976) also found that plenty of the diamond-dust in the Antarctica were plates at temperatures below -30°C . These results are remarkably different from experimental results of Aufm-Kampe *et al.* (1951), Mason (1953b), Hallett *et al.* (1958b) and Kobayashi (1961). They reported that columnar crystals were always predominantly formed at temperatures between -20 and -50°C . The reason of this difference is uncertain.

Table 1. The variation of the values of the axial ratio c/a of small ice crystals with the vapor diffusivity under a constant thermal conductivity ($34.4 \times 10^{-5} \text{ cal} \cdot \text{cm}^{-1} \cdot \text{sec}^{-1} \cdot \text{deg}^{-1}$). Standard deviations of each mean value in the table are below 0.05.

$P(\text{atm})$	$D(\text{cm}^2/\text{sec})$	-7°C	-15°C	-30°C	-44°C
15	0.05	1.65	0.27	0.44	0.22
10	0.08	1.60	0.32	0.48	0.30
5	0.15	1.52	0.42	0.54	0.43
1	0.77	1.32	0.64	0.68	0.72
1/2	1.54	1.24	0.73	0.75	0.85
1/3	2.31	1.19	0.79	0.78	0.92
1/4	3.08	1.16	0.83	0.82	0.97
1/5	3.85	1.13	0.86	0.84	0.99

Table 2. The variation of the values of the axial ratio c/a of small ice crystals with the thermal conductivity under a constant vapor diffusivity ($0.77 \text{ cm}^2 \cdot \text{sec}^{-1}$). Standard deviations of each mean value in the table are below 0.05.

$K(\times 10^{-5} \text{ cal/cm} \cdot \text{sec} \cdot \text{deg})$	-7°C	-15°C	-30°C	-44°C
3.89	1.08	0.94	0.86	0.95
34.4	1.32	0.64	0.68	0.72

Table 1 shows that the habit of small ice crystals varies with the vapor diffusivity under a constant thermal conductivity and c/a approaches unity with increasing vapor diffusivity. That is to say, the dependence of the habit of small ice crystals on temperature becomes less remarkable with increasing vapor diffusivity. At the same time, the growth feature becomes simpler with increasing vapor diffusivity.

Table 2 shows that the habit of small ice crystals slightly varies with the thermal conductivity

under a constant vapor diffusivity and c/a becomes far apart from unity with increasing thermal conductivity. That is to say, the dependence of the habit of small ice crystals on temperature is pronounced with increasing thermal conductivity. At the same time, the growth feature becomes complicated with increasing thermal conductivity. The detail of the physical meanings of the experimental results was described in a previous paper (Gonda and Komabayasi, 1971).

6. Summary and conclusions

Small single ice crystals were formed from vapor phase in helium and argon gases at various pressures (1/5–15 atm) in two cases. One was at -30°C and about 4% over ice saturation and the other was at -44°C and near ice saturation.

1. Almost all of small single crystals grown in free fall at -30 and -44°C were hexagonal plates.

2. The dependence of the growth feature of small ice crystals at -30°C on the pressure and the kind of carrier gas showed the same tendency as those at -7 and -15°C (Gonda, 1976), although the growth feature at -44°C did not depend on the pressure and the kind of carrier gas.

3. The dependence of the habit of small ice crystals at -30 and -44°C on the pressure and the kind of the carrier gas showed the same tendency as those at -7 and -15°C (Gonda, 1976).

4. It was concluded that the habit and the growth feature of small ice crystals with sizes below $50\mu\text{m}$ in diameter depended not only on the temperature and the degree of supersaturation but also on the diffusion coefficient of water vapor, the thermal conductivity of the carrier gas and the size of crystals.

Acknowledgments

The author wishes to express his deep thanks to Dr. M. Komabayasi of Osaka District Meteorological Observatory for helpful suggestions, discussions and encouragement. The author is also deeply indebted to Prof. K. Isono of Nagoya University for many helpful advices and encouragement during the course of this work.

References

- Aufm Kampe, H.J., H.K. Weickmann and J.J. Kelly, 1951: The influence of temperature on the shape of ice crystals growing at water saturation. *J. Met.*, 8, 168–174.
- Gonda, T. and M. Komabayasi, 1971: Skeletal and dendritic structures of ice crystals as a function

- of thermal conductivity and vapor diffusivity. *J. Meteor. Soc. Japan*, **49**, 32-42.
- Gonda, T., 1975: A high-pressure cold chamber for the study of ice crystal growth in compressed gases. *J. Meteor. Soc. Japan*, **53**, 334-339.
- , 1976: The growth of small ice crystals in gases of high and low pressures. *J. Meteor. Soc. Japan*, **54**, 233-240.
- Hallett, J. and B. J. Mason, 1958b: The influence of temperature and supersaturation on the habit of ice crystals grown from the vapor. *Proc. Roy. Soc. A.*, **247**, 440-453.
- Kikuchi, K. 1976: Paper presented in 1976 May, Meeting of Japan Meteorological Society.
- Kobayashi, T., 1961: The growth of snow crystals at low supersaturations *Phil. Mag.*, **6**, 1363-1370.
- Mason, B. J., 1953b: The growth of ice crystals in a supercooled water cloud. *Q. J. Met. Soc.*, **79**, 104-111.

−30°C と −44°C の高圧気体と低圧気体中に於ける氷晶の成長

権 田 武 彦

東京理科大学理工学部