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Role of Frozen Cloud Droplets on the Growth of Snow Crystals of Certain Shapes*

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Abstract

Based on a careful scrutinization of a number of microphotographs of snow crystals taken at Syowa Station, Antarctica during the period from February 1968 to January 1969, considerable data were obtained that the snow crystal of the shape of scalelike side planes grow from sintered frozen cloud particles. And further, based on microphotographs various stages of growth from frozen cloud droplets to snow crystals were seen indicating that the crystal shapes of radiating assemblages of dendrites and radiating assemblages of plates grow from relatively large frozen cloud droplets. In an attempt to obtain supporting evidence, laboratory experiments were conducted and the growth process of snow crystals from frozen droplets were observed using a convection type cold chamber. As a result, the crystal shapes of radiating assemblages of dendrites and radiating assemblages of plates were found to be producible from frozen droplets. However, it was very difficult to produce the shape of scalelike side planes. As a matter of course, when a frozen droplet is a polycrystal, the crystal grown from the droplet is a polycrystal, for instance, they appear as radiating assemblages of dendrites and plates. When, however, a frozen droplet is a single crystal, the crystals grown from the droplet may become single or polycrystals. In the case of polycrystal growing from the droplet, it was attributed to temperature dependency by which supercooled droplets froze to polycrystals on a single crystal under the conditions of relatively low temperatures. However, consideration about the change of size of the frozen droplet with growing the crystal was impossible.

1. Introduction

It is well known that the crystal habit of snow crystals depends on the air temperature and supersaturation with respect to the ice surface.[1),2),3)] However, the shapes of the following crystals, namely, spatial assemblage of plane branches, radiating assemblage of plane branches and columnar crystal with

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extended side planes[4] have not been included in their diagrams. On the other hand, it has been considered that when supercooled cloud droplets collided and froze on a snow crystal of plane type at a temperature of –20°C or thereabouts, branches developed especially from the frozen droplets on the plane of the snow crystals, and thereafter formed a spatial snow crystal.[4],[5] This consideration was experimentally confirmed by Higuchi and Yoshida,[6] Magono and Aburakawa[7] and Aburakawa and Magono[8] using a polarization microscope.

In addition, Kikuchi[9] made a statistical analysis of the shapes of single bullet and combination of bullets. As a result, he considered the origin of the shape of combination of bullets in which each bullet in a snow crystal grows either from dust particles with many corners or from frozen droplets with many spicules which are produced by sudden freezing of supercooled droplets. However, frozen cloud droplet is not always recognized at the center of crystal in natural. Therefore, it is considered that the frozen cloud droplet evaporates during growing process of the crystal and contributes to the growth of the crystal.

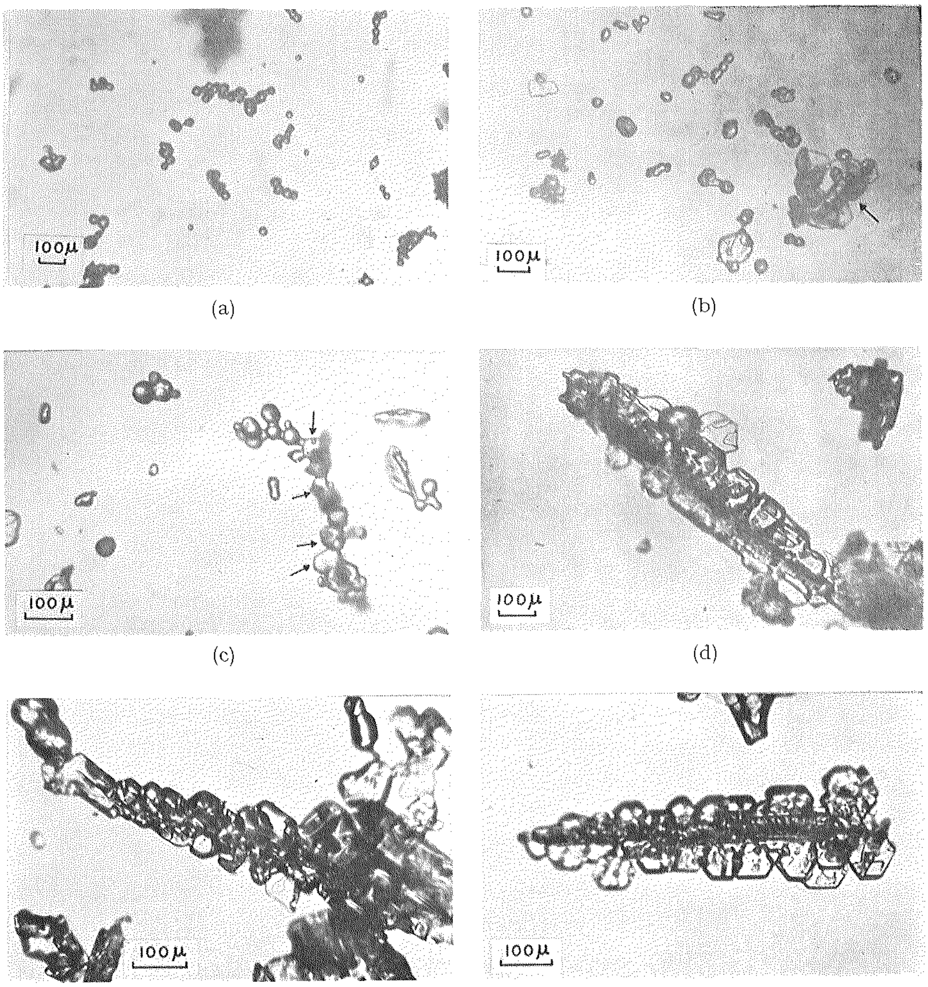
One of the authors (Kikuchi) carried out some observations in the field of cloud physics and atmospheric electricity when he was a member of the wintering party of the 9th Japanese Antarctic Research Expedition (1968–1969) at Syowa Station, Antarctica (69°00′S, 39°35′E). In relation to the observation of snow crystals, it had been taken microscopic photographs amounting to 3000 frames and 600 glass plates by the replica solution method and reported the presence of ten or more types of unknown and peculiar shapes.[10],[11],[12] "Sintered frozen cloud particles" was one of the unknown types.[13] Especially, in the case of June 8, 1968, the precipitation of sintered frozen cloud particles continued for about ten hours under the condition of surface air temperature of –20°C or thereabouts. They were composed of two or more particles in a chain fashion, occasionally of a few tenths of single particles. Sometimes, a few particles in sintered frozen cloud particles grew and indicated a (0001) plane. On the other hand, the shape of "scalelike side planes" was observed more frequently at Syowa Station. This paper will describe a hypothetical explanation of the growth from the sintered frozen cloud particles to the scalelike side planes and laboratory experiments about the change of the size of the center frozen cloud particles with artificial production of snow crystals of spatial assemblage of plane branches and radiating assemblage of plane branches.

2. Field observations

As described previously, sintered frozen cloud particles were composed of two or more particles and further they were formed as chains or straight lines as shown in Fig. 1 (a). When the sintered frozen cloud particles were composed of a few particles, they became short scalelike side planes as shown by an arrow in Fig. 1 (b) and the so-called side planes or crossed plate after they grew completely. If the frozen particles were connected randomly, they grew complicated side planes or combination of side planes, bullets and columns under some conditions. During the observation period at Syowa Station, scalelike side planes were observed more frequently than simple side planes. The following processes were considered. Each frozen cloud particle was connected with each other, sometimes up to ten or more during a relatively short period as a chain or a straight line. And a few frozen particles of these showed crystallization as indicated by small arrows in Fig. 1 (c). The crystal sizes of each plate composed of scalelike side planes grown in the same manner were almost the same. One of the examples is shown in Fig. 1 (d). In this figure, two droplets with a spike on the left end were seen. On the other hand, if each frozen droplet crystallized from the former end of "iciclelike crystal"[10] as seen in Fig. 1 (e), the crystal sizes of each plate were larger than the former end and the smaller the last end as seen in Fig. 1 (f). Iciclelike crystals were frequently observed simultaneously with sintered frozen cloud particles. Although the central bone of the crystals in this example was nearly straight, it was not necessary. Generally, the central bone of relatively large size of scalelike side planes forms of the shape of zigzag as seen in Photo. 3 in Kikuchi's paper.[11] Otherwise, a scalelike side planes was formed that each frozen droplet collided with one side of relatively short side planes or crossed plates and crystallized immediately. After that, next frozen droplet followed the same manner. And the crystal as seen in Fig. 1 (f) would be formed.

3. Laboratory experiments

Besides the crystal of scalelike side planes, we know the artificial frozen droplet acts as a germ of secondary growth on the ice surface in laboratory experiments.[6),7),8)] Furthermore, we know that the relatively large frozen cloud droplet is likely act as a center nucleus of radiating assemblage of dendrites (Fig. 2) and combination of bullets (Fig. 3). However, there were



(a) (b)

(c) (d)

(e) (f)

Fig. 1 Microphotographs of various stages from "sintered frozen cloud particles" to "scalelike side planes" taken at Syowa Station, Antarctica.

no reports about the early stage of growth of plates and dendrites from natural frozen cloud droplets up to present. Fortunately, thereupon, a number of microphotographs of them were taken during wintering period. Figs. 4 and 5 show examples of them. These examples were observed under the condition of the surface air temperature lower than −10°C. If a frozen cloud droplet is single crystal, it is considered that it grows a single crystal of hex-

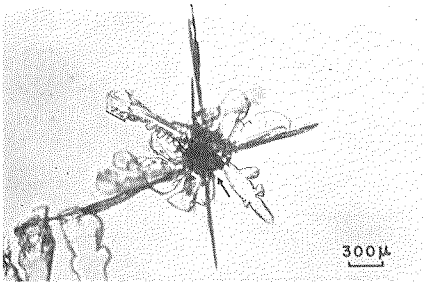


Fig. 2 Microphotograph of "radiating assemblage of dendrites" taken at Syowa Station, Antarctica.

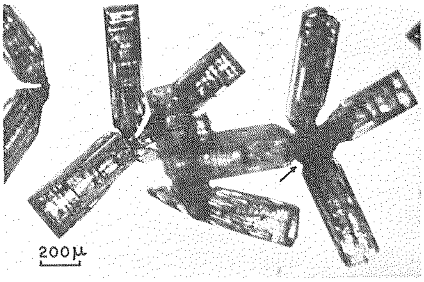


Fig. 3 Microphotograph of "combination of bullets" taken at Syowa Station, Antarctica.

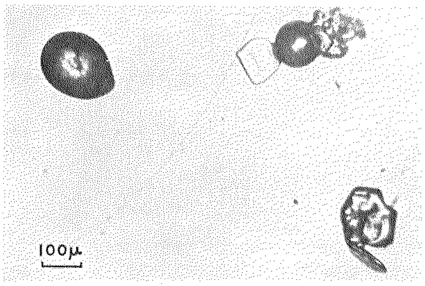


Fig. 4 Microphotograph of "frozen cloud droplets" taken at Syowa Station, Antarctica.

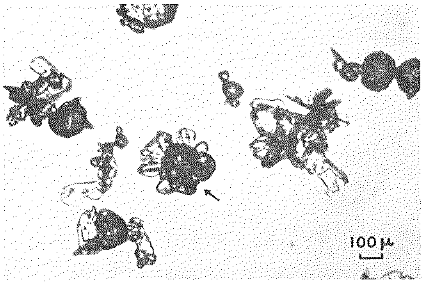
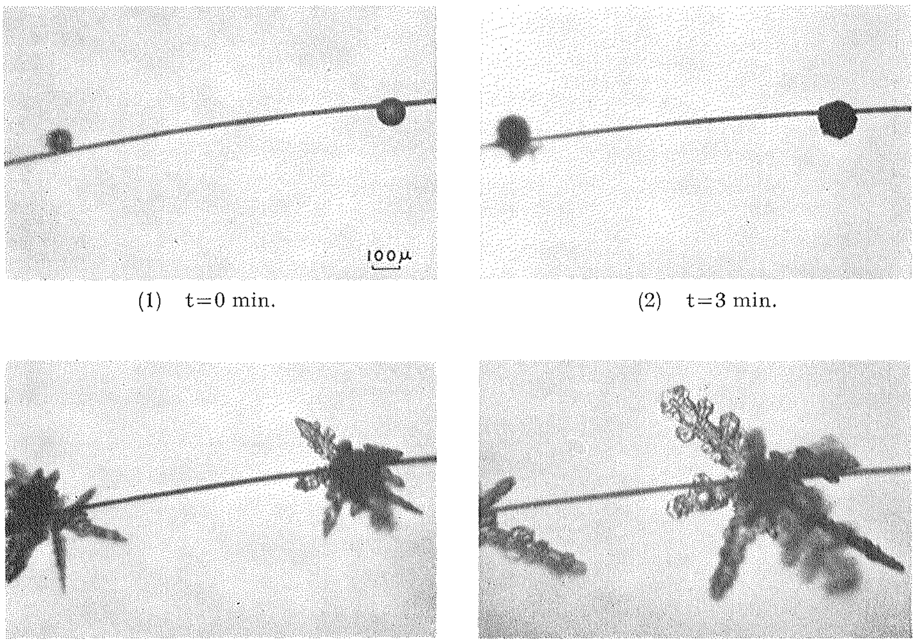


Fig. 5 Microphotograph of "frozen cloud droplets" taken at Syowa Station, Antarctica. The crystal indicated by arrow is a germ of radiating assemblage of plates growing from a frozen cloud droplet.

agonal plate or column. According to the experiment of Magono and Aburakawa,[7] however, the following nature was reported, although all supercooled droplets were frozen into single crystal with the same axis as that of the basal ice plate at -5°C, about half of the droplets were frozen into polycrystal at -10°C and further in the case of -15°C, the majority of rimed droplets were polycrystal.

Thus, the authors carried out laboratory experiments for artificial production of snow crystals, especially radiating assemblage of dendrites and radiating assemblage of plates, from frozen droplets and for the change of the size of the center frozen cloud particle after the method of Nakaya.[14] At first, supercooled water droplets were produced by using a plastic atomizer in a cold room (<−25°C). A few droplets were collected on a rabbit hair stretched from a metal arm. After a lapse of time, the frozen or unfrozen were observed and the number of crystal was counted under a polarizing microscope and color photomicrographs were taken. Next, the frozen droplets on the hair were placed in a snow making apparatus. Growing the crystal, microphotographs were taken at suitable time interval and length of a branch of a dendrite and diameter of center frozen particle were measured. The difference of this experiment and the former ones of Higuchi and Yoshida[6] and Magono and Aburakawa[7] was that a substrate of basal ice plate for freezing of supercooled droplets was not used and that Nakaya's convection chamber was utilized.

Fig. 6 shows and example of the cases of radiating assemblage of dendrites. In this case, both frozen droplets on the rabbit hair in this figure were polycrystals. Radius of droplet in right side was 55 μm. As seen in Fig. 7, beginning at the initial air temperature of −26°C, after six minutes at −17°C,



(1) t=0 min. (2) t=3 min.

(3) t=6 min. (4) t=13 min.

Fig. 6 A series of microphotographs of "radiating assemblage of dendrites" growing from frozen droplets on rabbit hair.

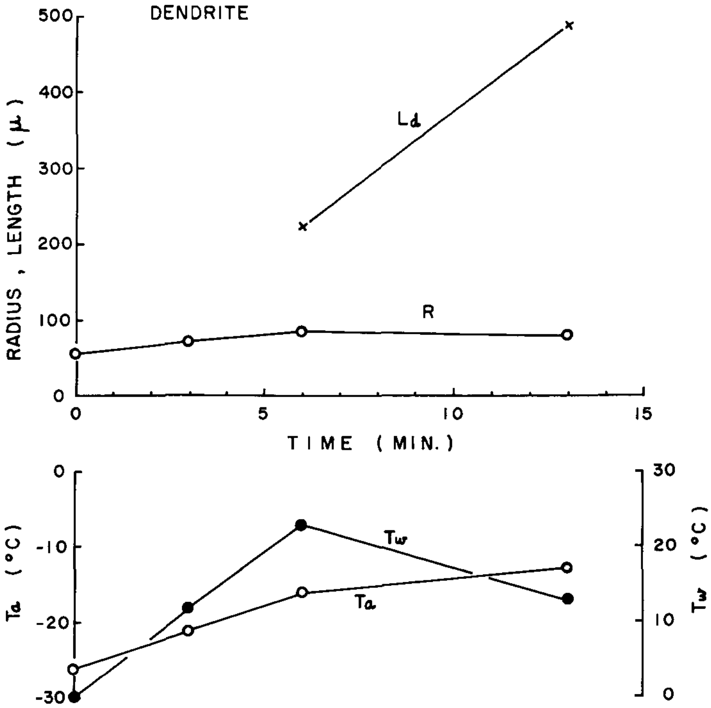
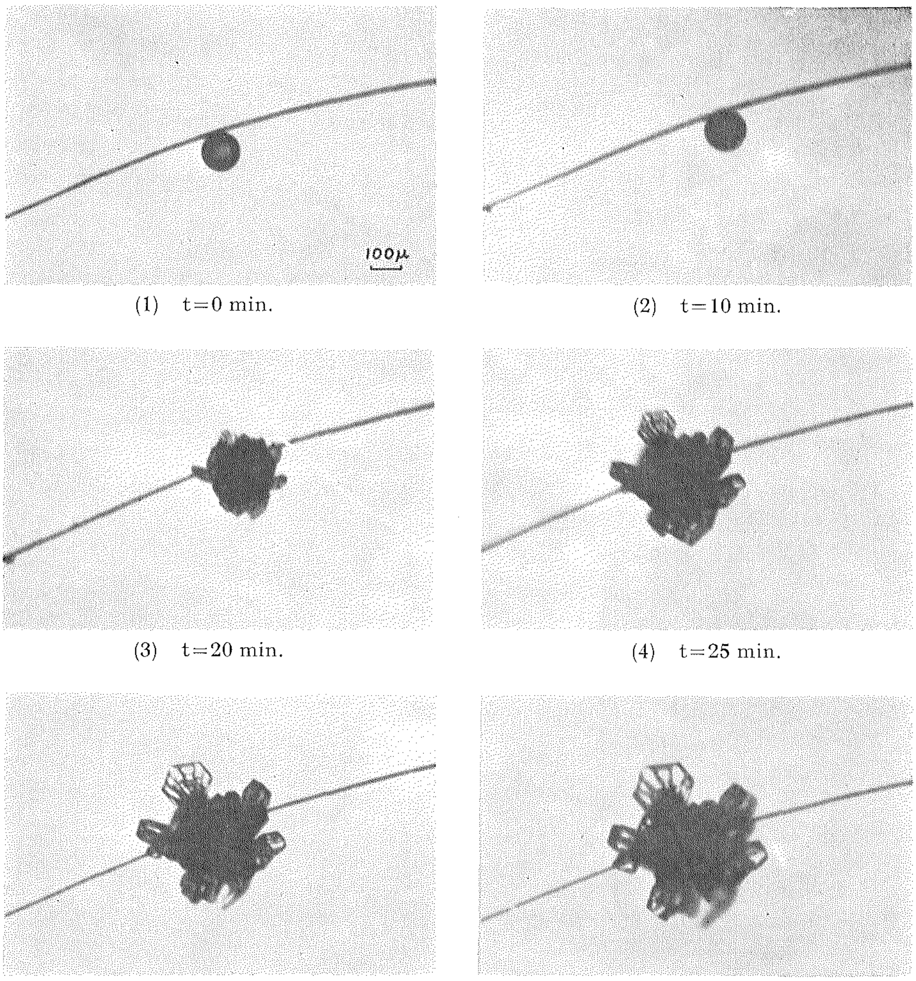


Fig. 7 Time changes of length of crystal (Ld) and radius of center frozen cloud particle (R) (upper) and Ta and Tw in the convection chamber (lower).

dendritic branches grew radially from the frozen droplets. This experiment was completed 13 minutes later. As seen from the Fig. 6, the number of the dendritic branches came to about ten. As described previously, the ten branches grew from the original polycrystals. However, the change of size of the droplet did not recognize after six minutes. Fig. 8 shows a series of radiating assemblage of plates. In this case, the main droplet was composed of two single crystals. After twenty minutes from the beginning, many small plates grew from the droplet radially and they were clearly polycrystals. This discrepancy may be considered as follows. As seen in the figure at ten minute later, a number of tiny supercooled droplets collided with the droplet in the convection chamber and they froze with different axes from the main droplet under relatively colder temperatures. And some of radiating branches grew from the frozen tiny droplets on the main droplet as reported by Magono and Aburakawa.[7] Further, it may be seen that the photograph of the state



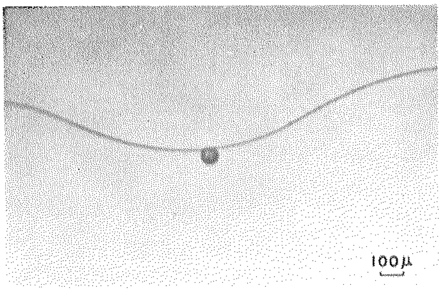
(1) t=0 min. (2) t=10 min.

(3) t=20 min. (4) t=25 min.

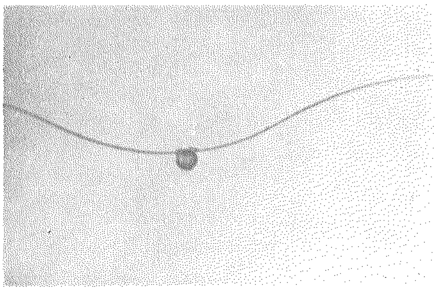
(5) t=50 min. (6) t=65 min.

Fig. 8 A series of microphotographs of "radiating assemblage of plates" growing from frozen droplets on rabbit hair.

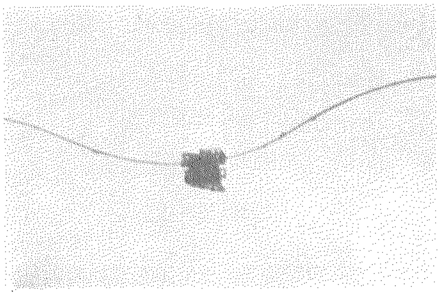
of the frozen droplet of twenty minute later bears a striking resemblance to the natural one pointed by an arrow in Fig. 5. In this case, the radius could not measure because of indistinct the periphery of the droplet. The example of hollow prism is shown in Fig. 9. Many hollow prisms grew from the main droplet on both sides. In this case, the air temperature in the chamber was held at nearly −10°C. While the hollow prisms grow from 30 min to 140 min,



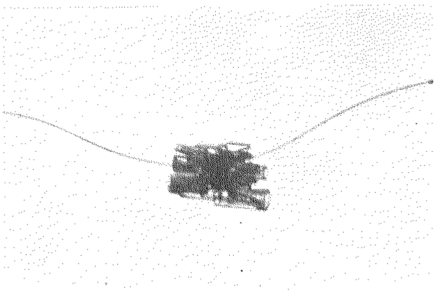
(1) t=0 min.



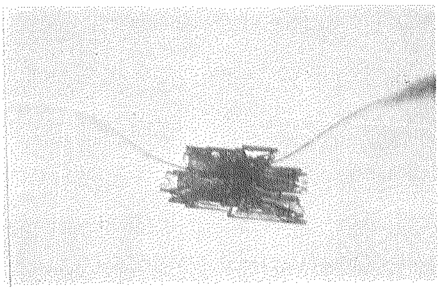
(2) t=10 min.



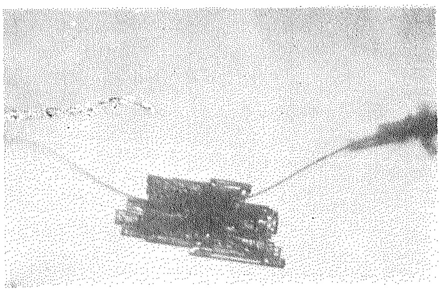
(3) t=30 min.



(4) t=70 min.



(5) t=100 min.



(6) t=140 min.

Fig. 9 A series of microphotographs of "hollow prisms" growing from a frozen droplet on rabbit hair.

the radius of droplet did not change sharply as seen in Fig. 10. However, for the sake of many hollow prisms, it was difficult to measure the radius.

4. Considerations and Conclusions

From careful scrutinization of a number of photographs of sintered frozen cloud droplets observed at Syowa Station, Antarctica, the authors found each

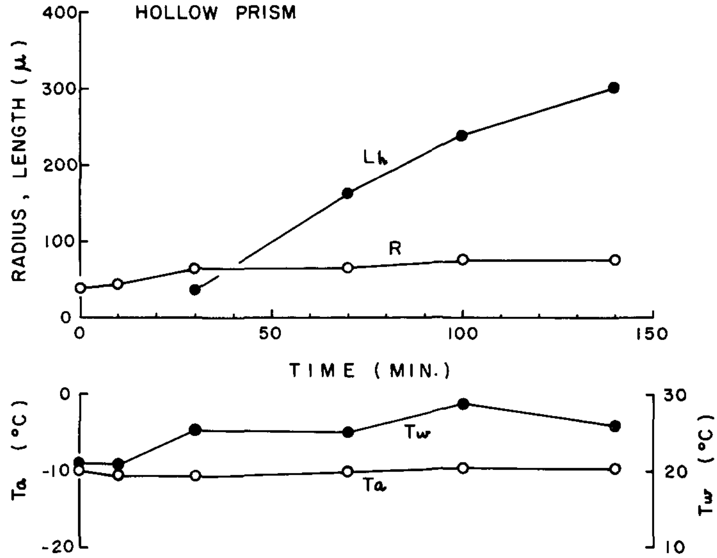


Fig. 10 Time changes of length of crystal (Lh) and radius of center frozen cloud particle (R) (upper) and Ta and Tw in the convection chamber (lower).

frozen cloud droplet to be connected in a relatively straight line with each other sometimes up to ten or more particles. Further, some of particles composed of "sintered frozen cloud particles" crystallized. Because of the various stages of the crystal growth of side plane crystals were taken by photographs, following processes were considered. When the sintered frozen cloud particles were composed of a few particles, they became short scalelike side planes after they grew completely. Generally, they were simply referred to as "side planes" or "crossed plates." If, however, crystallization of sintered frozen cloud particles which were connected up to ten or more particles began randomly in them, the crystal became "scalelike side planes" as seen in Fig. 1 (d). In this case, the crystal sizes of each plate composed of the side planes would be almost nearly the same. On the other hand, if each frozen cloud droplet collided with one side of relatively short side planes or crossed plates and crystallized immediately, and further if the next frozen droplet followed the same manner, the short side planes would appear scalelike side planes as seen in Fig. 1 (f). Otherwise, each frozen cloud particle composed of iciclelike crystal crystallized from the former end as seen in Fig. 1 (e). As a result, the crystal sizes of each plate were larger the anterior end and smaller the posterior end as seen in Fig. 1 (f). The crystal habit of side plane crystals was considered nearly the same as that of columns and combination of bullets in the colder region by Magono et al.[15] Furthermore, it was considered that each plane composed of scalelike side planes and side planes was on the plane of (0001) as a result of etch pit technique experiments by Magono and Sasaki.[16] Therefore, even if it was assumed that the scalelike side planes were grown from the frozen cloud particles, it still remains obscure as to why the planes composed of the scalelike side planes grew from the same region of columns and combination of bullets. Therefore, considering the temperature range alone, the plane was on $(10\bar{1}0)$, namely this was the plane presented by Nakaya.[5]

In the laboratory experiments, crystals of various shapes of radiating assemblages of plates and dendrites and hollow prisms were produced from a frozen droplet in a cold chamber of convection type artificially. When the frozen droplet was composed of polycrystals, as a matter of course, the crystal grown from this was a polycrystal, namely, it was in the form of radiating assemblages of plates and dendrites. And also, when the frozen droplet was a single crystal, the crystal grown from this was a single crystal. However, in a few cases, although the frozen droplet was a single crystal, the crystal grown was a polycrystal. This difference was considered as follows. A number of tiny supercooled droplets collided with the main droplet supported by a rabbit hair in the convection chamber and they froze with different axes from the main droplet under relatively colder temperature. And some of radiating branches grew from the frozen tiny droplets on the main droplet. Thus, the crystal rather than becoming single became polycrystal. In Antarctica, the plate type crystals, of course, they were single crystals, were more frequently observed during the falling of the shapes of radiating assemblages of plates and dendrites and with scalelike side planes and crossed plates. And sometimes, relatively large frozen cloud droplets, approximately 200 μm in diameter, were found on branches of radiating assemblages of plates and dendrites.[12]

Thus, as a result of our present experiments considerable data related to the formation mechanisms of the shapes of radiating assemblage of plates and of radiating assemblage of dendrites was obtained, leaving however the formation of scalelike side planes to be studied experimentally later. And further, it was concluded that it was hardly possible to discuss the change of size of the droplet in this experimental manner.

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