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Report of the Mauna Loa Expedition in the winter of 1956–57*

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Abstract

The expedition to the Mauna Loa in Hawaii Island was carried out in the winter of 1956–57 in order to study the snow crystals at the summit, 13,450 ft, and also to investigate the condensation nuclei in this district. The nuclei number above the overcast, about 6,000 ft. high, was very small in fine days, being 100–200 per c.c. 7 profiles of nuclei number were made and it was found that the number is fairly large in the cloud or fog, and very small in rain or snowfall. The height of the maximum nuclei number coincided with the boundary of air masses in the time cross section made from the data of radio sonde at Hilo. At the spot on the lee of the stationary front of fog the number was very large.

About 150 microphotographs of snow crystals were taken at the summit, and it was noticed that almost all types of snow crystals were observed at this spot. The frequency of occurrance was different from that observed in Hokkaido, and the needle crystals of various kinds were frequently observed. The transition of the prevailing type of snow crystals to the other type in the course of one snowfall was sharply defined, and the transition was rapid. Several photographs were taken, which show the stage just after the attachment of an ice crystal to a supercooled rain drop. These photographs show the mechanism of formation of ice pellets. Many photographs of frost crystals were also obtained. They showed that the thermal property of the object on which the frost cyrstals grow influences the shape of the crystal.

§ 1. Introduction

In the preliminary experiment of the effect of aerosol particles on the shape of snow crystals,[1] it was found that the shape of snow crystal was influenced by the presence of aerosol particles. In a certain range of temperature and degree of supersaturation, the crystal changed the shape completely, when the aerosol free air was used. The experiment was carried out by using the similar apparatus as our old artificial snow apparatus. It was confirmed that the old diagram[2] showing the relation between the shape of

snow crystal and the temperature and the supersaturation was applied in the case of this new apparatus, when the ordinary air wes used. In the later experiments it was found that the presence of a trace of foreign vapor was another factor which transforms the crystal shape into another type. The details of these experiments will be published as the succeeding report of this series of investigations.

So long as the presence of aerosol particles seems to affect the shape of snow crystals, it is considered desirable to investigate the shape of snow crystals which fall in the district where the least aerosol particles are observed. For that purpose the summit of the Mauna Loa in Hawaii Island, T. H., was chosen as the spot suitable for this purpose. The expedition to the Mauna Loa was attempted in the winter of 1956–57.

§ 2. The Expedition to the Mauna Loa

The expedition to the Mauna Loa in Hawaii Island was carried out last winter, and we stayed there from 7 December 1956 until 22 January 1957. There is the Slope Observatory at the level of 11, 130 ft, which belongs to the U. S. Weather Bureau. This Observatory is well equipped so that several persons can stay comfortably for a long period of time. There is another hut near the summit of the Mauna Loa at the level of 13,450 ft, which is called the Summit Unit. This Summit Unit also belongs to the U. S. Weather Bureau. This is a small hut, 8 ft × 10 ft in dimension, and has no living facility. There is no heating, no power; and it is very difficult to live in this hut. We, therefore, stayed at the Slope Observatory and went up to the Summit Unit for microphotography of snow crystals according to the weather forecast of snowfall. The forecast was done in a splendid way, and we did not miss any chance of snowfall.

The distance between the Slope Observatory and Hilo, the nearest town, is about 45 miles, and the transportation was done by a fourwheel drive vehicle which was supplied from the Kilauea Millitary Campus. The Summit Unit is 8.9 miles far from the Slope Observatory and the road is very rough. The driving was done by the Army driver. There is the Kulani prison half way up the mountain at the level of 5,100 ft, which is the nearest

neighbor. We sometimes got the help from this establishment.

In the earlier days of our stay at the Slope Observatory, the weather was fine every day and only one slight snowfall was observed on 15 December 1956, and another slight one on 6 January 1957. In both cases only a few microphotographs could be taken. After waiting for nearly 40 days, a heavy snowfall started in the evening of 14 January 1957 and it continued until 21 January. In the evening of 18 January the snow deposit near the summit reached about 1.5 ft, which is the maximum depth for the availability of the vehicle in this rough road, We, therefore, stopped the observation and cleared the Summit Unit late in the evening of 18 January. About 150 microphotographs were taken during these four days.

While waiting for the snowfall for 40 days, we carried out two kinds of investigations; the one is the measurement of condensation nuclei in this district and the other is the time lapse movie of high clouds. These two works were sponsored by the Munitalp Foundation, Schenectady, N. Y. The GE condensation nuclei meter, two time lapse movie cameras and the necessary films were supplied by the Munitalp Foundation.

This scientific report is made of two Parts, the one is the result of the observation of snow crystals at the summit of the Mauna Loa, which is a part of Contract No. AF 62 (502)-1228 with Geophysics Research Directorate, Air Force Cambridge Research Center. The other Part is the investigations on the condensation nuclei observed in this un-inhabited land. The Grand-in-Aid for this work was given by the Munitalp Foundation through the Hawaii Institute of Geophysics, University of Hawaii.

PART I. INVESTIGATIONS ON THE CONDENSATION NUCLEI

§ 3. The condensation nuclei meter and its function

The EG condensation nuclei meter[3] is a modification of Nolan-Pollak counter. The expansion is made in two steps. The first is a fast partial expansion which produces the desired supersaturation before the appreciable growth of water droplets could occur. The first condensation of water vapor on the nucleus can

occur in an appreciable amount in a few milliseconds, and this condensation will reduce the supersaturation so that the smaller droplets evaporate before they grow into the drops of appreciable size. In order to prevent this effect, the second expansion is given immediately after the first expansion. This is done by the leakage through a capillary to another evacuated chamber. The rate of the second expansion is adjusted so that the process is slow enough to permit the growth of droplets but fast enough to be considered as adiabatic. The fog particles thus produced give rise to the attenuation of light beam, which is measured photoelectrically. The meter is calibrated to show the number of fog particles on the scale. The range is between 2×10^2 and 5×10^6 per c.c., and below 2×10^2 the reading is not accurate.

The meter is designed to show the initial vacuum (p_0-p_1) of the evacuated chamber and that (p_0-p_2) after expansion, p_0 being the atmospheric pressure.

$$\text{The expansion ratio} \quad m=\left(\frac{p_0}{p_0-p_2}\right)^{\frac{1}{\gamma}}. \qquad (1)$$

For a certain value of p_0, p_2 is a function of p_1. The relationship is linear in the range of p_1 between 8″ and 17″, as shown in Fig. 1.

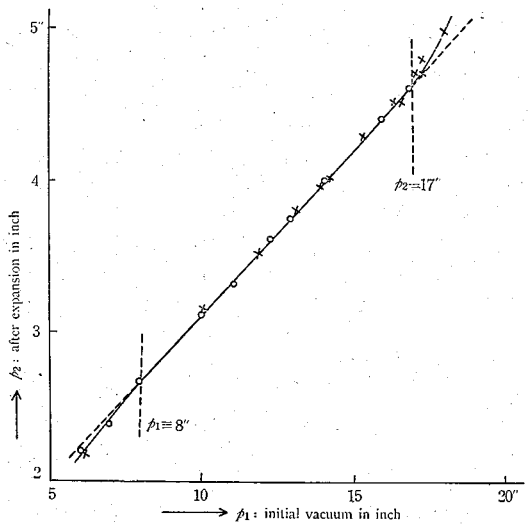

Fig. 1. The relation between p_1 and p_2; $p_0=20.1''$.

The number of nuclei N per c.c. was measured, as the function of p_1, in the room of the Slope Observatory in the living condition. One example is shown in Fig. 2. Increasing p_1, p_2 also increases, resulting in the increase of the expansion ratio m, eq. (1).

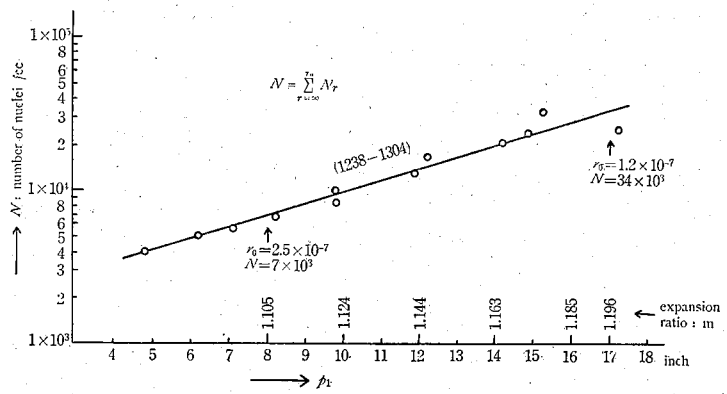

Fig. 2. The relation between p_1 and N; $p_0=20.1''$.

Fig. 2 shows that the number of nuclei counted increases when m increases. It is possible, therefore, to find the size distribution of the nuclei from Fig. 2. According to eq (1), the expansion ratio m is calculated as the function of p_2; that is, p_1, Fig. 1. The variation of supersaturation with expansion ratio is calculated by assuming that the temperature falls according to the well known adiabatic equation. Then the critical radius of the r_0, the condensation radius, is obtained from the supersaturation if we assume the classical KELVIN's formula. These calculations are shown in the paper of DAS GUPTA and GHOSH.[4]

TABLE 1. The relation between the condensation radius and the initial vacuum

p_1	m	r_0
8.0 inch	1.105	2.5×10^{-7} cm
10.0	1.124	2.1 "
12.0	1.144	1.75 "
14.0	1.163	1.5 "
16.0	1.185	1.3 "
17.0	1.196	1.2 "

The relation between the initial vacuum and the condensation radius thus obtained is shown in Table 1. Let the number of nuclei per c.c. with the radii between $r \times 10^{-7}$ cm and $(r+0.1) \times 10^{-7}$ cm be N_r.

$$N = \sum_{r=\infty}^{r_0} N_r \, .$$

Then the size distribution is obtained from the $p_1 - N$ relation, Fig. 2. The result is shown in Fg. 3. This distribution curve, however, cannot be considered to be a truth without doubt, because there are some difficulties in the theory. The first weak point is in the calculation of supersaturation. Recently DANUTA STACHÓRSKA[5] measured the temperature changes during adiabatic expansions of air saturated with vapor by using the resistance thermometer of thin tungsten wire and a cathode ray oscillograph. The temperature change was much less than that calculated from the ordinary adiabatic equation. If this is ture, the former calculated values of supersaturation are too high; that is, the values of r_0 deduced from such supersaturation value are too small. The second difficulty is in the point that whether KELVIN's formula can be applied to such small particles as 10^{-7} cm or so. Fig. 3, therefore, may be considered at present as showing the qualitative nature of the size distribution. It must be considered that the condensation radius r_0 used in this report has such a meaning as described above. The value of p_1 was chosen at about 0.8 p_0 throughout this series of observations. This means that the condensation nuclei are counted, which radii are a little larger than 10^{-7} cm.

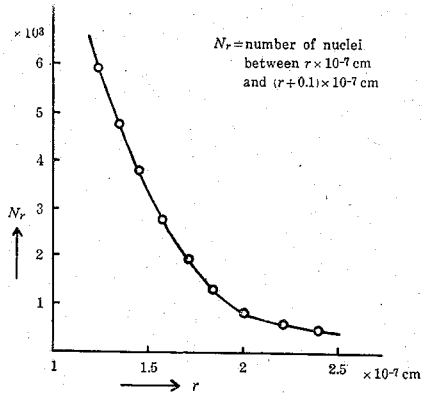

Fig. 3. The size distribution of nuclei.

§ 4. The effect of local pollution

The most important problem in the investigation of condensation

nuclei is the effect of local pollution. The number of condensation nuclei in this district is very small, being in the order of a few hundreds. A slight local pollution increases this number to the order of 10^3 very easily. It is, therefore, very important to eliminate the effect of local pollution. The experiments concerning the local pollution were carried out rather thoroughly as follows.

a) Effect of generator exhaust; 29 Dec. 1956.

A generator using heavy oil is set at about 100 ft W of the balcony, on which the measurement of the condensation nuclei is carried out. The effect of the exhaust gas was remarkable when the wind had a western component. One example is shown in Fig. 4. Before the generator started, the number of nuclei N was

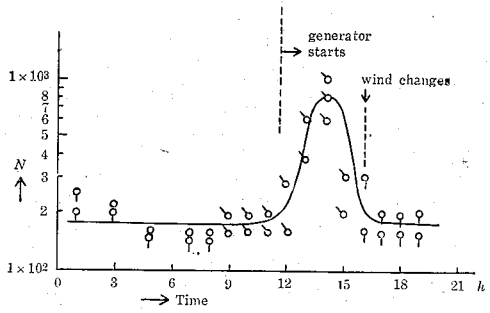

Fig. 4. The effect of generator exhaust; wind vel = 14–20 m/h, T = 3.5°C–14.2°C.

$1-1\times10^2$, having been near the measurable lower limit. This condition lasted for about 11 hours, and no variation was observed when the wind direction changed from S to NW. When the generator was started, the number increased suddenly near to 10^3. The wind was NW and the balcony was on the partly lee side. At 1600 the wind direction changed to S, and the number decreased to the former value of $1-2\times10^2$. S is the direction towards the summit, and there is no danger of pollution when the wind is S. Fortunately the prevailing wind at this spot in this season of the year was between ES and S, and not much trouble was caused from the generator exhaust. When the wind was W or NW, we had to expect the effect of local pollution of the order of 10^3. The short bars attached to the circles in Fig. 4 and the following

Figures show the wind direction.

b) Effect of car exhaust, I; 14 Jan. 1957.

The measurement was done near Kulani at the level of about 5,000 ft. The meter was set at nearly 30 ft from the road, and the wind was feeble. The air was clean and the number of nuclei was 2×10^2. This value jumped up to nearly 1×10^5, when a truck passed the road, Fig. 5. This effect remained for a considerable

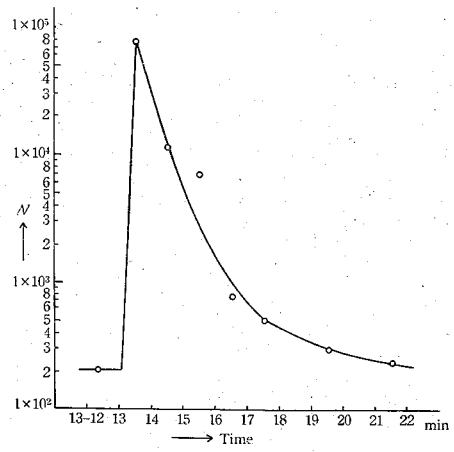

Fig. 5. The effect of car exhaust; T=14.5°C, feeble wind.

time, and it took about 10 min before the original value was restored. The mode of recovery is nicely seen in Fig. 5. From this result it will be concluded that this kind of measurements cannot be done in inhabited land.

c) Effect of car exhaust, II; 4 Jan. 1957, 1655–1700.

The effect of car exhaust could be detected at the distance of several hundreds ft away. The measurement was done at the Slope Observatory; wind=NE 9, T=10.5°C. A car passed the road in the windward side at the distance of about 200 ft. The effect was remarkable, and N increased 10 times.

i) Before the car passed, $N=3\times10^2$.
ii) Effect of the car passing 200 ft away on the windward side, $N=3\times10^3$.
iii) 5 min after the car passed, $N=2\times10^2$.

d) Effect of cigarette smoking; 3 Jan. 1957.

The effect of smoking of a cigarette was checked in the open lava field at the level of 9,400 ft; T=15°C, wind=E 3, clear sky. When a cigarette was smoked on the windward side at the distance of about 12 ft. N suddenly increased from 1×10^2 to 2.7×10^4 and came back to the original value in 2 min after stopped the smoking.

i) 1100, before smoking started, $N=1\times10^2$.
ii) 1102, effect of cigarette smoking, $N=2.7\times10^4$.
iii) 1104. 2 min after smoking stopped, $N=1\times10^2$.

e) Effect of inhabitation; 4 Jan. 1957, 1105–1210.

The effect of inhabitation was studied at Kulani prison. The campus is at the level of 5,100 ft, and is isolated from the surroundings. The nearest neighbor is 20 miles away. The air in this campus looks to be very clear, but N measured in the ground at the center of the campus showed the value of 2×10^3, having been 20 times larger than the surroundings.

i) In front of the gate, 0.25 mile from the center, $N=2\times10^2$.
ii) In the ground at the center of the campus, $N=2\times10^3$.
iii) 3 mlies, the other side of the center, $N=3\times10^2$.

f) Effect of aeroplane exhaust; 4 Jan. 1957, 1515–1530.

The effect of aeroplane exhaust was measured at the air port in Hilo, Hawaii; T=24°C, wind=E 13.

i) A car at 70 ft, windwards, exhaust, $N=3\times10^4$.
ii) A loader in action, 300 ft ahead, $N=7\times10^3$.
iii) The loader stopped the engine, $N=3\times10^3$.
iv) Hawaiian Air Line, 300 ft ahead, 1 engine, $N=2\times10^4$.
v) " , " , 2 engins, $N=2\times10^5$.
vi) HAL, starts on runway, $N=1.3\times10^5$.
vii) No aeroplane on windward side, $N=1\times10^3$.
viii) Aeroplane in air, about 800 ft away, $N=7\times10^3$.

When no car or aeroplane is on the windward side, N is considered to be between 1×10^3 and 3×10^3 in the field of this air port.

From the results enumerated above, it is concluded that at least a few thousands of condensation nuclei must be expected to be present in c.c. in the ordinary condition, if there is any sign

of inhabitation. The region of the Mauna Loa will be one of the most suitable places for the study of the condensation nuclei.

§ 5. Dondesation nuclei and meteorological conditions

Most of the observations of condensation nuclei in relation to the meteorological conditions were carried out at the Slope Observatory, 11,130 ft. When the weather was fine, the top of the overcast having been at about 6,000 ft or less, the number of nuclei at this spot was usually very small. It was about 200 per c.c. or less. 100 per c.c. is the lower limit measurable by the meter used.

a) Relation between the nuclei number and the wind direction.

The prevailing wind at this spot was S in this season of the year. S is the direction towards the summit, and the air must pass over the lava field for about 30 miles before it reaches this spot. The number of nuclei is very small when the wind is S, being $1-2\times10^2$ per c.c. When the wind direction changes, the number sometimes increases to several times of this value. In one example, the number of nuclei increased to a few thousands from $1-2\times10^2$ by the change of wind direction, as shown in Fig. 6 A.

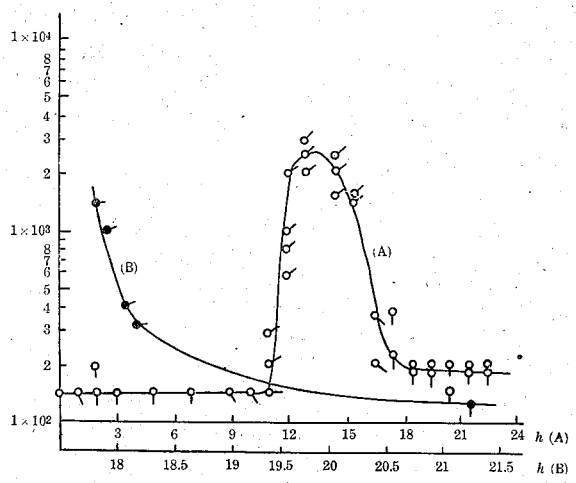

Fig. 6. A) Dec. 28, wind vel = 11–21 m/h, T = 5.8–4.0–12.7–6.5°C.
B) Jan. 5, wind vel = 6–9 m/h, base of inversion = 11,400 ft.

The observation was carried out for 24 hours. From midnight to 1100, the wind was almost S, and the nuclei number kept the constant value of 1×10^2 per c.c. At 1100 the wind changed to NE. Then the number increased gradually to about 3×10^3, and kept this high value while the wind was NE. At about 1700 the wind came back to S again, and the number decreased to 2×10^2. This value is a little higher than that observed in the forenoon. It may be interpreted that the nuclei brought by the NE wind are diffused in the atmosphere covering the lava field and they come back with the S wind. The more marked example is shown in the next section b). When the wind is NE, the course of the wind is in such a way that it blows up the mountainside from the ocean. In this case usually a fog appears in the lower portion of the mountainside, but it rarely reaches the Slope Observatory. The spot of the observation is, therefore, on the lee of the place where the fog is dissipating. As the result a plenty of nuclei is brought to the spot of observation. When the weather is fine in the lower altitude, no marked increase in the nuclei number is observed with the NE wind.

The similar case is shown in Fig. 6 B). The base of inversion measured at Hilo at 1645 of this day was 11,400 ft, being nearly the level of the Slope Observatory. The weather was fine, but felt the feeling of a slight mist. The wind was NE in the initial period of the observation, and the number of nuclei was 1.5×10^3 per c.c. This value was gradually decreased and came down to 1×10^2 when the wind became S.

b) Relation between the nuclei number and the fog.

The condensation nuclei are abundantly observed on the lee of the place where the fog is dissipating. In the afternoon of 12th January, the overcast was gettig higher and higher, and the fog climbed up the mountainside towards the Slope Observatory, and was dissipating at the distance of several hundreds yards away from the Observatory. The spot of observation, therefore, is on the lee and quite near to the place of dissipation. The wind varied in the range of NNW and NE. The mode of variation of the nuclei number with distance to the front of the fog is shown in Fig. 7. When the fog approaches to the Observatory, the number

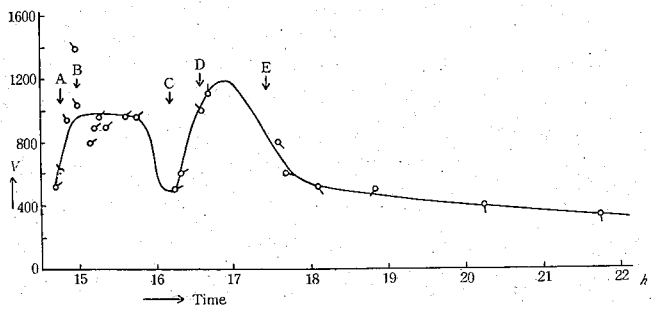

Fig. 7. Jan. 12, 1430–2200. A. Fog climbs up the mountainside towards the Observatory from the north. B. Fog stops at 250 yards from the Observatory, being stationary. C. Fog retreats to the distance of about 1 mile. D. Fog approaches to 300 yards. E. The wind direction changes and the fog starts to disappear.

of nuclei increases remarkably, and decreases as the fog retreats from the spot of observation. When the wind direction changes and the fog starts to disappear, the nuclei become less and less. The rate of decrease, however, is fairly small notwithstanding the most favorable condition of the S wind. Four hours after the change to the sourtherly wind and disappearance of the fog, the nuclei number was still 3×10^2. The whole lava field must have been covered with the atmosphere containing many nuclei. The condensation nuclei seems to be a good indicator for the nature of the local air mass.

c) Number of condensation nuclei during snowfall.

Two slight snowfalls and a series of three heavy snowfalls were observed during two months of December and January. In all cases a slight increase in nuclei number was noticed before the snowfall, but it decreased to an unmeasurable amount when the snowfall started. One example observed at the summit during the snowfall of 16th January gives the values; $N=0.6\times10^2$, 0.8×10^2, 0.6×10^2. Another example observed at the Slope Observatory on 14th January gives $N=2\times10^2$, 1.5×10^2. The profile of distribution of condensation nuclei shows this point more clearly as will be described in §6.

§ 6. The profile of distribution of condensation nuclei

The distribution of the nuclei number was measured between Hilo and the Slope Observatory or the Summit Unit for seven cases, and the profile was made as the function of altitude. The travel by the jeep took about 3 or 4 hours between Hilo and the Observatory and 2 or 3 hours between the Observatory and the Summit Unit.

a) Profile of condensation nuclei in fine weather.

When the weather is settled, the land of this district is always covered with an overcast of about 5,000 or 6,000 ft high, and above this cloud the whole sky is cloudless. The profile shows a characteristic nature in this case. One example is shown in Fig. 8. The observations were done on 3 Jan. and 4 Jan. The weather was

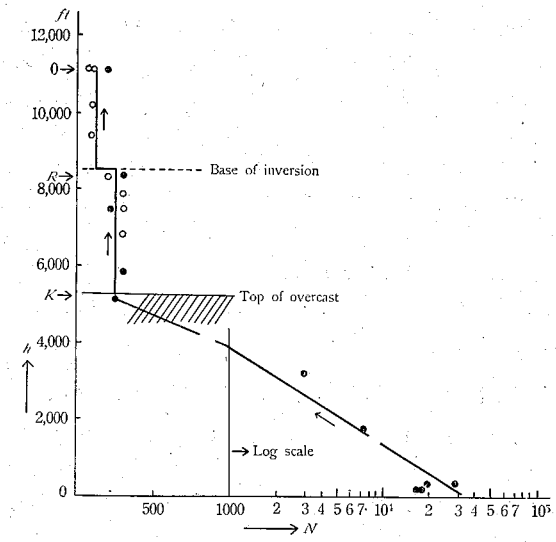

Fig. 8. Profile of nuclei number in fine day. White dot 3 Jan. and black dot 4 Jan.

very similar in these two days, and the nuclei number was very small and almost constant above the overcast. The difference was not observed between the lava field and the bush or forest zone. In the upper portion of this clean district, the number is 100 or 200, and in the lower portion it increases to 300. The amount of

increase is very slight. The base of inversion observed at Hilo on 4 Jan. is 8,500 ft, and it looks that the boundary of the upper and the lower portions coincides with the base of inversion, but the data are not enough for the conclusion.

b) Profile of condensation nuclei in cloudy weather.

On 13th January the cold front appeared north Hawaii Island, and the sky was covered with cirrus. The number of condensation nuclei became several times larger than that of the fine day. The profile is shown in Fig. 9. The measurement was started at the Summit Unit and came down to the Slope Observatory. The nuclei

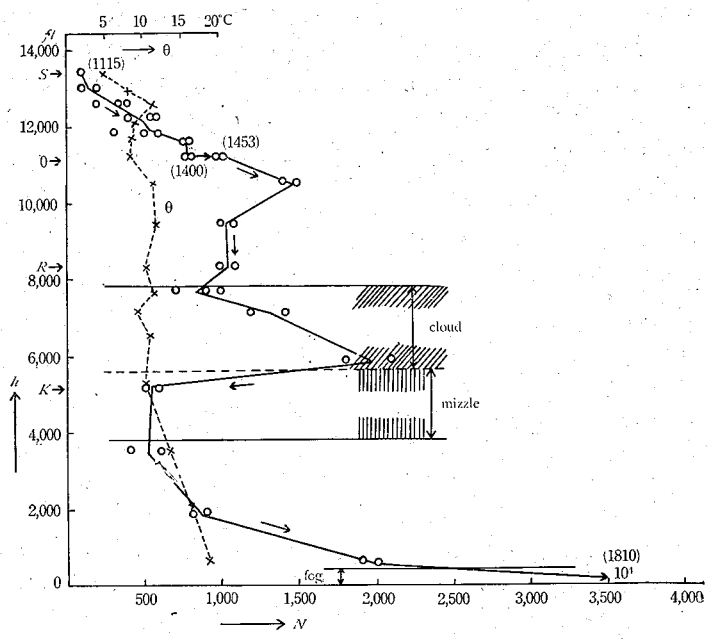

Fig. 9. Profile of condensation nuclei. 13 Jan.; Summit to Observatory, Observatory to Hilo.

number increased remarkably and it reached 900 at the level of the Observatory, 11,100 ft. The air mass near the ground must have climbed up above 10,000 ft. Further down the number increased still more, and at 10,500 ft it reached 1,500. Below this level the number decreased to 1,000, and then increased again in the cloud layer, the top of which was at about 8,000 ft. It is well

known that there is a plenty of active nuclei of the order of 10^3 in the cloud, as observed by AITKEN and others. In this series of observations it was found that the number of condensation nuclei in the cloud was always larger than that of outside. In the rain or snow, however, the number is very small, being sometimes numeasurable. In this case a mizzle zone was observed between 5,600 ft and 4,000 ft. Passing from the cloud layer into the mizzle zone, the number decreased suddenly from 2,000 to 500. Below this mizzle zone, the number increased rapidly and became 10^4 in the inhabited land. In most of the former reports in this field of investigation, the results of measurements are plotted in the logarithmic scale, because the data usually cover such a wide range as between 10^2 and 10^6 or so. This wide variation is mostly caused by the effect of local pollution, and in the uninhabited district as this place the variation does not cover such a wide range. In these profile curves, therefore, the numbers are plotted in the ordinary scale.

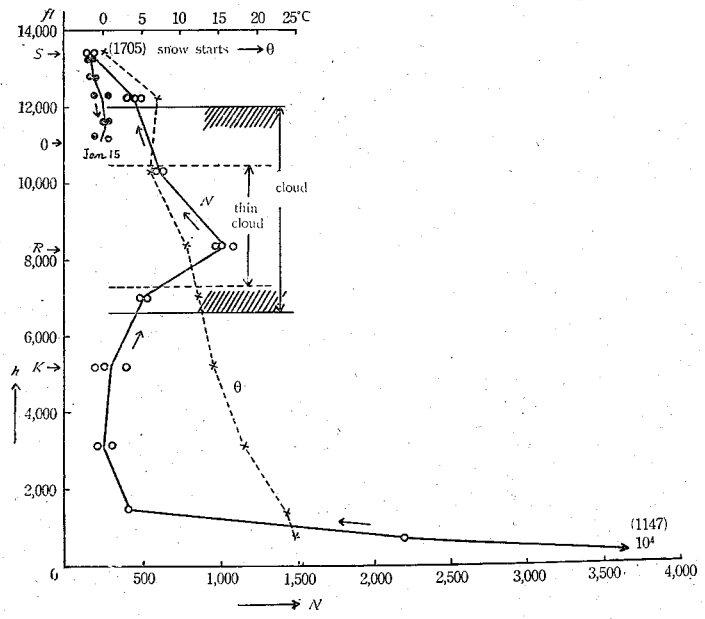

Fig. 10. Profile of condensation nuclei.
14 Jan., Hilo to Summit.

Another example similar to Fig. 9 is shown in Fig. 10. This curve was taken in the next day of Fig. 9, and the weather condition did not change so much. There was a thick layer of cloud between 6,600 ft and 12,000 ft. The number of nuclei was always larger in the cloud than outside. It is interesting to notice that the number is markedly large in the layer of thin cloud. By the eye observation in cloud or fog, it is noticed that cloud particles are often in the state of dissipation and they are replaced by the drift of new particles. The zone of thin cloud in the thick cloud layer is considered to be the result of active dissipation. In that case the abundance of the nuclei is to be expected. In the former measurement, Fig. 7, it was observed that the amount of condensation nuclei was very large on the lee of the front of stationary fog. The same phenomenon is observed inside of the cloud.

In the case of Fig. 11, two cloud layers are observed; the one between 7,600 ft and 9,400 ft, the other between 10,600 ft and 12,000 ft. It is noticed that the number of nuclei is remarkably large in the clear zone between the two cloud layers. This phe-

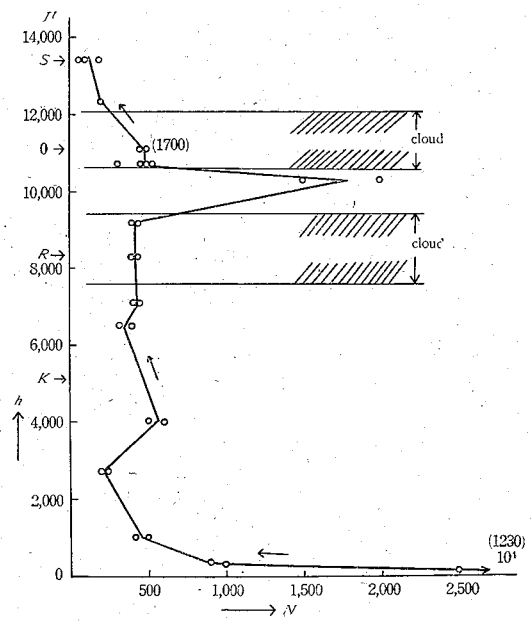

Fig. 11. Profile of condensation nuclei. 17 Jan., Hilo to Observatory, Observatory to Summit.

nomenon is also explained as the result of dissipation of cloud particles in this zone.

c) Profile of condensation nuclei in rain or snowfall.

Three examples of profile of condensation nuclei in the rain or snowfall are shown in Fig. 12 a)–c).

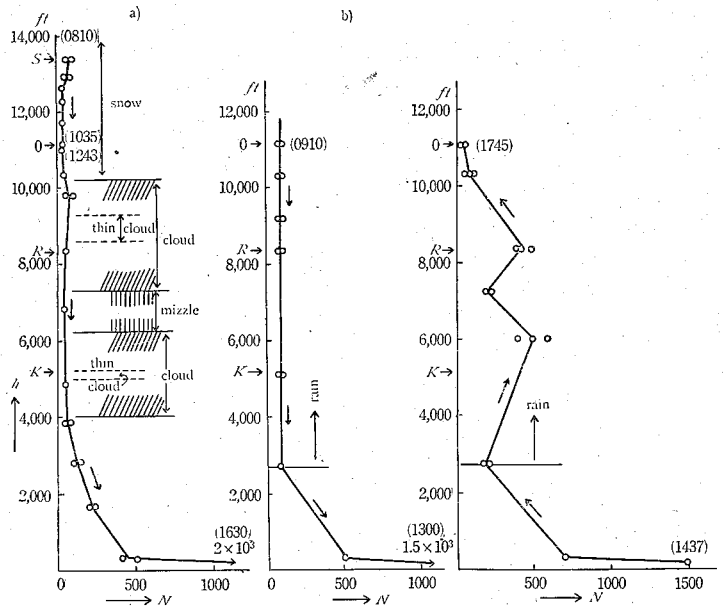

Fig. 12 a)–c). Profile of condensation nuclei in rain or snowfall.
a) 16 Jan.; Snowfall between Summit and Observatory, mizzle and fog below Observatory.
b) 19 Jan. forenoon; rain, Observatory to Hilo.
c) 19 Jan. afternoon; rain began to stop, Hilo to Observatory.

Fig. 12 a) was taken on 16 January. Snow started in the evening of 14th at the summit and it was rain below the Slope Observatory. The measurement of the nuclei was done after the continuous snowfall and rain which lasted almost two days. The atmosphere was cleaned completely and the amount of nuclei was unmeasurably small throughout the wide range of altitude; say, from 2,000 ft up to the summit.

The almost same profile was obtained on 19 January, Fig. 12 b). The snowfall and rain started at noon of the previous day, 18th

January, and continued until the evening of 19th. The amount of rain was 1.8 inches on 19th at the Slope Observatory. Fig. 12 b) shows the profile obtained in the forenoon of 19th and the nature is exactly the same as Fig. 12 a). In the afternoon of the same day the rain began to stop in the lower altitude, and most part of the way was foggy except near the Observatory, where it was still raining. The number of nuclei started to increase in some parts of the way, and sometimes reached 500, as shown in Fig. 12 c). From these results it is quite clear that the amount of nuclei becomes negligibly small in the rain or snowfall, which has lasted for a considerable time; say, one day or so.

PART II. SNOW CRYSTALS OBSERVED AT THE SUMMIT OF THE MAUNA LOA

§ 7. Varieties of snow crystals observed at the Mauna Loa

Five snowfalls were observed at the summit of the Mauna Loa during our stay from 7 December 1956 until 22 January 1957. The two snowfalls of 15 December and 6 January were slight and only a few photographs were taken. The temperature was near 0°C or a little higher than 0°C, and it was very difficult to take the pictures. Other three snowfalls were observed as a sequence, starting from the evening of 14th January; from 14th 1705 till 15th 0445, from early morning till midnight of 16th, from 18th 1045 till 22nd. These three snowfalls were caused by one storm, but the nature of snowfall was different from the standpoint of crystal types. They were fairly heavy snowfalls, and about 170 microphotographs of snow crystals were taken. Besides them, 23 pictures of frost crystals developed on various materials were taken, some of which were very similar in shape and structure to snow crystals. Some pictures were taken of ice pellets and snow crystals of initial stage captured in rain drops.

Examining the microphotographs, it was found that the varieties of snow crystals were very abundant and almost all types hitherto known were observed at the summit of the Mauna Loa. Comparing with the data obtained in Hokkaido, the difference is in the frequency of each type of crystals and the mode of transition from one type to the other. This point will be fully discussed

later in § 8.

In order to show the variety of crystal types observed in this district, 18 pictures are picked up and are reproduced in Photos. 1–18, Pls. I–III.

a) Crystals of the needle character.

Photo. 1, Pl. I, is an example of a single needle. This kind of needle has been considered as a type rarely observed. Among our collection of 3,000 microphotographs of snow crystals obtained in Hokkaido, only 3 are found. This single needle, however, is rather frequently observed in this place, and 14 pictures are counted among 170 pictures obtained. Photo. 2, Pl. I, is the ordinary needle. Most of the needle crystals hitherto known belong to this type. They show the structure like a bundle of single needles. Another good example showing this structure is reproduced in Photo. 23, Pl. IV. In our former observations carried out in Hokkaido, almost all needle crystals belonged to this type and the single needles were exceptional. In this district, however, this "ordinay" needle was much less frequently observed than the single needle.

Photo. 3, Pl. I, shows a needle crystal with a strange structure. This is different from the rimed needle which is a needle crystal attached with supercooled cloud droplets. In this case the structure shows that many small hexagonal columns attach side by side to a needle crystal. This type has not been observed yet among natural snow crystals, but the similar structure was found in the artificial snow crystals made in a diffusion cloud chamber. This type will be called a "columnar needle". Crystals of this type are found among many crystals reproduced in Photo. 23, Pl. IV. A needle crystal of the more strange shape is reproduced in Photo. 4, Pl. I. The needle appearing horizontally in the picture shows a peculiar shape which has not been observed before. The better example is seen in Photo. 22, Pl. IV. This may have been caused by partial melting and refreezing, but at present it seems to be improbable. This type is called a "peculiar needle" for the descriptive purpose. Photo. 5. Pl. I, is an example of the rimed needle. The most of needle crystals observed in Hokkaido belong to this type. In this place also this type was rather frequently observed. Photo. 23, Pl. IV, is another example. Photo. 6, Pl. I, is an example

of the rare type of needles. Many needles extend out in parallel with each other from a mass of ice granules. Only one photograph of this kind was obtained. Photo 7, Pl. II, shows ice pellets attached with needles. This is an interesting photograph, because this seems to show the mechanism of formation of ice pellets or frozen raindrops. This point will be discussed later in §9.

In the former investigations the difference between the needles and the columnar crystals has not been cleared yet. Both of them are developed in the direction of principal axis and have a hole at each end, as seen in Photo. 1, Pl. I, and Photo. 9. Pl. II. Some people sorted out the needle crystals from the columns by the ratio of the length to the thickess. For example, the elongated columns are grouped as needles when the ratio exceeds five. From the results of our artificial snow experiments, this view is not considered to be adequate, because the condition of formation is quite different for the needle and the column. In the course of the observations at the Mauna Loa, a new type of crystals was found, which is an intermediate state of the column and the needle. One example is shown in Photo. 8, Pl. II, and two others in Photo. 30, Pl. V, and Photo. 34, Pl. VI. From the shape of the crystal it is difficult to distinguish the elongated column from the needle, and at present this elongated column is included in the group of needles for the discussion of the relation between the crystal shape and the meteorological condition. However, the experiments on the effect of aerosol particles and the trace of some foreign vapors on the shape of snow crystals, which are now being investigated and will be published in a near future, will give a more detailed classification of the group of various needles.

b) Crystals of the columnar character.

A good example of the columnar crystal is shown in Photo. 9, Pl. II, and another example in Photo. 29, Pl. V. This is the typical hexagonal column with a hole at each end and is considered to be a twin crystal. Photo. 10, Pl. II, shows a crystal of the peculiar structure. This type was observed not so rarely in Hokkaido and also made artificially in the cold chamber. The structure has not been cleared yet, but it looks to be the combination of columns with extended side planes. For the descriptive purpose this kind

of crystals is called simply side planes. Another example is in Photo. 27, P l. V.

Photo. 11, Pl. II, is a combination of crystals of bullet type. In the case of snow crystals, the crystal individual is considered to be this bullet and consequently the hexagonal column is considered to be a twin crystal. In this view the crystal of ice must have a polar nature. The bullet crystal is sometimes attached with a plane crystal at the bottom end. One example is shown in Photo. 26, Pl. V. A hexagonal column with a plane crystal at each end is called a capped column. One example of this capped column is reproduced in Photo. 12, Pl. II.

c) Crystals developed in the basal plane.

Crystals of snow developed in a basal plane may be classified into two groups, the dendritic shape and the plate. The former shows the form like a flower with six petals and has been considered as the representative form of snow crystal. This dendritic shape is classified further in several kinds; the star-like, the fern-like, the one with broad branches, etc. Of course there are intermediate stages between these kinds. Many dendritic crystals were observed at the summit of the Mauna Loa, and it was found that most of them belonged to the broad-branch type, as shown in Photo. 24, Pl. IV, and Photos, 25 and 28, Pl. V. Photo. 13, Pl, III, and Photo. 21, Pl. IV, are the intermediate stage between the fern-like and the broad branches. The tip portion of each of branches shows a planar nature and this crystal develops in the shape like those in Photo. 24, Pl, IV, if the crystal is kept in the final condition of formation for more time. Strictly speaking, the purely dendritic crystal must be the star-like, or the fern-like, which has the branches with pointed tips.[6] The purely dendritic crystal means the crystal that can develop the branches in dendritic form in the next stage of growth. No fern-like crystal was observed in this place. In this meaning all dendritic crystals observed here were not purely dendritic. Photo. 14, Pl. III, is an example of the similar crystal as that of Photo. 13. In this case many supercooled cloud particles are frozen to the crystal. This type is called "rimed dendritic". The crystal of the rimed plate type was very rare in our observations in Hokkaido, but a good example was obtained

in this place, which is reproduced in Photo. 15, Pl. III. Photo. 31, Pl. VI, shows a plate with broad branches. The plate is developed from an initial stage which shows a parallel growth. The left and right portions are not in one plane, and this kind of crystal can be separated into two parts very easily.

When so many cloud particles are frozen to a plane crystal, the crystal becomes fairly thick. One example of this thick plate is shown in Photo. 16, Pl. III. When many dendritic branches extend out from an initial stage of snow in the form of a spatial assemblage of plates or columns, a spatial dendrite is obtained. One example is shown in Photo. 17, Pl. III. This type was rarely observed at the Mauna Loa, and only one photograph was taken.

d) Initial stage of snow crystals.

Ice fog and cirrus particles are considered as the initial stage of snow crystals. Any type of crystals can be called the initial stage in the initial state of formation. Accordingly there are all kinds of crystals in this category, but usually minute columns, needles, side planes and the like are frequently observed. One example is shown in Photo. 18, Pl. III. Besides these crystals of columnar or needle character, there are many crystals of irregular shape in the initial stage of snow crystals. The varieties of these particles were fully studied by ITOO[7] with respect to the particles of ice fog observed in Manchuria. Examples of these irregular particles are seen in Photo. 18, Pl. III, and Photos. 26, 29 and 30, Pl. V. The crystals in the initial stage were abundantly observed in the snowfalls of 16 Jan. and 18 Jan., but very few in the snowfall of 14–15 Jan. This point will be discussed in §8.

§8. The meteorological conditions and the nature of snowfall

The weather was fine throughout the most period of our stay at the Mauna Loa. The lower land was covered usually with an overcast of about 6,000 ft high, and above this cloud the whole sky was cloudless. After waiting for about 40 days, the weather started to change on 13 January and the cirrus appeared abundantly in the high altitude. The snowfall started in the evening of 14 January and a series of three snowfalls were observed during

14–22 January. The microphotographs of snow crystals were taken during 14–18 January, because we had to clear the summit in the evening of 18 January.

a) The weather condition during the snowfalls of 14–18 January 1957.

The sign of the change of weather was noticed on 13 January. The weather map of 0200 (1200 GCT) 13 January is shown in Fig. 13. The cyclone off the coast of California is sending the cold air current towards the district of Hawaii, and the number of condensation nuclei in the higher region of the Mauna Loa is getting

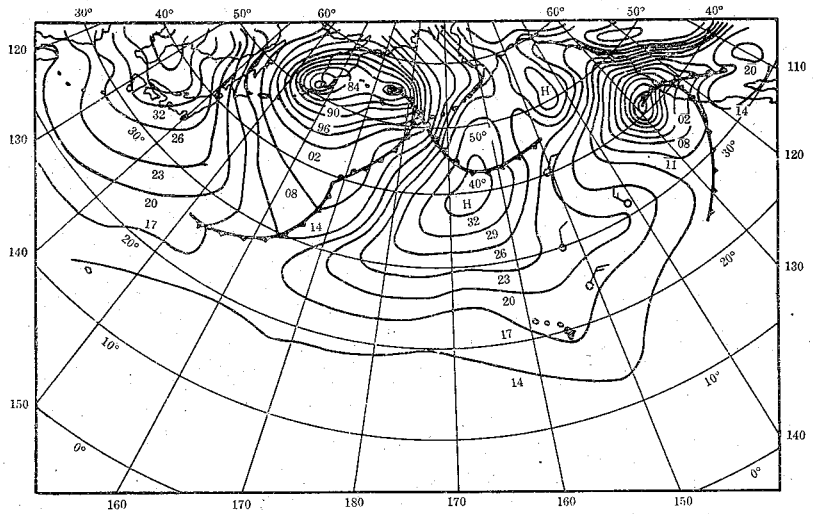

Fig. 13. Weather map of 0200 (1200 GCT) 13 January.

very large comared with the corresponding value of the fine weather; compare Fig. 8 and Fig. 9. In order to look for the relationship between the nuclei profile and the weather condition, the upper air condition at Hilo, Hawaii Island, was studied from the data of radio sonde at Hilo, extending over the period of 13–19 January. This work was kindly done by Mr. Nobushige MORI, member of the Meteorological Research Institute in Tokyo, under the supervision of Dr. Koichiro TAKAHASHI, the Chief of Forecast Research Laboratory of that Institute. The time cross section is made from the data of velocity and direction of wind, temperature and dew point, and the result is shown in Fig. 14 in an abbreviated

form. The thermal isopleth is shown with the full line and the isotach, the line of equal wind velocity, is shown with the broken line. The data obtained in GCT is converted into the local time of Hawaii.

The line SS is the height where the microphotographs of snow crystals were taken. Judging from the data of temperature and

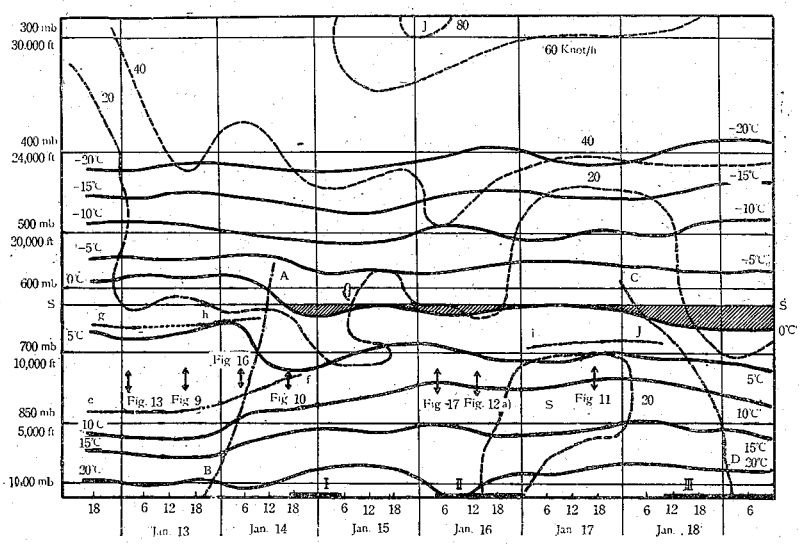

Fig. 14. The time cross section at Hilo; 19°44′ N, 155°04′ W.

wind, two boundaries of air masses are estimated to exist at AB and CD. Besides, two discontinuous surfaces e f and g h are observed in the early stage of this period, and one surface of slightly discontinuous nature i j is observed on 18 January. The shaded portion shows the period of time when the temperature at the spot of observation fell down below freezing temperature. These three portions coincide with the three snowfalls respectively. It is interesting to notice that some of the characteristics of the profile of condensation nuclei are explained by this diagram. Referring to Fig. 9, the nuclei number shows two maxima at about 6,000 ft and 11,000 ft. These heights roughly correspond to the heights of the discontinuous surfaces e f and g h respectively. In the profile obtained in the evening of 14 January, Fig. 10, the point of maximum goes up to about 8,000 ft. The discontinuous

surface e f also ascends nearly to this height at the time of nuclei observation. When the observation of Fig. 12 a) was carried out on 16 January, it was snowing above 11,000 ft and mizzle and fog were observed in the lower altitude. The atmosphere is cleaned with rain and snow, and the nuclei number is very small throughout the way. On 17 January a region of strong wind, S in Fig. 14, appeared in the lower altitude, and a discontinuous surface i j is noticed at the level of nearly 11,000 ft. This height corresponds to the height of the maximum nuclei concentration, as shown in Fig. 11. From these results it seems to be confirmed that the number of condensation nuclei is markedly large near the boundary of air masses.

b) The frequency of occurrence of each type of snow crystals.

As described in §7, almost all types of snow crystals hitherto known are observed at the summit of the Mauna Loa. In this respect there is no difference between the crystals observed in the ordinary land and those fall in the place where the least aerosol particles are present. The difference, however, was observed in the frequency of appearance of each type of crystals and the mode of transition from one type to the other. The needle crystals were very frequently observed, compared with our observations carried out in Hokkaido. In the case of two slight snowfalls of 15 December 1956 and 6 January 1957, only needle crystals were observed. Two examples of these needles observed on 15 December 1956 are shown in Photos. 19 and 20, Pl. IV. Most of the needle crystals observed in this snowfall were the single needle type, which has been considered as the very rare type of needles.

The mode of transition from one type of crystals to the other was of interest. One example is shown in Photos. 21–24, Pl. IV. They belong to the snowfall of 14 January. The most of the crystals observed at 2222 were the rimed dendritic crystals, one example of which is shown in Photo. 21. At 2235 the snow suddenly changed into needle crystals as shown in Photo. 1 and 2, Pl. I, and Photo. 22, Pl. IV. After 10 min, rimed needles started to fall mixed with the needle crystals, Photo. 23, Pl. IV, and then the whole snow changed into the dendritic type at 2300. One example of this dendritic crystals is shown in Photo. 24, Pl. IV.

In order to show the mode of transition of crystal type during one snowfall, the crystals were classified into 6 kinds; dendritic, rimed dendritic, needle, rimed needle, columnar, irregular. Columns and irregular crystals mostly belong to the initial stage of snow crystals. The bullet, the side-plane type and the capped column were included in the group of columns. The elongated columns as seen in Photo. 8, Pl. II, and Photo. 30, Pl. V, were temporarily included in the needle type. The frequency of occurrence of each type of crystals is shown in Fig. 15 a)–d). Fig. 15 a) b) shows the mode of change in crystal shape in the snowfall I. The mode of

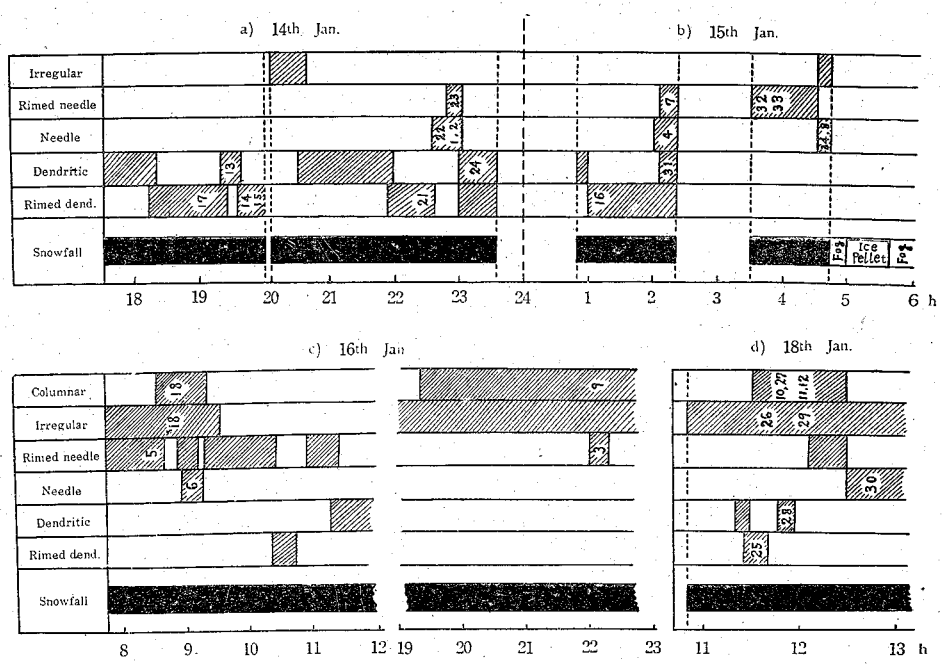

Fig. 15 a)–d). The type of snow crystals versus the time of fall.
a) b) Snowfall I; 14th 1705–15th 0445,
c) Snowfall II; 16th early morning-midnight.
d) Snowfall III; 18th 1045–22nd.

transition from the rimed dendritic, Photo. 21, to the needle, Photos. 22 and 23, and then to the dendritic again, Photo. 24, is clearly seen in Fig. 15 a), in which the numbers refer to the number of photographs. In Fig. 15 b), the mode of transition of one type to

the other; from the dendritic, Photo. 31, Pl. VI, to the rimed needles, Photos. 32 and 33, and then to the unrimed needles, Photo. 34, is clearly shown. Photos. 25–30, Pl. V, and Fig. 15 d) show the mode of transition of crystal type in the snowfall III, 18 January 1957. The most of crystals were columns or irregular crystals, and the dendritic or rimed dendritic crystals were added to this "background" for short period of time. The transition from the rimed needle to the unrimed needle of elongated column type occurred at 1230, and the transition took place rather suddenly. These phenomena suggest that the shape of snow crystal is characterized with the nature of the air mass.

c) The type of snowfall and the weather condition.

Examining Fig. 15, it is noticed that there is a qualitative difference among the snowfalls I and II and III. In the snowfall I, from the evening of 14th till the morning of 15th, the frequency of occurrence of the initial stage is small and that of the crystals of dendritic type is fairly large: Fig. 15 a) b). In the case of the snowfalls II and III, 16th and 18th January, most of the crystals observed are the initial stage of snow crystals and the crystals of the dendritic type are occasionally observed. The frequency of occurrence of these crystals is clearly seen in Fig. 15 c) d). In order to look for the relationship between the nature of snowfall and the weather condition, the 700 mb chart was examined. The

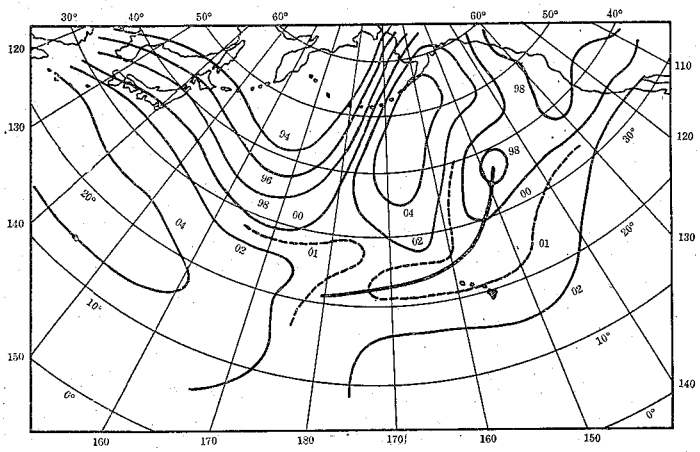

Fig. 16. 700 mb chart; 0500 (1500 GCT) 14 Jan. 1957.

700 mb chart is important, because the observation spot is near the 700 mb level. Fig. 16 shows the chart at 0500 Jan. 14, the weather condition before the start of the snowfall I. The front is near the Hawaii Island, and an active ascending current is expected near the spot of observation. In such a case snow crystals of the dendritic type is expected.

In the case of the snowfalls II and III, the weather condition is quite different from the case of the snowfall I. The 700 mb chart at 0500 Jan. 16, just before the start of the snowfall II, is shown in Fig. 17. The front retreated from the district of Hawaii far away north in the Pacific, and no active ascending current is expected near the spot of observation. Fig. 15 c) shows that needle crystals are frequently observed with occasional snowfalls of dendritic crystals in this case. Small crystals in the initial stage of snow formation are most abundantly observed. The 700 mb chart at 0500 Jan. 18, just before the start of the snowfall III, is more

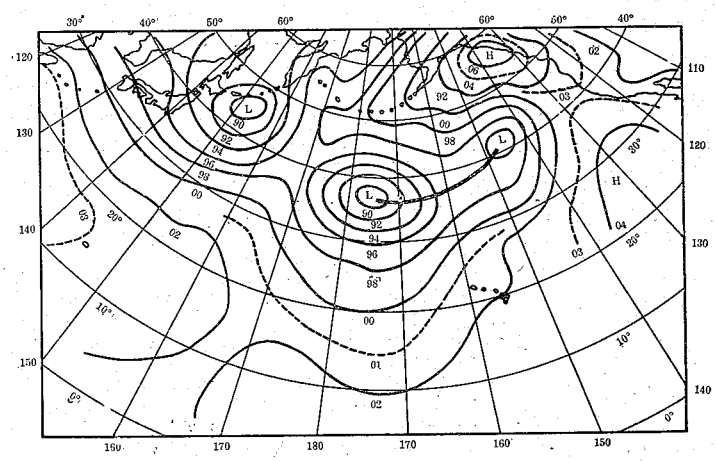

Fig. 17. 700 mb chart ; 0500 (1500 GCT) 16 Jan. 1957.

or less the same as Fig. 17. and the nature of the snowfall III is similar to that of II, Fig. 15 d). These examples show that the dendritic crystals are associated with the ascending current near the front.

Another characteristic of the snowfalls observed at the Mauna Loa is the sudden change of the crystal shape during the course of one snowfall. In our former experience in Hokkaido, usually

many types of snow crystals were observed at the same time, and the transition of the prevailing type into the other was gradual. If many kinds of snow crystals are formed at various altitudes and they fall to the ground with different velocities, it is to be expected that various types of crystals are observed mixed with each other and the transition of the prevailing type to the other is gradual. At the Mauna Loa, however, the transition was rather sharp; for example, the snowfall of the dendritic type suddenly changed into the needles and after several minutes back to the dendritic again. Such examples are seen at about 2300 in Fig. 15 a), at about 1100 in Fig. 15 c), at 1200 in Fig. 15 d). The rimed crystals show the existence of supercooled clouds of large droplets. The transition from the rimed crystals into the unrimed is also sharply defined as seen in Fig. 15 a)–d). These phenomena suggest that the atmosphere is composed of many local air masses and each mass gives a certain type of snow crystals. The temperature and the supersaturation, at least the temperature, will not be so much different for these air masses. It is, therefore, suggested that the nature of the air mass will be another factor controlling the shape of snow crystals. In our recent laboratory experiments, it was found that the trace of some foreign vapors affects the crystal shape remarkably. These results will be published shortly as the succeeding report of this series of investigations.

§9. Ice pellets and frost crystals observed at the Mauna Loa

Ice pellets or frozen rain drops are not rarely observed in the cold climate all over the world. The mechanism of formation of ice pellets, however, seems to have been not cleared yet. The supercooled water drop will not freeze until it is cooled below −40°C, and it is improbable to reach such supercooling. Some kind of seeding must have taken place for the formation of ice pellets. In nature the most probable and active seeding material is ice, and it is supposed that the ice pellet is formed by the attachment of a minute ice crystal to a supercooled rain drop. In fact, many examples were observed, which showed the state just after the attachment of an ice crystal to a supercooled rain drop, as shown

in Photos. 35 and 36, Pl. VI, and Photo. 37, Pl. VII. In the state reproduced in these photographs, ice coexists with water and the whole mass must be at 0°C. Let the mass of the drop be M, and that of crystal m, and the temperature $-T$°C. At the moment of seeding, x gram of the drop freezes and gives rise to the liberation of latent heat $80x$ calories. This heat will warm the drop and the crystal to 0°C. Taking the specific heat of ice as nuity,

$$80x = T(M+m) .$$

$$\frac{x}{M} = \frac{T}{80}\left(1+\frac{m}{M}\right) .$$

If the temperature is -10°C and $m/M=0.2$, $x/M=0.15$. In this case, therefore, 15% of the volume of rain drop will freeze at the moment of seeding and the temperature of the system will become 0°C. This system will lose heat by evaporation and convection and become the ice pellet. It might be suspected that these photographs show the state of melting of an ice crystal, but the photographs showing the attachment of a needle crystal to a rain drop, Photo. 7, Pl. I, and Photo. 32, Pl. VI, will clear the mechanism of formation of this doubt.

Many frost crystals were observed at the summit of the Mauna Loa. Most of them were the sheath type, and the shape was different for the crystals developed on the different materials. Photos. 38–41, Pl. VII, show the frost crystals formed under the same meteorological condition, except the objects on which the crystals grow. Photos. 38 and 39 are formed on wooden objects, and Photo. 40 developed on the lava block. The crystals were grown side by side, and the ambient conditions are considered to be the same. The difference in the shape must be due to the difference in the thermal property of the base material. Photo. 41 shows the frost crystals developed on the surface of snow cover. In this case, the temperature may be a little different and the supply of water vapor is more abundant than the former cases. The crystals grow into the cup type in this case; that is, develop both in the directions parallel and perpendicular to the optic axis. Photo. 42, Pl. VII, is a frost crystal formed in the crevass of lava rock. This is the sector type and the crystals sometimes grow

very large, being several cm in dimension. Due to the earth temperature, the supply of water vapor is very abundant and the temperature inside of the crevass is higher than the ambient temperature. In such a case, frost crystals develop in the basal plane, and plate or sector form is obtained.

§ 10. Summary

This expedition to the Mauna Loa was undertaken in order to study the nature of snow crystals in the place where the least aerosol particles are present. The number of condensation nuclei was measured at various altitudes as well as at the spot of observation, 13, 450 ft, and it was found that the nuclei number was very small in this district. After checking the effect of local pollution very carefully the relation between the nuclei number and the meteorological condition was studied, and it was confirmed that this district was one of the rare places in the world suitable for the study of condensation nuclei.

Before this expedition was started, it was supposed that the shape of snow crystals observable in this "aerosol free" district might be quite different from that observed in the ordinary place. This expectation, however, was not the case, and almost all types of snow crystals were observed. In our former artificial snow experiments, the dendritic crystals were obtained at the temperature around −15°C, and near the freezing point, say −3°C or −4°C, crystals of irregular needle type were produced. In this case the ordinary air was used. Recently the similar experiment was repeated by using the aerosol free air, which was made by the use of a thermal impactor. When the snow crystals were made in this aerosol free air, the irregular needle transformed into a plate or a dendritic type under the same temperature condition.

In the other experiment it was found that the crystal changed the shape completely when an unmeasurably small quantity of some foreign vapor was added to the air. For example, the trace of vapor of sillicone oil transformed the dendritic or plate type into a needle for the wide range of the temperature and the supersaturation. The shape of snow crystals is determined not only by the temperature and the supersaturation but also influenced by

the aerosol particles and some impurity. The nature of snowfalls observed at the summit of the Mauna Loa was characterized by the sudden transition of one type of crystals to the other. It is suggested from this fact that the atmosphere is composed of many local air masses and the snow crystals are characterized with the nature of the air mass. The future laboratory experiment will be forwarded in this line.

Acknowledgment

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kind assistance, owing to which this expedition was carried out successfully.

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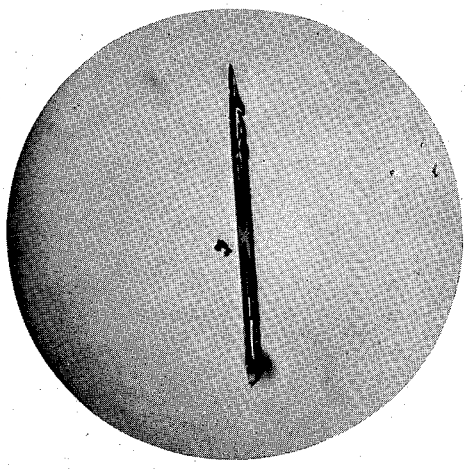
List of photographs

Plate	Photo. No.	Item	Date	Time	Film No.
I	1	Single needle	Jan. 14	2240	54
	2	Ordinary needle	14	2250	58
	3	Columnar needle	16	2206	145
	4	Peculiar needle	15	0205	75
	5	Rimed needle	16	0830	102
	6	Bundle of needles	16	0856	107
II	7	Needle and ice pellet	15	0203	71
	8	Elongated column	15	0430	86
	9	Column	16	2215	149
	10	Side planes	18	1145	189
	11	Bullets	18	1200	197
	12	Capped column	18	1155	194
III	13	Dendritic crystal	14	1923	34
	14	Rimed dendritic	14	1935	35
	15	Rimed plate	14	1939	36
	16	Thick plate	15	0110	69
	17	Spatial dendrite	14	1900	31
	18	Irregular, initial stage	16	0850	106
IV	19	Needle, column	Dec. 15	0750	8
	20	Rimed needle	Dec. 15	0800	9
	21	Rimed dendritic	Jan. 14	2222	51
	22	Peculiar needle	14	2236	53
	23	Rimed needle	14	2250	57
	24	Dendritic	14	2315	59
V	25	Rimed dendritic	18	1130	182
	26	Irregular, bullet	18	1140	186
	27	Side planes	18	1145	190
	28	Dendritic, irregular	18	1150	193
	29	Irregular, column	18	1155	196
	30	Elongated column	18	1237	205

Plate	Photo. No.	Item	Date	Time	Film No.
VI	31	Dendritic	Jan. 15	0210	79
	32	Needle, ice pellet	15	0330	80
	33	Rimed needle	15	0340	81
	34	Elongated columns	15	0430	84
	35	Snow crystal in raindrop	16	1810	122
	36	" " " "	16	1900	132
VII	37	Snow crystal in raindrop	16	1923	138
	38	Frost on wood	18	0720	162
	39	Frost on wood	18	0740	171
	40	Frost on rock	18	0740	170
	41	Frost on snow surface	18	0845	173
	42	Frost in rock crevass	18	0950	179

1



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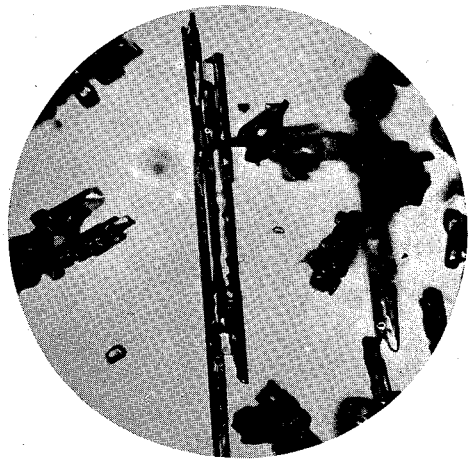

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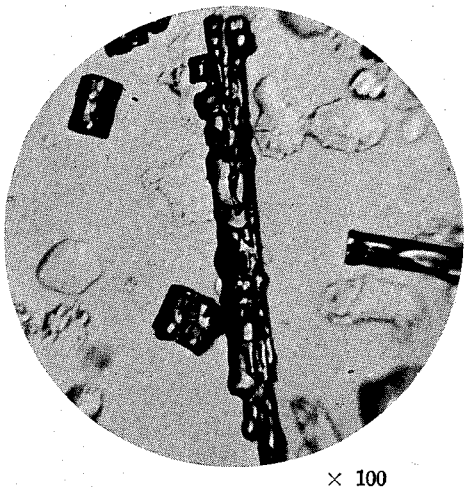

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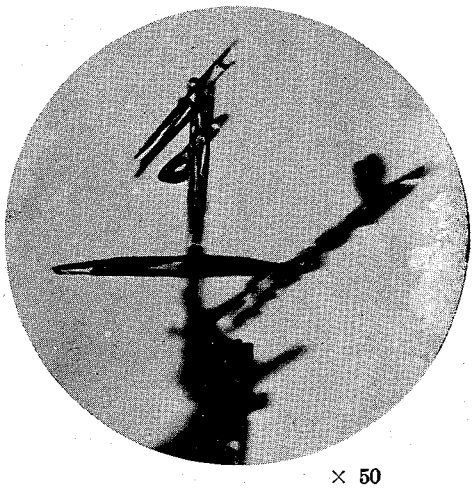

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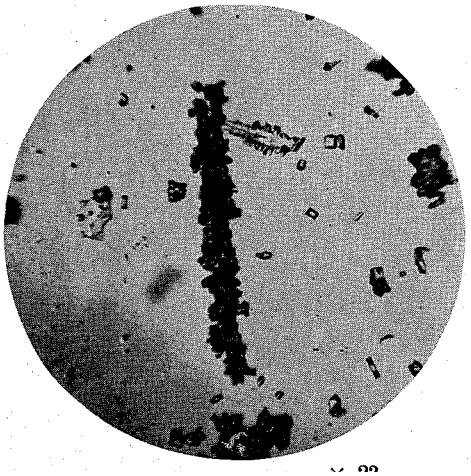

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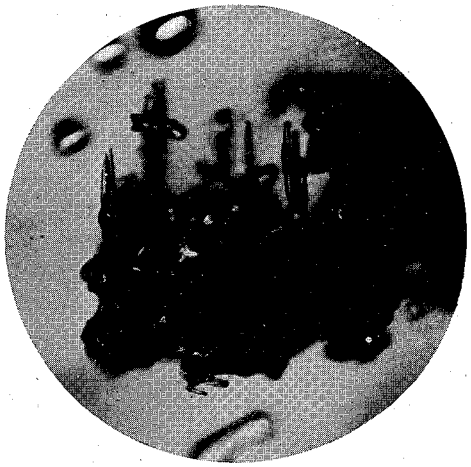

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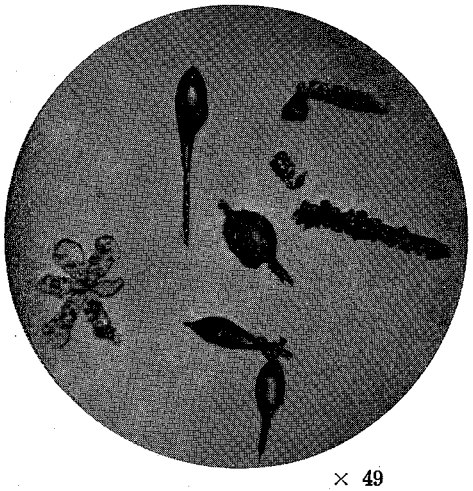

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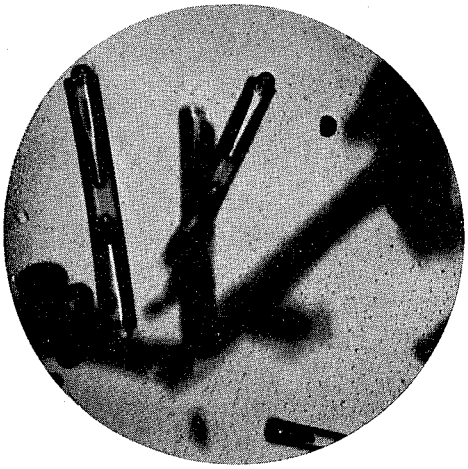

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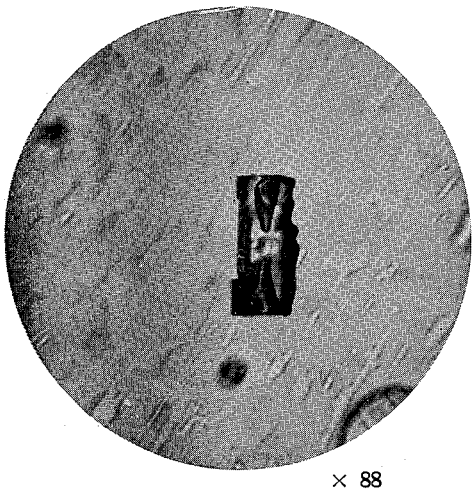

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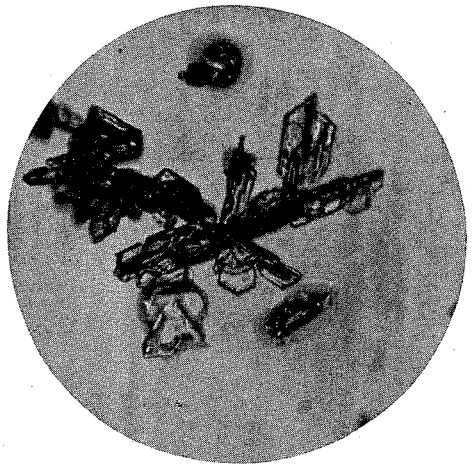

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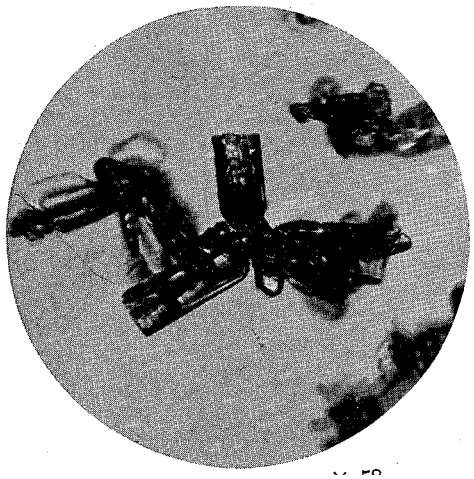

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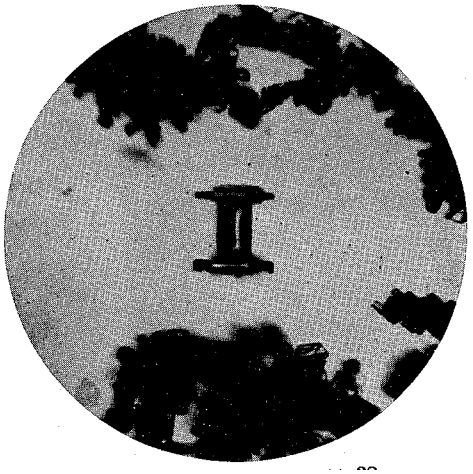

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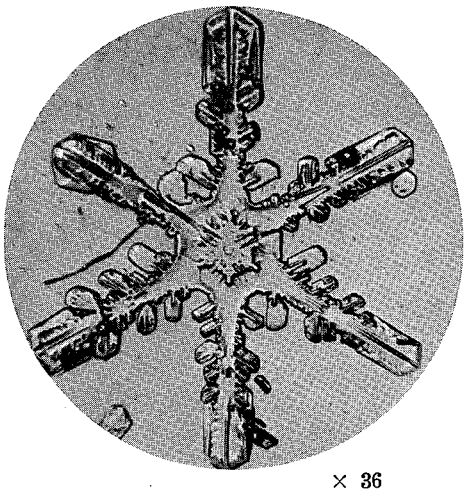

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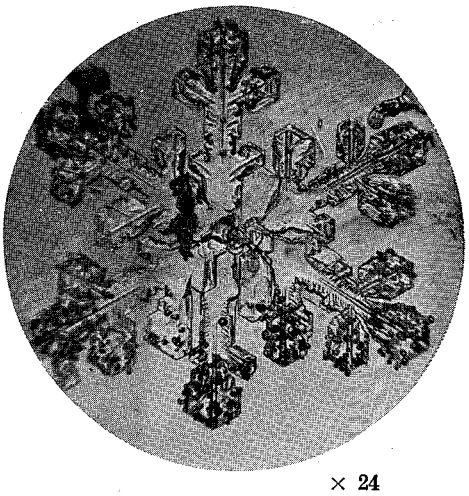

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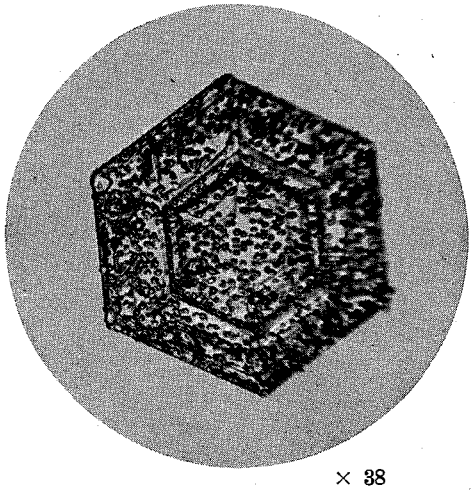

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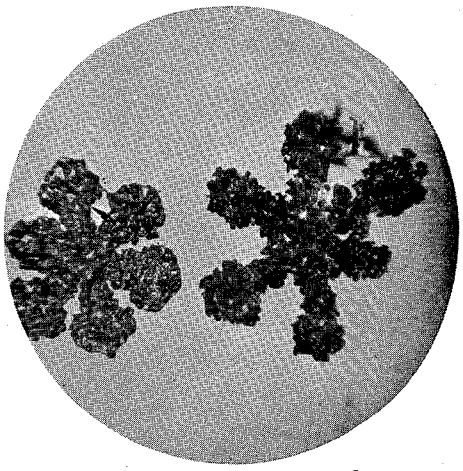

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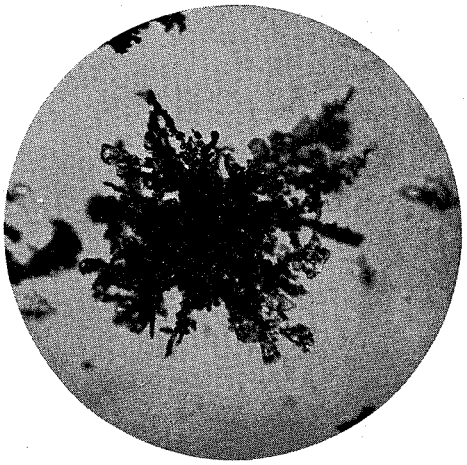

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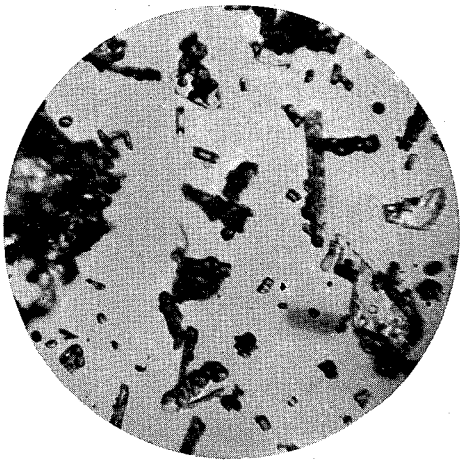

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× 19

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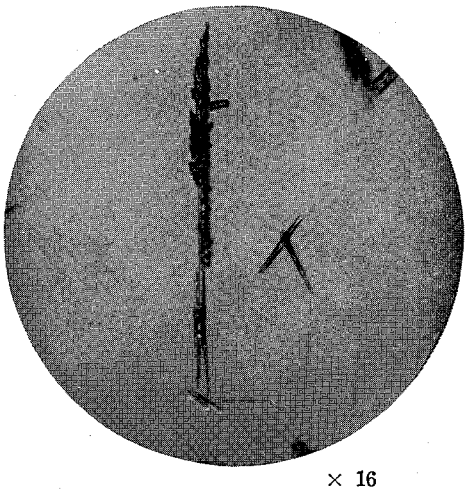

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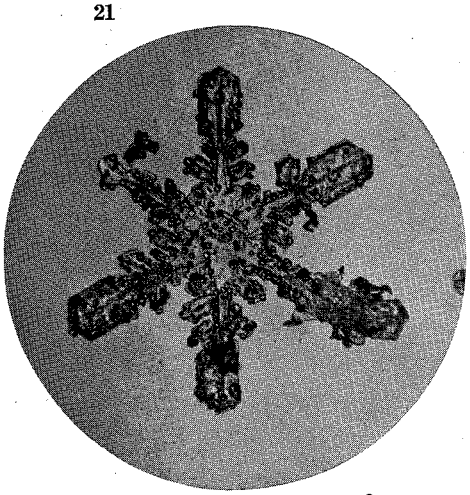

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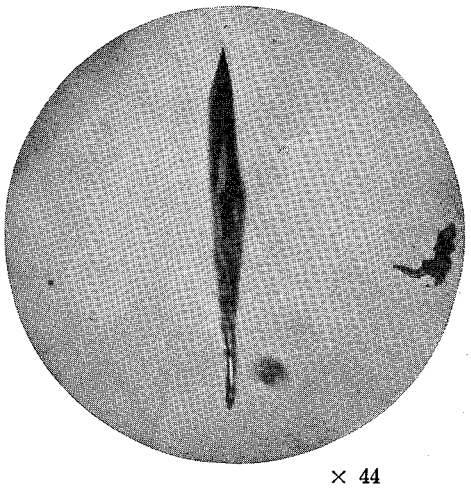

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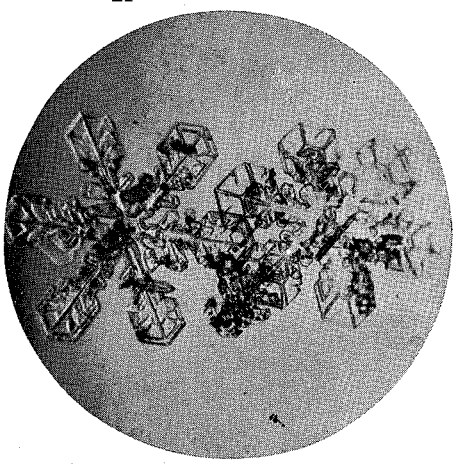

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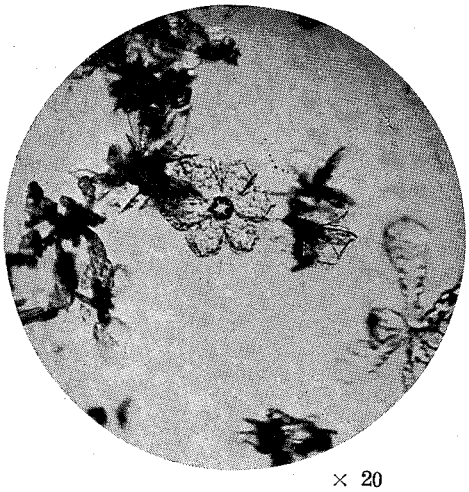

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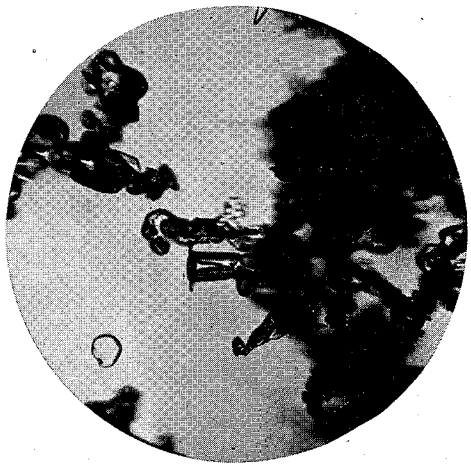

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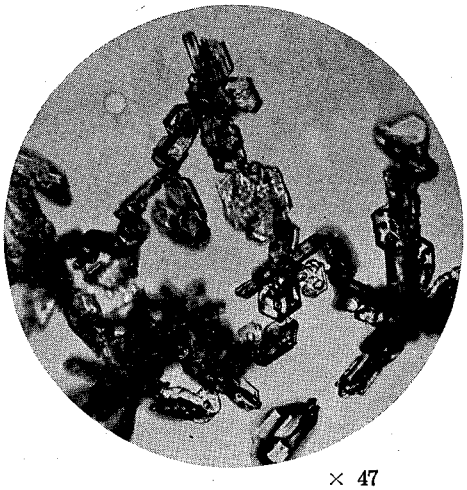

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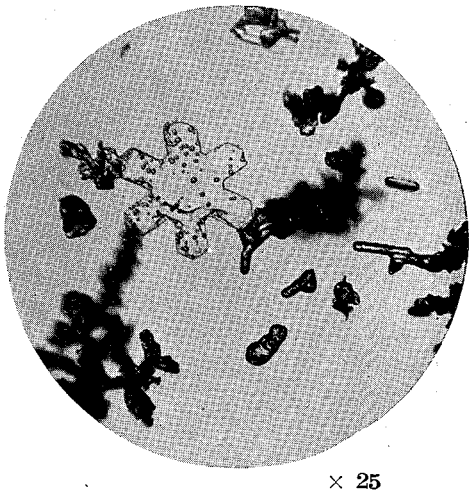

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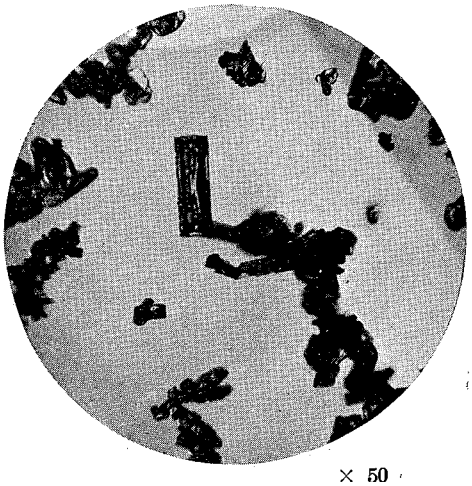

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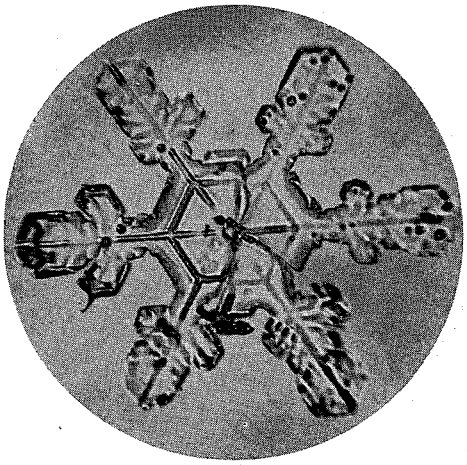

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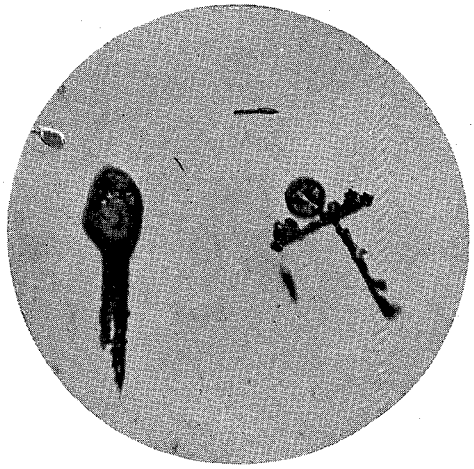

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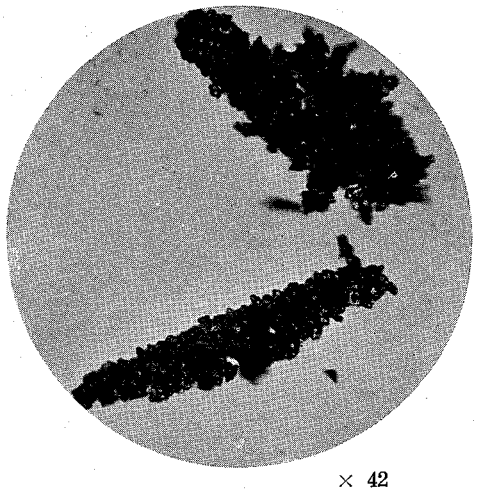

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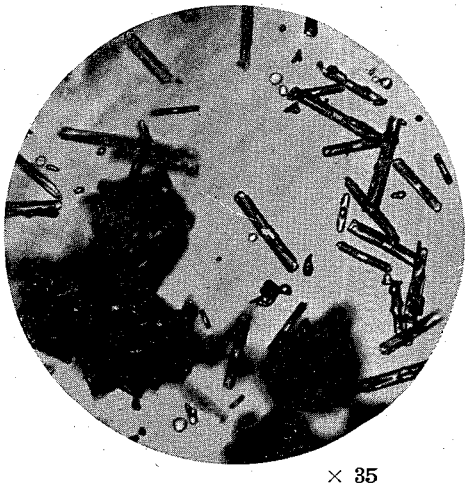

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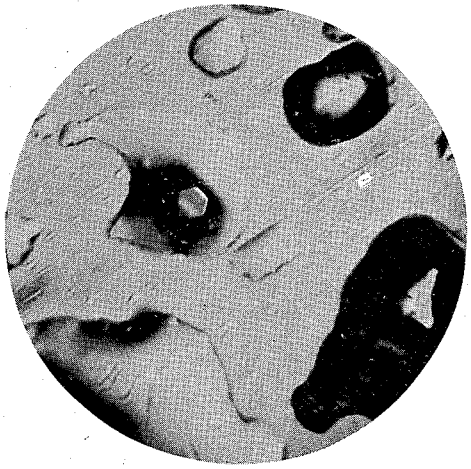

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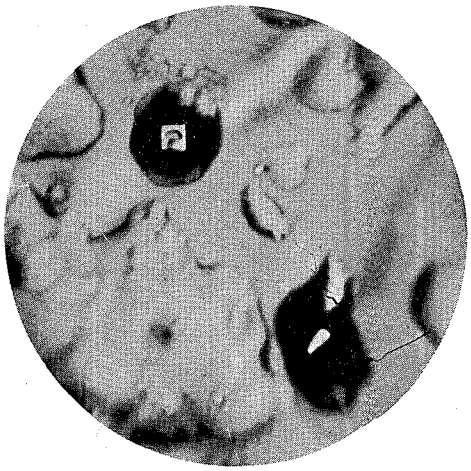

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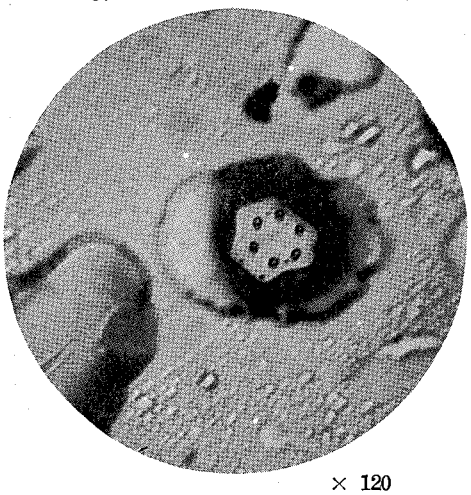

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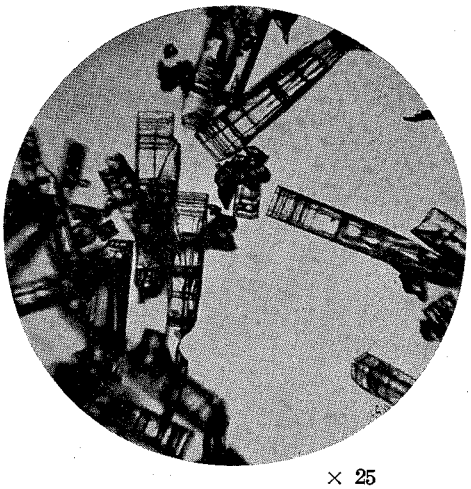

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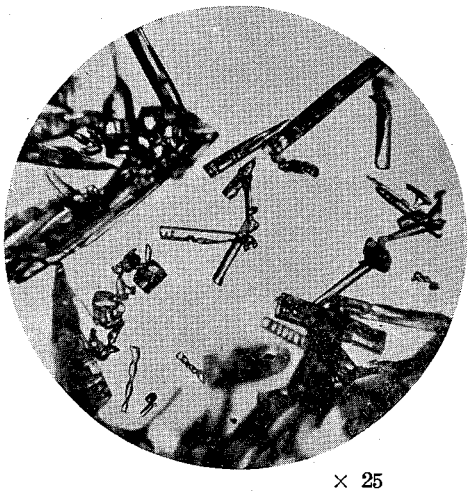

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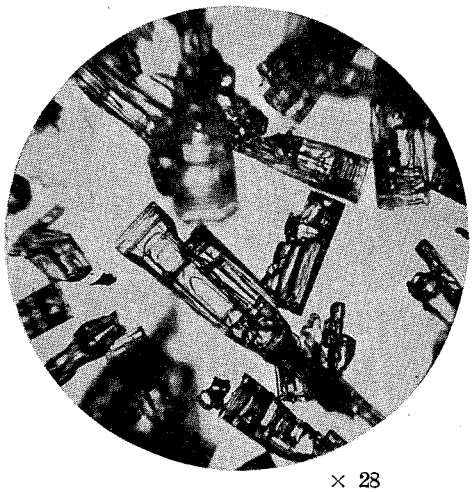

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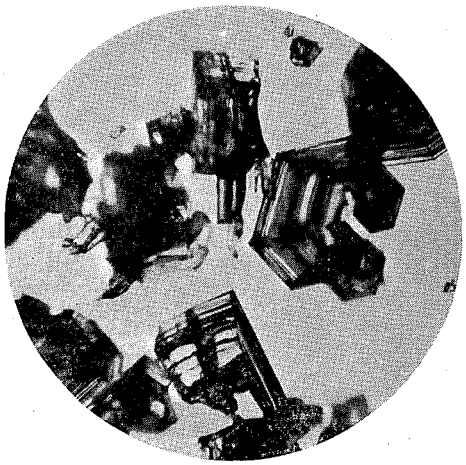

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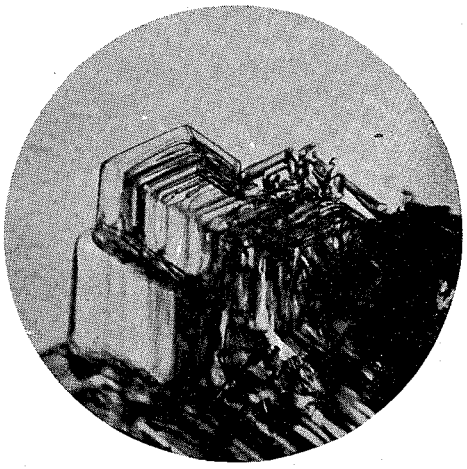

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