Physical Investigations on Snow. Part II, Classification and Explanation of Snow Crystals Observed in the Winter of 1933-34 at Mt. Tokati and at Sapporo.

By

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1. Introduction

In the previous paper[1] the results were described of observations on snow crystals at Sapporo in the winter of 1933. During the next winter of 1933–34 the authors followed similar studies on snow crystals at Sapporo and at Mt. Tokati. Mt. Tokati is situated near the centre of the main island of Hokkaido and its height is 2063 metres above sea level. There is a mountain cottage called Hakuginsô half way up the mountain, the altitude being 1030 metres. Expeditions to Mt. Tokati were made twice, at the end of December 1933 and at the beginning of February 1934. The authors stayed at the cottage for one week each time and succeeded in getting about 250 photographs of snow and frost crystals. The spot where the cottage is situated is protected from a strong wind by the surrounding ridges, and all the meteorological conditions are very favourable for the formation of large and perfect crystals of snow. The temperature was normally between $-5°C$ and $-10°C$ during the first stay and $-10°C$ and $-15°C$ during the second, the difference of maximum and minimum temperature being usually very small in this district. When the temperature was below $-10°C$ it was possible to do some manipulations on a snow crystal: for example, to separate a twine crystal into its components or to cut a crystal in a manner desired and to take a microphotograph of the side view by erecting it on a deck glass of the microscope, without much damaging the crystal. It was thus possible to obtain some rare photographs which seem not to have been published yet. At Sapporo it was relatively warm and humid during last winter, and crystals with water droplets were observed most frequently. Needle crystals with

1) U. NAKAYA and T. IIZIMA, Physical Investigations on Snow, Part I, This Journal, Series II, Vol. I, No. 5.

water droplets were observed twice. Altogether the authors were able to obtain 103 photographs of snow crystals and flakes at Sapporo. Among those photographs obtained at Mt. Tokati and at Sapporo, ninety eight pictures are chosen and reproduced in the accompanied Pl. I–XIV.

2. Classification of the Snow Crystals

As described in the previous paper, Part I, the meteorological condition of Hokkaido seems to be favourable to the formation of a copious variety of snow crystals. In the course of the observation in the last two winters we could get almost all types of crystals hitherto known except a simple pyramid, which is cited by many authors in the classification of snow crystals. It is said to have been observed by a few workers in this line, but we have not yet come across its microphotograph in the collection of literature at hand.

Classification of snow crystals is not uniquely defined, as the physical nature and origin of various types of crystals are not yet clarified at our present state of knowledge on this subject. We know, however, that the type of crystallisation falls into two distinct categories: the one, the hexagonal plate, is developed in a basal plane of the hexagonal system of crystallisation and the other, the columnar crystal, is grown in the direction of the principal axis. The former gives a dark field under a polarisation microscope with crossed Nicols, while the latter appears coloured under the same condition. This point was verified by our polarisation microscope Leitz's KM, which was used throughout the observation of last winter. For taking ordinary microphotographs by transmitted light it was used with the Nicols removed. All crystals of various types belong to either one or to a combination of these two general types. It need not be said here that the classification of snow crystals is that of crystal habits, and it will be desirable especially for descriptive purposes to classify them further in detail.

The former classifications of NORDENSKIÖLD,[1] HELLMAN[2] and PERNTER[3] are more or less similar to each other, classifying the crystals into plates, columns and their combinations. The recent classification of HUMPHREYS[4] adds to them triangular plates and twelve-sided plates.

1) G. NORDENSKIÖLD, Nature, 48 (1893) 592.

2–3) Cited in WEGENER's Thermodynamik der Atmosphäre, dritte Auflage, Leipzig, 1928, p. 285.

4) BENTLEY and HUMPHREYS, Snow Crystals, New York, 1931, p. 5, cited in our previous paper Part I.

Not all snow crystals which one actually observes are perfect and simple crystals belonging to one of the forms described above. As for the crystal developed in the basal plane of hexagonal system, the one grown in one plane, a stellar plate crystal, is usually noticed and photographed by many people. There are, however, many crystals which belong to this category but their stellar branches extend in spatial distribution instead of lying in one plane. They are called, as a group, "a spatial assemblege of plane branches". These crystals are more frequently observed by the present authors than those of ordinary plane form at the places where their observation was made, but no photograph of this type of snow is to be found in the collection of literature at hand. The authors consider it not as a phenomenon particular to our climate but universal to all countries, because a bur-like or wool-like crystal is sometimes described by European observers. As pointed out by WEGENER,[1] crystals of irregular form or especially of spatial extensions have a tendency to escape a microphotographical investigation.

It is proposed to classify the snow crystals, including all types observed, in the following manner.[2] This classification is only provisional but it seems ample and convenient for the description of snow crystals hitherto observed.

I. Plane Crystal.

This is the most common type, being developed in one plane perpendicular to the principal axis of crystallisation.

i) Plane dendritic form.

This is usually called a stellar crystal, representing a fern or plume-like appearance.

a) Hexagonal symmetry. Photos. 1–6, they are relatively large and show elaborate structures. Sometimes they are so large being 7–8 mm. in diameter, that the minute structure can be seen with the naked eye.

b) Trigonal symmetry. Photos. 9 & 10. Number 9, especially, shows the most beautiful example of trigonal symmetry.

c) Digonal symmetry. Photos. 7 & 11–14. To this group belong the crystals of two, four and five branches. Photo. 7 showing a crystal of two branches only is a rather rare example. It

1) WEGENER, Thermodynamik der Atmosphäre, loc. cit., p. 286.

2) Some parts of our classification are quite similar to that of Humphreys.

must also be noticed that in the crystal of five branches, Photo. 14, the fifth branch is balanced, so to say, with two small branches attached to the opposite side. This is not a matter of accident but of physical meaning, because it can be interpretated that the water vapour of the atmosphere surrounding the crystal is consumed by the large branch on one side and by the two small branches on the other side.

ii) Crystal of areal extensions.

This group comprises the crystals composed of branches radiating from the centre such as those of group i), but their branches are broad and sometimes form tabular sectors.

a) Hexagonal symmetry. Photos. 15 & 16 show branches of the form of tabular sectors. Photos. 18, 87 & 88 show examples of broad branches.

b) Trigonal symmetry. Not reproduced here.[1)]

c) Digonal symmetry. See Part I, Photo. 6.

iii) Plate crystal.

Hexagonal and triangular plates are reproduced in a large number in Bentley's book, and recorded to be relatively large in size. This type is relatively seldom observed in Hokkaido and is comparatively small in size.

a) Hexagonal symmetry. Photos. 19 & 20. In the course of the observations at Mt. Tokati, the authors sometimes noticed minute hexagonal plates of the order of 0.01–0.03 cm. in diameter, Photos. 76 a, b & 77 a, b, Pl. XII. They look to be crystals in an early stage of their development.

b) Trigonal symmetry. Some of this kind show trigonal nature both in form and design, while others take the form of a regular hexagonal plate with a design of marked trigonal symmetry (Part I, Photos. 10 & 11).

c) Digonal symmetry. No good example has yet been obtained.

iv) Plate with extensions at corners.

This is a combination of i) or ii) and iii). Extentions at corners may be simple or very elaborate (Photos. 17, 20, 22, 25, 26). Symmetry can be hexagonal, trigonal (Photo. 23) or digonal (Photo. 24). Strictly speaking, the innermost

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1) See Fig. 2c in the succeeding communication, "On the Correspondence of Snow and Frost Crystals" which will be published in the near future in this Journal.

design frequently shows a trigonal nature (Photos. 25 and 26).

II. Columnar crystal.

This is a crystal grown in the direction of the principal axis of crystallisation and is a well known form.

i) Hexagonal column with one end pyramidal.

As mentioned in the previous paper, this crystal is considered at present as a crystal individual of ice (Part I, Photo. 15).

ii) Hexagonal column with both ends plane.

This is considered to be a twine crystal composed of two crystal individuals described above. The side view is reproduced in Photo. 14 and 16 a, b of Part I, and the end-on view is shown in Photo. 33, this paper.

iii) Needle.

According to Wegener, this type is not yet studied in detail and it cannot be decided whether it is an elongated prism or a skeleton form of pyramid. The present authors had an opportunity to observe this type of crystal twice last winter. Some of the photographs obtained are reproduced in Photos. 27, 28, 29 & 41. Close examination of them shows that the crystal is composed of a bundle of very thin pillars. In appearance, and probably in the mechanism of growth, it is similar to frost pillars formed in the ground.

iv) Combination of columns.

In Part I it was noted that the pyramidal terminations of the crystals of type i) have a tendency to unite with each other at their heads. Examples of two, three and four of these crystals uniting at their pyramidal ends are reproduced in Photos. 17–19 of Part I. Combination of five or six of these crystals was observed last winter[1] (Photos. 30 & 31).

III. Spatial assemblege of plane branches.

The crystals composed of plane branches extending in spatial distribution are grouped in this class. The component branches may be of dendritic form or plates. The photographs of the crystals of this kind have hitherto been scarcely, if ever, pub-

1) A microphotograph of a similar crystal composed of many columns is illustrated in Dobrowolski's book, Historja Naturalna Lodu, Warsaw, 1922, p. 182.

lished. They are, however, very frequently observed in Hokkaido, especially in a heavy snowfall.

i) Spatial assemblege of dendritic branches.

a) Dendritic branches radiate in space from a centre. Photo. 36 shows a typical example of this kind. In general appearance it resembles a small chestnut-burr. This crystal seems to be closely related to a snow ball, as will be described later.

b) Dendritic branches extend in space from a stellar base crystal. As shown in Photo. 37, the base is an ordinary dendritic crystal, to which many dendritic branches similar to those of the base crystal are attached at various points and extend upwards. The side view is given in Photo. 39, in which we see a remarkable fact that most of these side branches are attached to one side of the base crystal. Sometimes a crystal is observed with spatial branches extending from both sides of the base, but in this case many elongated branches develop on one side and few short branches on the other side, as shown in Photo. 40. The angles which these side branches make with the basal plane were very difficult to measure accurately, but one sees by eye observation with microscope that most of them were near 60°. Photo. 38a is a photograph of a crystal of this kind taken with the focus adjusted on the basal plane, and 38b on the branches extending upwards from the basal plane of the same crystal. These pictures give an idea of the distribution of those upward branches over the base crystal. The base crystal may sometimes be a plate with extentions at the corners, as shown in Photo. 21a, b.

ii) Spatial assemblege of plates.

a) Plates only. One example of this kind is shown in Bentley's album p. 210, which is composed of four plates. In Photo. 42 many crystals of this type are illustrated. Photo. 43 shows a crystal similar to 42 crushed on a glass plate to lay the component plates in one plane for the purpose of photography. This crystal is composed of nine plates.

b) With dendritic branches. Sometimes dendritic branches extend from the corners of the component plates of the crystal above described. Photo. 44 shows an example of a crystal of this kind with numerous water droplets attached on the extended branches.

IV. Combination of the plane crystal and the column.

It is usually understood that this type means a hexagonal column with two plane crystals attached to both ends. We are going to include a twelve-sided crystal also in this section, because we knew that it is nothing but a combined form of two of these crystals. A crystal of this type was usually erected on a glass plate under microscope and its side view was photographed.

i) Hexagonal column with a plane crystal at each end. Photos. 47 & 48 show side views of crystals of this type, the end crystals being of dendritic form in these cases. Photo. 57a is a photograph of a similar crystal, the focus being adjusted on the upper plane crystal, and 57b is the side view of the same crystal. Photo. 58a or b is taken by adjusting the focus of the microscope on the upper or lower end crystal. Sometimes a small hexagonal plate is attached to one end and a large stellar crystal to the other end. Photo. 59 is an example of this kind, which is photographed by adjusting the focus on the upper small plate.

At Mt. Tokati the writers observed many crystals which belong to this type but have attached other branches extending in spatial distribution from the end plane crystals. Photo. 51 shows a typical example. This type was observed by Kassner who reported it as a new type of snow crystal.[1] In our observation at Mt. Tokati this type was frequently found.

ii) Hexagonal column with end plates and also one or more intermediate plates. Photos. 49 & 50 are examples having a dendritic crystal at each end and also a small plane crystal at the middle part of the column. In Photo. 52 may be seen several intermediate plates as well as spatial dendritic branches on the end crystals. Water droplets are attached to the intermediate plates and to the column. Photo. 54 shows a similar crystal to 52.

iii) Combination of many columns and plane crystals.

Crystals belonging to this group show the most complicated

1) KASSNER, Met. Zeit., 17 (1900) 225. He observed it with a magnifying glass and its sketch is illustrated.

and beautiful structure (Photos. 53, 55, 56, 60). In Photo. 53 a crystal is shown which is composed of four columns standing one above another and several sheets of well developed dendritic crystals. Photos. 55 and 56 show crystals of more or less similar structure to 53. In Photo. 60 is seen a beautiful crystal which is made up of three columns with pyramidal faces, each having a dendritic crystal at the base. The three columns are united with each other at their pyramidal terminations, (cp. Photo. 18 in Part I). A crystal similar to Photo. 60 but composed of four columns has already been observed and its photograph reproduced in DOBROWOLSKI's book.[1]

iv) Twelve-sided or Eighteen-sided crystal.

A twelve-sided crystal has sometimes been observed by many people. Usually six of their branches are one kind and alternately six a different kind; a crystal with twelve branches that are exactly similar to each other is rather a rare case. Photo. 61 shows a crystal with twelve branches of dendritic form, six being a little longer and the other six shorter. Photo. 63 is an example showing twelve branches which in form and design are almost exactly similar to each other. As was already remarked by BENTLEY,[2] this crystal can be separated into two pieces, each being an ordinary stellar crystal. Shedd considers that it may be a combined form of column and plates as IV i), the connecting bar between the two stellar crystals being very short in this case. We separated a crystal of this type into its two components and took a microphotograph of the side view of one of the component parts (Photo. 65). The short bar at issue can be clearly seen in the photograph. Difficulty arises from the fact that a branches of one stellar crystal bisects the angle between two branches of the other crystal, instead of being superimposed on one of the other as in Photo. 57a or 58b. Shedd proposes to explain this phenomenon by assuming a strong electrical charge on the component pieces. It is, how-

1) DOBROWOLSKI, loc. cit., p. 144.

2) BENTLEY's remark on this point is cited in Shedd's paper, Month. Weather Rev., 47 (1919) 691.

ever, not always that all crystals of this type take a regular twelve-sided form. As shown in Photos. 62 & 67 (lower crystal) many crystals of this nature were observed which show a marked deviation from a twelve-sided symmetry. We found that a twelve-sided crystal is made up by simple overlapping of two component crystals one of which is shown in Photo. 65, and an eighteen-sided one by three of them. An example of the last mentioned crystal is reproduced in Photo. 64 and the mode of overlapping of the component parts is shown in Photo. 66.

V. Malformed crystal.

This is not a scientific term; irregular crystals which are not included in the sections above described are included in this section. A piece that is considered to be a broken part of a regular crystal is excluded.

i) Crystal of hexagonal symmetry developed from two nuclei.

Occasionally a crystal is observed which is apparently of regular form but shows evidence that it was developed from two nuclei. Photos. 68–72 are examples. In Photo. 68 three branches on left form one piece and the other three another piece, these two pieces forming an apparently regular crystal of dendritic form. A crystal of this type is already known and a similar photograph to this is reproduced in DOBROWOLSKI's book.[1] Photo. 69 shows an example of a crystal which is made up of two pieces of two and four branches respectively. These crystals usually can be separated into their component pieces by simply pulling them apart (Photo. 70a, b). After the original form (70a) was photographed, it was separated into two and another photograph (70b) was taken. The fact that the branches belonging to two component pieces are similar in form to each other, must be remembered in the discussion of the mechanism of the symmetrical growth of branches in a regular crystal. Such similar crystals were observed in the case of a stellar crystal with broad branches (Photo. 71) or a plate (Photo. 72).

ii) Crystal developed from many nuclei.

An example is givin in Photo. 74. The writers have not

1) DOBROWOLSKI, op. cit., p. 248.

yet enough material for the elucidation of its nature.

iii) Irregular malformed crystal.

Irregular malformed crystals are reproduced in fairly large number in Bentley's book. We also observed them not rarely. One example is reproduced in Photo. 75.

VI. Transformed crystal.

Under this section may be included crystals which seem to have been subjected to some change in appearance by some external agency after their formation.

i) Crystal with water droplets.

To snow crystals there are sometimes attached such numerous water droplets that their structure or outline is almost lost. In our climate these crystals are abundantly observed. An example of the case of a plane crystal is given in Photo. 12 of Part I. Columns and needles also frequently have droplets attached as shown in Photos. 27, 32, 34 & 35.

ii) Thick plane crystal.

During the first stay at Mt. Tokati it was extraordinarily humid and a dense fog sometimes covered the whole district. In such case the snowfall usually consisted of thick plates, which showed ordinary hexagonal symmetry in general but were remarkable in thickness, being sometimes half a millimetre thick. Under microscope such a plate looks like a piece of a turf of moss when observed by reflected light as shown in Photo. 78, and appears opaque by transmitted light (Photos. 79–83). These thick crystals seem to comprise almost all types of crystals above described. For example: Photo. 80 shows a stellar type radiating from a centre, Photo. 81 a hexogonal plate with extensions at corners, Photo. 82 an irregular type and Photo. 83 a crystal of trigonal symmetry. The writers succeeded in cutting a crystal of this type into two and in taking a photograph of its section, which is reproduced in Photo. 84. It may be seen in the picture that one side of the crystal is covered with numerous frozen fog particles while the other side is almost perfectly free from them. In other words it is a snow crystal with a rime-frost attached. It may be a matter of interest that the characteristic nature of the rime-frost, that is deposited only on

the weather side of an exposed object, is seen also in such a special case as this when the exposed object is a falling snow crystal.[1)]

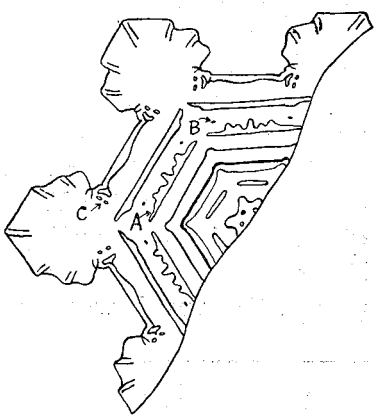
iii) Powder snow.

As already described in Part I, the term "powder snow" that is used in daily life does not necessarily mean an assemblege of columnar crystals, but more frequently signifies a sort of deformed crystal, a general view of which is shown in Photo. 45. A typical component of powder snow is shown in Photo. 46. Comparing this photograph with Photo. 40, one can easily understand that this is a mal-formed crystal of the type classified as III, i), b), that is, a crystal of dendritic form having the upward branches grown from a stellar base crystal. As this type of crystal is formed only in windy weather as described in Part I, the deformation may probably be due to a strong wind but the mechanism of the transformation is not yet clarified. We consider a graupel or a snow pellet as an advanced state of this type, but a detailed discussion will be left to a future communication.

3. On the Symmetry of the Crystal

The extraordinarily symmetrical nature of six branches of a snow crystal has been long an object of wonder and mystery, but the condition that controls the formation of such a symmetrical form has not yet been discussed in detail by scientists. It used scarcely be said that the theory of crystal lattice cannot explain the symmetry of the macroscopic form of a crystal. Photo. 73 is one of the best examples showing the symmetrical nature both in form and design. A schematic sketch of a part of the crystal is shown in Fig. 1. It is an admirable phenomenon that not only the curved line marked by A but also the small dots B

Fig. 1



1) The crystal represented in Photo. 21a of Part I may belong to this kind.

and even the pair of dots C show almost exactly the nature of hexagonal symmetry. Judging from these points, it is natural to suppose the existence of some action which is in favour of producing this symmetry.

SHEDD,[1] WEGENER[2] and others consider that a dendritic crystal is first formed in a sufficiently supersaturated atmosphere and then the space between the skeleton branches is filled up with ice crystal under less supersaturated condition, transforming the dendritic crystal into a hexagonal plate. Other dendritic branches extend from the corners of the hexagonal plate. Shedd, thus, considers the crystals of the second, the third and even the forth growth as the states of an evolution of snow crystals. According to this view, the symmetrical nature of the design of a hexagonal plate originates in the symmetry of the form of dendritic branches belonging to one crystal. This similarity of the form of the branches is itself a problem that is difficult to explain. There is apparently no reason why a similar twig must grow, in the course of the growth of the crystal, from one main branch when a corresponding twig happens to extend from another main branch. The best examples are Photos. 5 & 6. In order to explain this phenomenon we must suppose the existence of some means which informs other branches of the occurrence of a twig on a point of one branch. One way of explanation is that the occurrence of a bud of the twig causes some distortion in the crystal lattice which is transmitted to the centre and then to the other branches, but it is very improbable that such distortion is transmitted to the other branches through so large a number of atoms, say 10^7 atoms, without failure. The crystals which are apparently of a regular form but are grown from two nuclei, Photos. 68–72, give support to this consideration; in this case the transmission of some distortion of lattice from one branch to another is most improbable.

As for the dendritic growth of crystal, Lehmann's experiment[3] on the formation of the snow-like crystal of iodoform is most instructive. Iodoform was crystallized out from a solution in a form similar to that of snow under a favourable condition. He could, then, observe a dilution of the solution surrounding the crystal by a lightening of the colour. He explains that the gradient of concentration is steeper near a pointed part of the crystal, where a diffusion of the solute is quicker, resulting

1) Op. cit., p. 692.
2) Op. cit., p. 284.
3) O. LEHMANN, Molekularphysik, Band I, Leipzig, 1888, p. 333.

in a promotion of the crystal growth from that pointed part. VOGEL[1] extended this idea by introducing a consideration on the heat of crystallisation. From these results the present authors consider that there may be a gradient in both concentration and temperature in the atmosphere of microscopic dimension which surrounds the snow crystal, in the intermediate state of its development. In such a space, convection of the air would take place on a microscopic scale, and this effect would surpass that of diffusion of water vapour in the contribution to the dendritic growth of the crystal. Prof. T. Terada made a suggestion to the authors to the effect that such a convection is very probably accompanied by periodic columnar vortices which were studied in full detail in his experiment with liquid[2] and also with air.[3] The periodic nature of this kind of vortex seems to be closely related to the symmetrical character of the form of the dendritic crystal. The present authors are at present inclined to investigate this problem with this idea as a working hypothesis.

4. The Frequency of Occurrance of a certain Type of Snow Crystal

From their daily experience the authors know that during some period in a snowfall a certain kind of crystal is chiefly observed, but it is not confined to only one type of crystal. Usually two or three other types of crystals are mixed with the prevailing one. For example, dendritic crystals are mixed with hexagonal plates or even with columns. Some unusual crystals classified above as malformed, digonal symmetrical or twelve-sided, have been considered to occur in small quantity, being mixed with innumerable crystals of common type, say plane dendritic crystals. It was just so in the observation at Sapporo which lies nearly at sea level. In the course of the observation at Mt. Tokati (1030 m.), however, an unexpected phenomenon was met with; that is, these unusual crystals were observed in a large number during a short time interval in the course of a snowfall. This time interval may be a few minutes or a little longer. For example, the twelve-sided crystals reproduced in Photos. 61–67, except 63 which was observed at Sapporo, were all observed between 10 and 10.30 p.m. on the 11th of February. The crystals developed from two nuclei, Photos. 68–70, began to fall at 7.30 a.m. on the 10th of February and

1) VOGEL, ZS. f. Anorg. Chem., 116 (1921) 21.
2) T. TERADA, Rep. Aer. Res. Inst., Tokyo, 3 (1928) 1.
3) T. TERADA and M. TAMANO, Ibid., 4 (1929) 447.

continued to fall in fairly large number for about ten minutes, then the type of crystal was changed to the ordinary dendritic form. From these experiences one is led to conclude that these unusual crystals are not formed by mere chance, that is they are not malformed crystals in the literal sense but there must be some external conditions favourable for their formation. At sea level these phenomena are difficult to observe, as these unusual crystals are mixed with an innumerable number of common crystals while they are falling to the ground.

The resemblance of crystals with each other which are received on a glass plate at a single instant, is also a problem of significance. In the observation at Mt. Tokati a striking resemblance was sometimes noticed between them when the weather was very calm. Photo. 85 shows two crystals of almost exactly the same form. Many others of nearly the same appearance were received on a glass plate at the same time, among which two were chosen to show the resemblance of the form. The duration of falling of the crystals of such definite form is usually very short, being for a few minutes or less. Photo. 86 is a similar example of the crystals of small hexagonal plate with long dendritic extensions. The six crystals in the picture are almost similar to each other not only in their form but also in their dimension. Judging from these similarities it is quite natural to suppose that these crystals were formed at the same time under a certain condition and fell to the ground along more or less the same course. Consequently the altitude where they are formed cannot be very high up. Photos. 87 & 88 show another example; these two crystals were also received on a glass plate at the same time. Sometimes even the malformed crystals such as shown in Photos. 89 & 90 were observed in a good number during a very short time interval.

These phenomena seem to the writers of significance in elucidating the mechanism of formation of the snow crystals. A systematic investigation on the frequency of occurrance will be continued at Mt. Tokati next winter.

Explanation of Photographs

Pl. I. Regular hexagonal crystals of dendritic form.

1.	Tokati,	1934,	II. 11.,	×19.7	
2.	„ ,	„ .	II. 8.,	×27.5	
3.	„ ,	„ .	II. 11.,	×36.6	
4.	„ ,	„ .	II. 10.,	×33.8	
5.	„ ,	„ .	II. 8.,	×11.6,	large crystal, dia. = 6 mm.
6.	„ ,	„ .	II. 8.,	×18.5	

Pl. II. Crystals of two, three, four and five extensions.

7.	Tokati,	1934.	II. 10.,	×36.6
8.	„ ,	„ .	II. 10.,	×19.5
9.	„ ,	„ .	II. 10.,	×18.2
10.	„ „	„ .	II. 10.,	×35.2
11.	„ ,	„ .	II. 11.,	×25.9
12.	„ „	„ .	II. 7.,	×18.7
13.	„ ,	„ .	II. 8.,	×16.9
14.	„ „	„ .	II. 9.,	×41.9

Pl. III. Crystals of areal extensions and hexagonal plates.

15.	Tokati,	1934.	II. 11.,	×37.1
16.	„ ,	„ .	II. 11.,	×37.1
17.	„ ,	„ .	II. 10.,	×36.6
18.	„ ,	„ .	II. 9.,	×38.6
19.	„ ,	1933.	XII. 21.,	×59.5
20.	„ ,	„ .	XII. 21.,	×44.5

Pl. IV. Hexagonal plates with dendritic extensions.

21.	Tokati,	1934.	II. 10.,	×19.7,	a) Focused on the basal plane. b) Focused on the branches extended upwards from the basal plane of the same crystal.
22.	Tokati,	1933.	XII. 21.,	×46.9	
23.	„ ,	1934.	II. 10.,	×18.4	
24.	„ ,	„ .	II. 10.,	×36.2	
25.	„ ,	„ .	II. 10.,	×35.7	
26.	„ ,	„ .	II. 8.,	×36.2	

Pl. V. Hexagonal columns and needle crystals.

27.	Sapporo,	1934.	III. 13.,	×11.0.	Columns and needles with small water droplets attached.
28.	„ ,	„ .	III. 9.,	×27.1.	Needle crystal.
29.	„ ,	„ .	III. 13.,	×19.5.	Two needle crystals.
30.	„ ,	„ .	III. 9.,	×36.7.	
31.	„ ,	„ .	III. 9.,	×27.1.	Six columnar crystals united together.
32.	„ ,	„ .	III. 9.,	×36.4.	Hexagonal columns with water droplets attached.

33.	Tokati, 1934.	II. 10.,	×62.6.	End-on view of a hexagonal column.
34.	Sapporo, „ .	III. 13.,	×19.5.	
35.	„ , „ .	III. 13.,	×19.4.	Longer column or needle with water droplets.

Pl. VI. Crystals with dendritic branches extending in three dimensional form.

36.	Tokati, 1934.	II. 8.,	×12.0.	Dendritic branches extend in space from the centre.
37.	„ , 1933.	XII. 22.,	×10.9.	Dendritic branches extend in space from a steller base crystal.
38.	„ , „ .	XII. 22.,	×20.4,	a) Focused on the basal plane. b) Focused on the branches extending upwards from the basal plane of the same crystal.
39.	Tokati, 1933.	XII. 27.,	× 9.9.	Side view of the similar crystal.
40.	„ , 1934.	II. 8.,	×17.5.	„ „ „

Pl. VII. Miscellaneous.

41.	Sapporo, 1933.	XII. 12.,	×29.7.	Needles.
42.	„ , 1934.	III. 9.,	×17.9.	Snow crystal form of an assemblage of plates.
43.	„ , „ .	III. 9.,	×26.3.	Crystal similar to 42 crushed on a glass plate so that the component plates lie in one plane.
44.	„ , „ .	III. 9.,	×34.0.	Crystal similar to 42 with dendritic extensions upon which water droplets are attached.
45.	„ , „ .	II. 22.,	×19.7	Structure of the so-called powder snow.
46.	„ , „ .	II. 22.,	×24.7.	Component crystal of a powder snow flake.

Pl. VIII. Combination of plane crystals and columns. Side view.

47.	Tokati, 1934.	II. 7.,	×18.7
48.	„ , „ .	II. 8.,	×21.6
49.	„ , „ .	II. 10.,	×61.5
50.	„ , „ .	II. 8.,	×21.8
51.	„ , „ .	II. 10.,	×20.8
52.	„ , „ .	II. 11.,	×36.6
53.	„ , „ .	II. 10.,	×16.7
54.	„ , „ .	II. 10.,	×19.5
55.	„ , „ .	II. 10.,	×34.5
56.	„ , „ .	II. 11.,	×36.6

Pl. IX. Combination of plane crystals and columns, continued.

57.	Tokati, 1934.	II. 8.,	×28.2,	a) Focused on the upper plate. b) Side view of the same crystal.
58.	„ , „ .	II. 10.,	×35.2,	a) Focused on the lower plane. b) Focused on the upper plane of the same crystal.

59.	Tokati,	1934.	II. 10.,	×44.3.	The upper plate is a small hexagonal plate and the lower is a larger crystal; focused on the upper plate.
60.	„ ,	„ .	II. 11.,	×56.5.	Three columns with pyramidal ends united together, each having a stellar crystal attached on its basal plane.

Pl. X. Twelve-sided and eighteen-sided crystals.

61.	Tokati,	1934.	II. 11.,	×19.7	
62.	„ ,	„ .	II. 11.,	×19.7	
63.	Sapporo,	„ .	III. 9.,	×43.7	
64.	Tokati,	1934.	II. 11.,	×20.0	Eighteen-sided crystal.
65.	„ ,	„ .	II. 11.,	×35.2.	Side view of a component of the twelve-sided crystal.
66.	„ ,	„ .	II. 11.,	×21.3.	Side view of an eighteen-sided crystal, three components being seen to lie one on top of another.
67.	„ ,	„ .	II. 11.,	×17.4	

Pl. XI. Crystals developed from two nuclei.

68.	Tokati,	1934.	II. 10. a.m.	$7^h 30^m$.,	×49.5. Three branches extended from either nucleus.
69.	„ ,	„ .	II. 10. a.m.	$7^h 40^m$.,	×20.5. Two branches developed from the one nucleus and four from the other.
70.	„ ,	„ .	II. 10. a.m.	$7^h 30^m$.,	×20. a) Before separation. b) After separation of the same crystal.
71.	„ ,	„ .	II. 10.,	×33.3	
72.	„ ,	„ .	II. 11.,	×36.6.	After separation.

Pl. XII. Crystals showing perfect symmetry, malformed crystals, minute crystals.

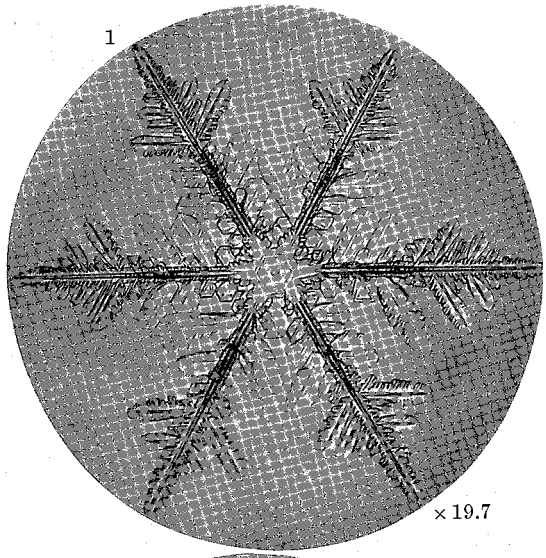
73.	Tokati,	1933.	XII. 24.,	×47.8.	Crystal showing extreme regularity in its design.
74.	Sapporo,	1934.	II. 20.,	×18.7	Example of malformed crystal.
75.	„ ,	„ .	II. 20.,	×25.9.	„ „ „ „
76a, b.	Tokati,	1934.	II. 7.,	×56.5.	Minute crystals.
77a, b.	„ ,	„ .	II. 8.,	×65.0.	„ „

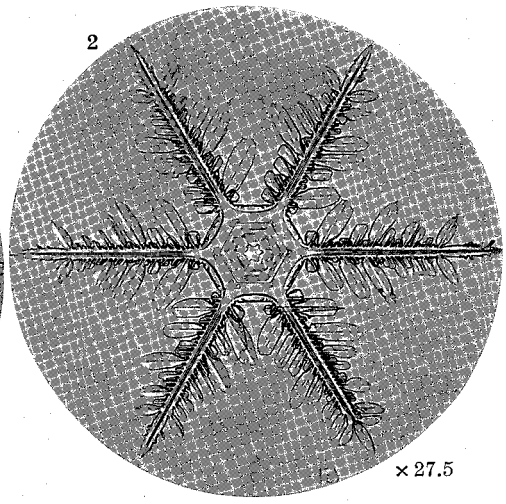
Pl. XIII. Crystals of thick plates.

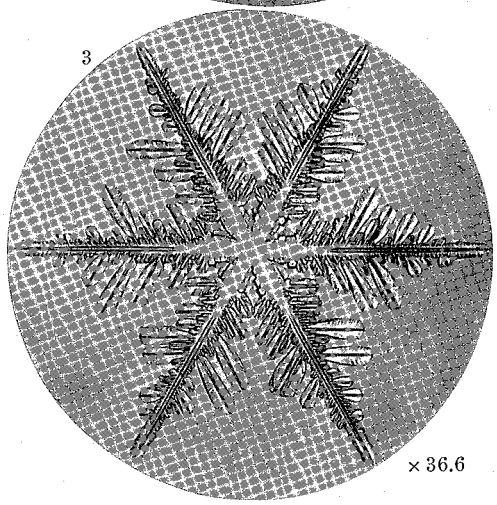
78.	Tokati,	1933.	XII. 27.,	×10.2.	A crystal of thick plate photographed with reflected light.
79.	Sapporo,	1934.	III. 5.,	×18.8.	General view.
80.	Tokati,	1933.	XII. 23.,	×12.8.	Transmitted light.
81.	„ ,	„ .	XII. 25.,	×18.8.	Thick hexagonal plate with extensions.
82.	„ ,	„ .	XII. 23.,	×13.9.	Thick plate of unsymmetrical character.
83.	„ ,	„ .	XII. 25.,	×21.8.	Thick plate of trigonal symmetry.
84.	„ ,	„ .	XII. 25.,	×18.7.	Section of a thick plate.

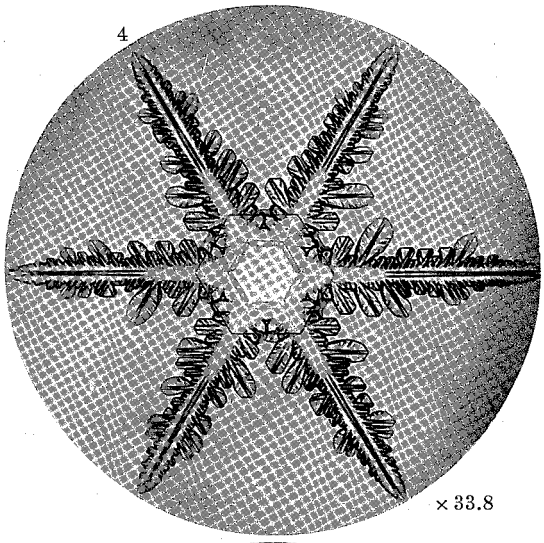
Pl. XIV. Examples showing that crystals of very similar form fall at an instant during a snowfall.

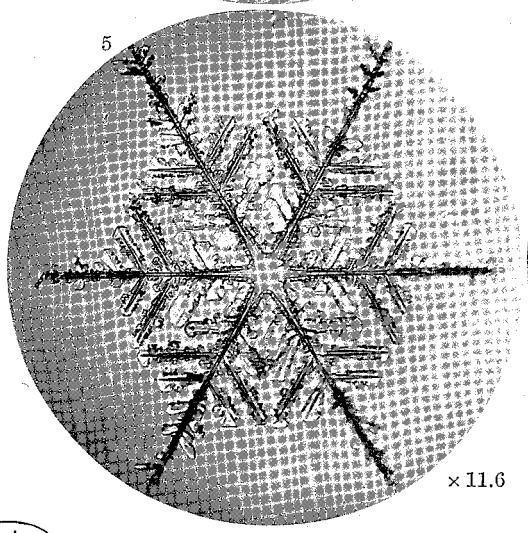
85.	Tokati,	1934.	II.	8.,	×20.8.	Two crystals of nearly the same appearance received on a glass plate.
86.	„ ,	„ .	II.	11.,	×11.5.	Similar example to 85.
87. 88.	„ ,	„ .	II.	8.,	×26.9.	Received on a glass plate at almost the same time.
89. 90.	„ ,	„ .	II.	8.,	×19.2, ×14.9.	Examples showing that sometimes these malformed crystals fall in a good number at an instant.

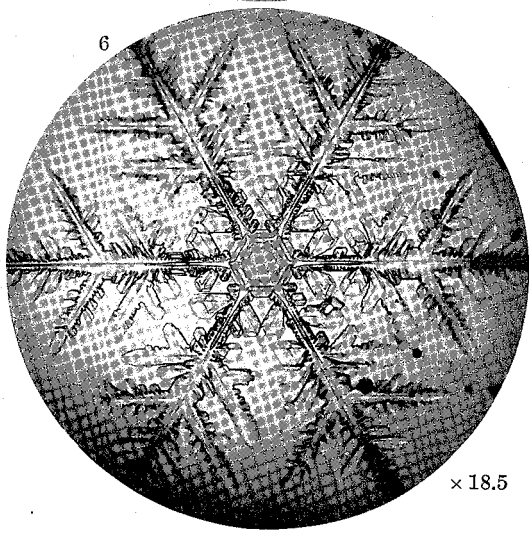












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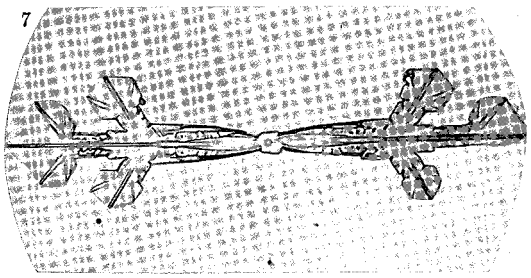

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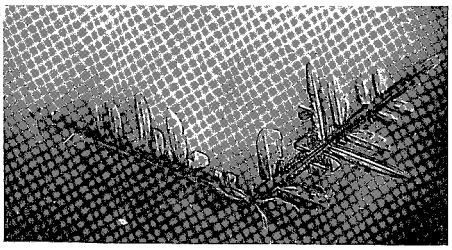

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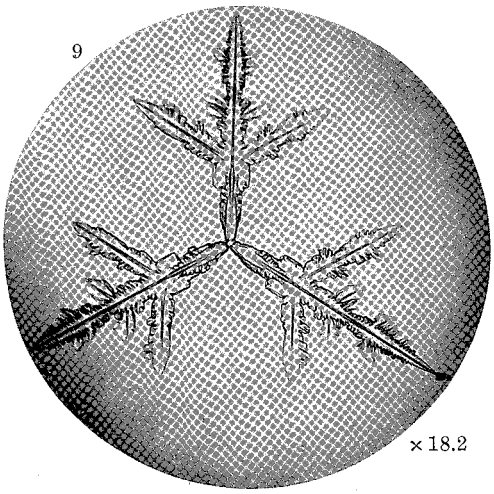

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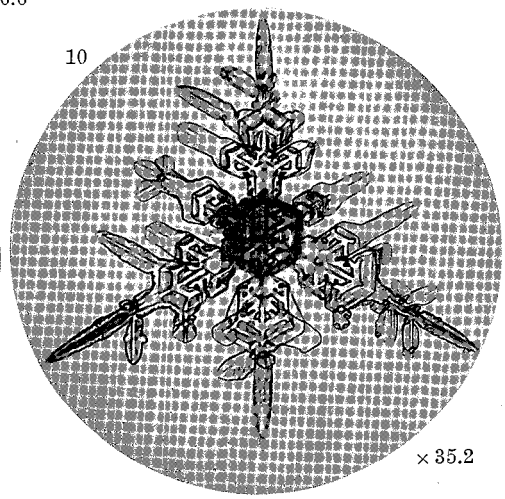

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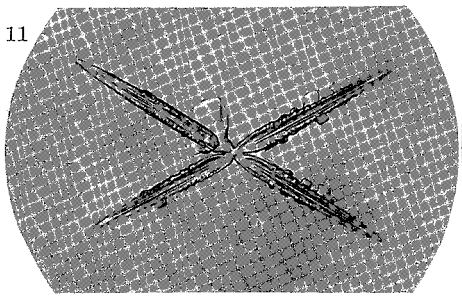

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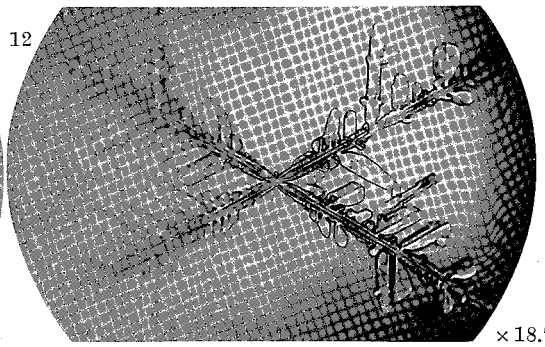

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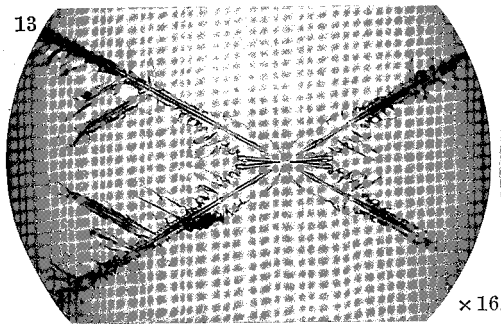

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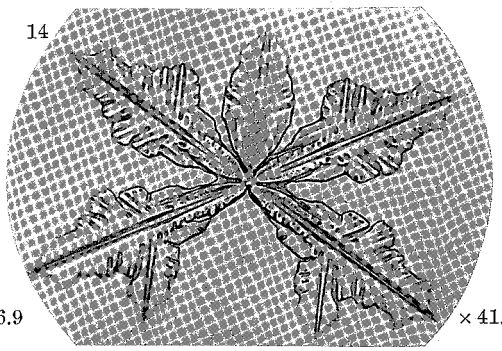

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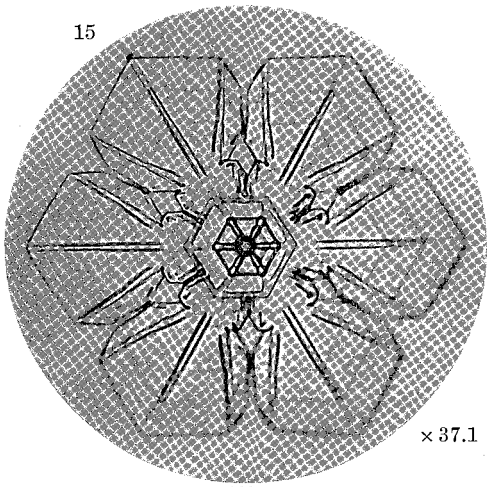

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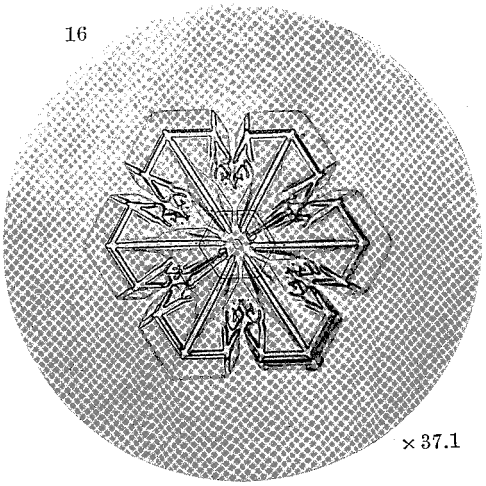

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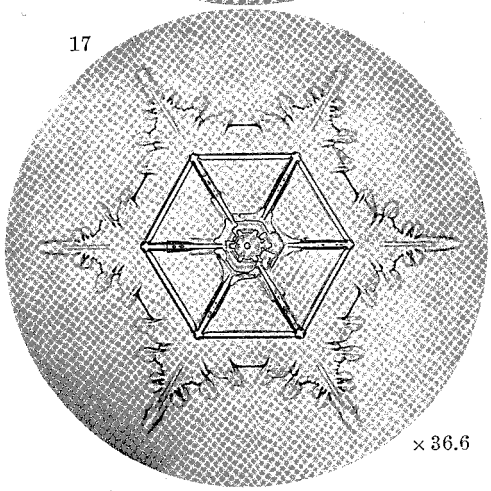

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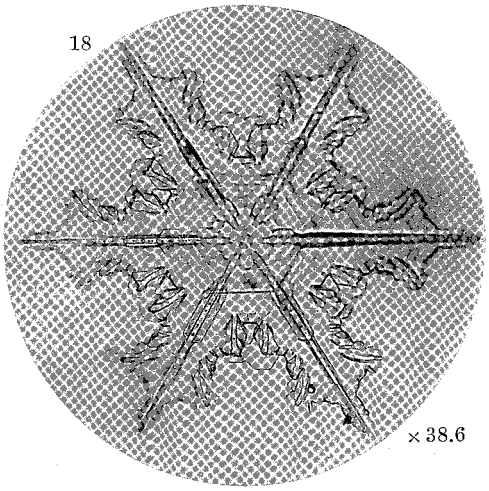

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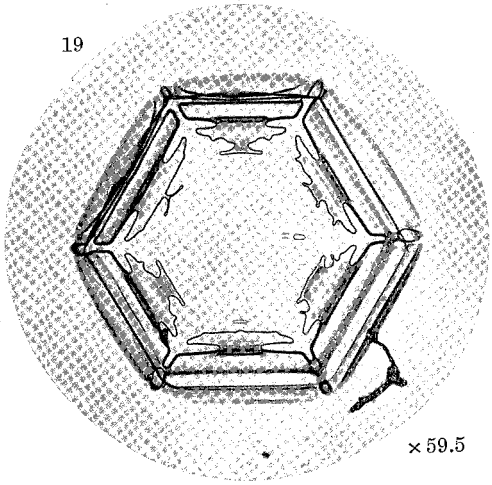

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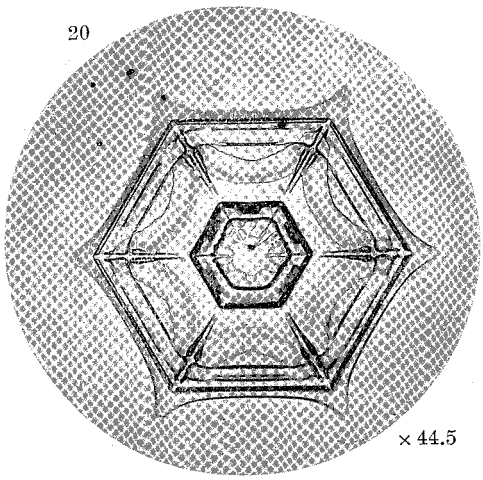

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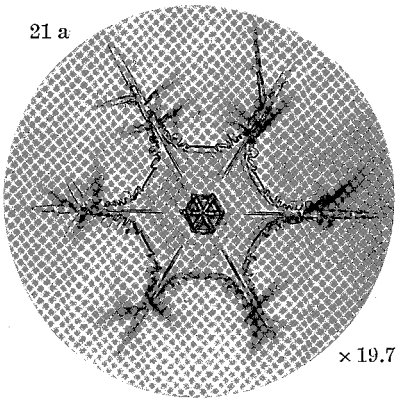

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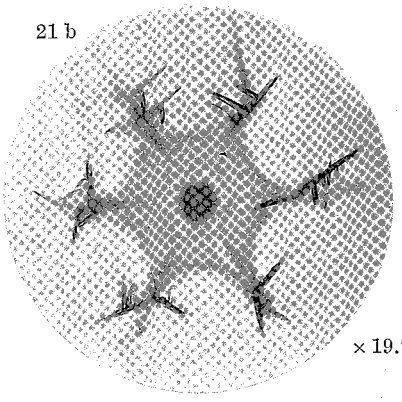

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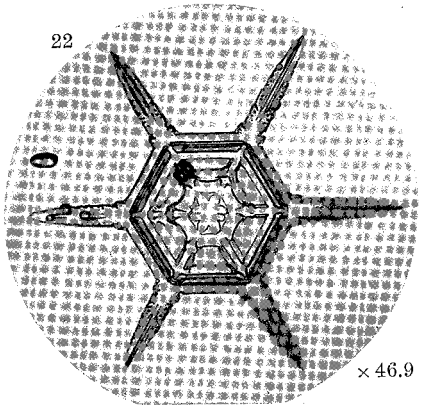

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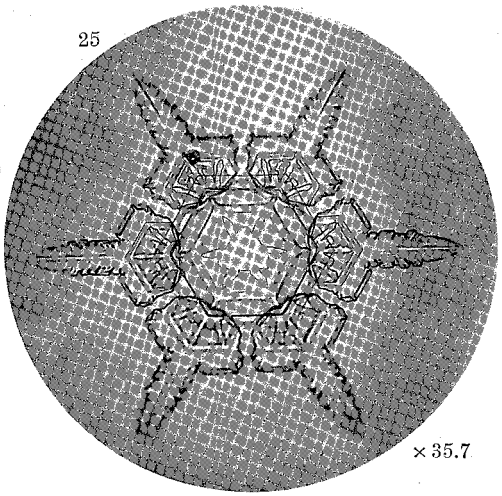

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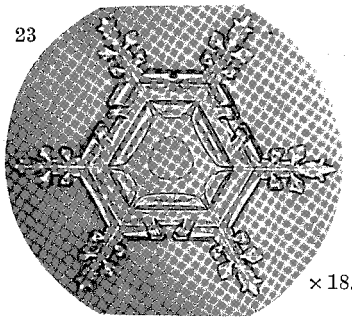

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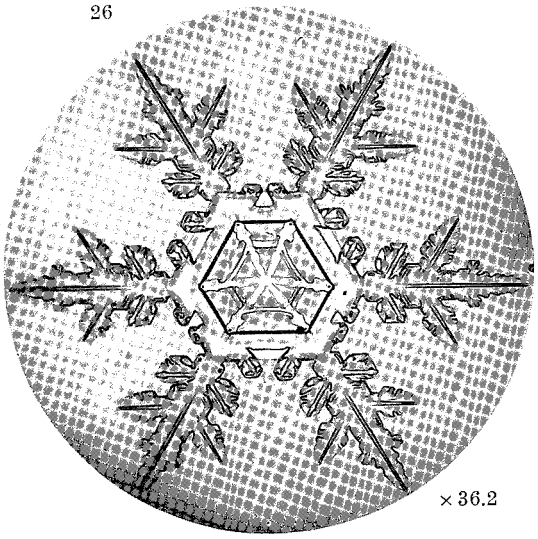

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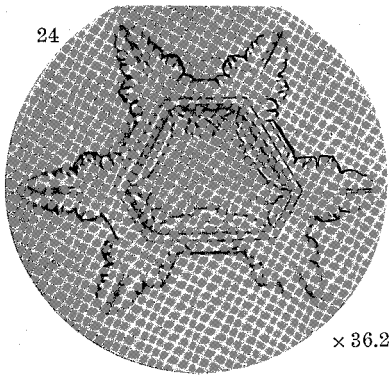

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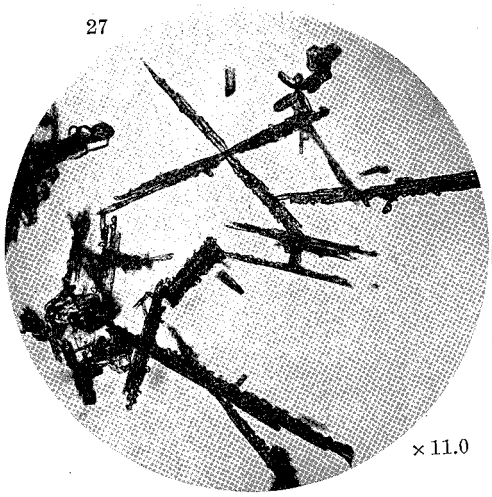

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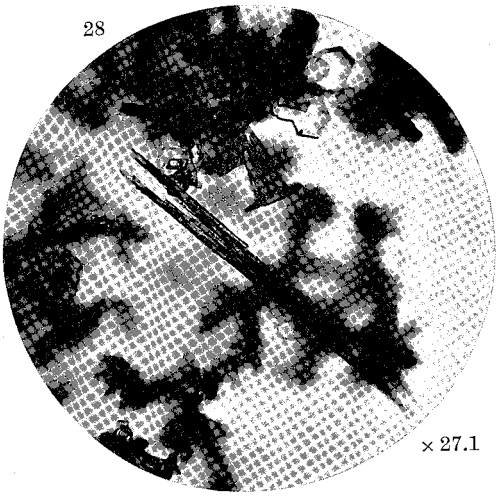

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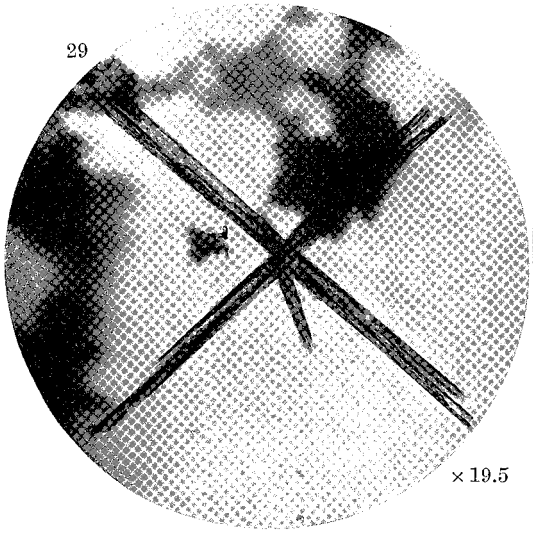

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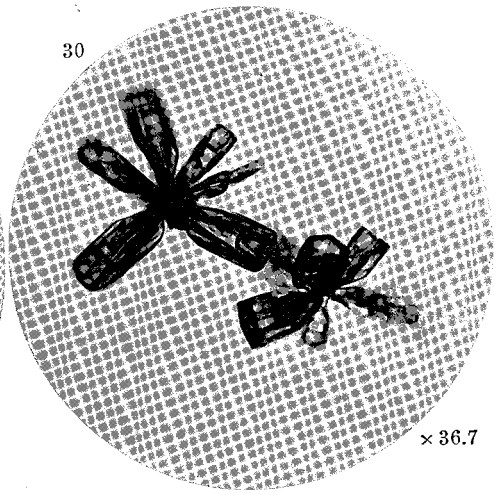

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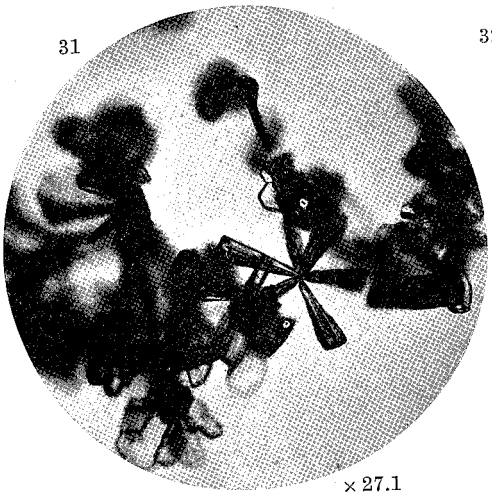

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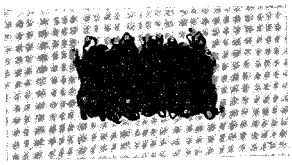

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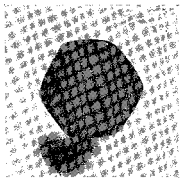

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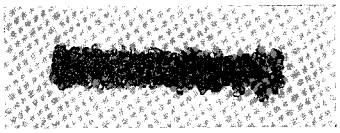

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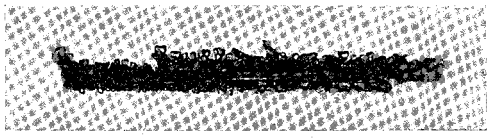

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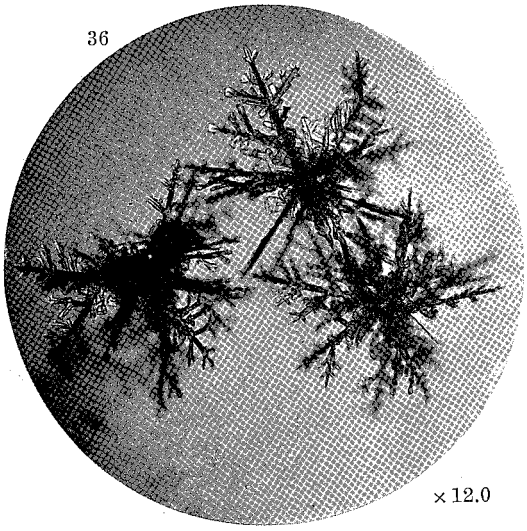

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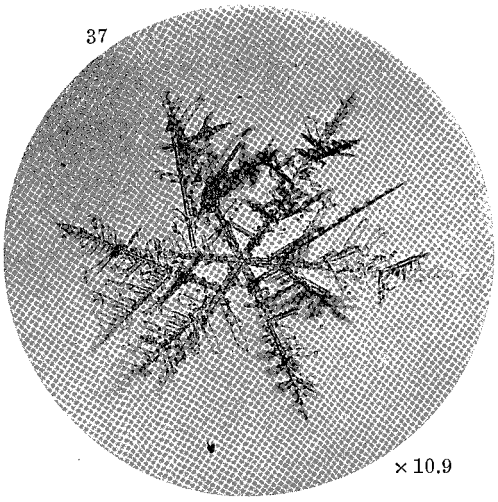

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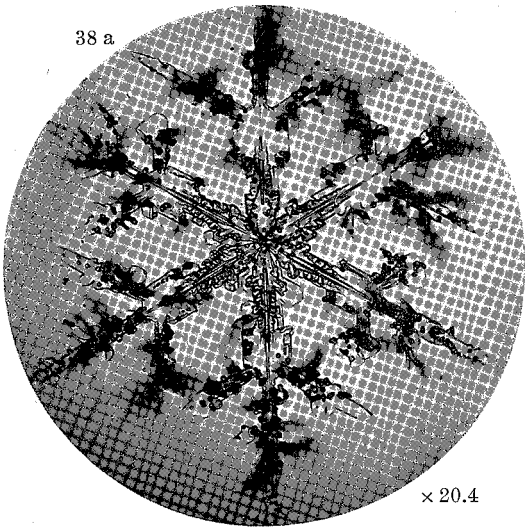

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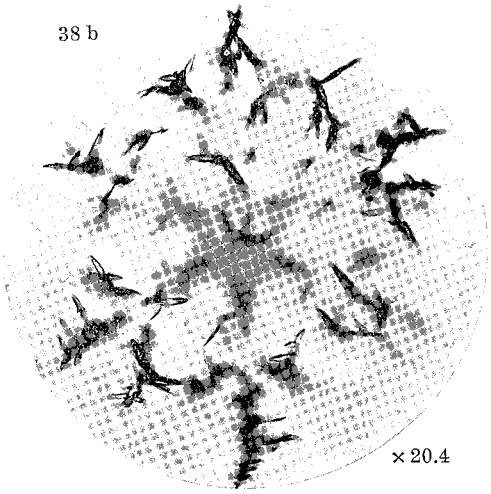

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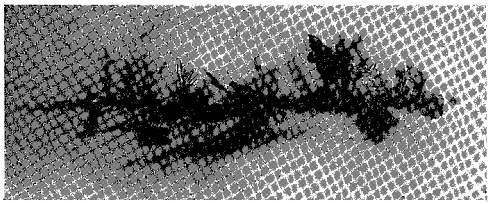

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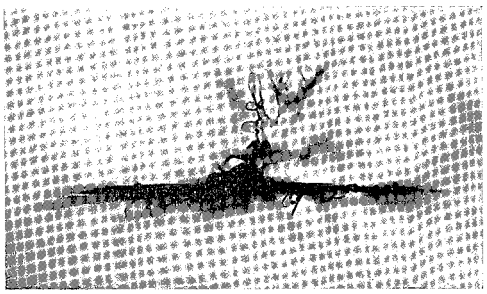

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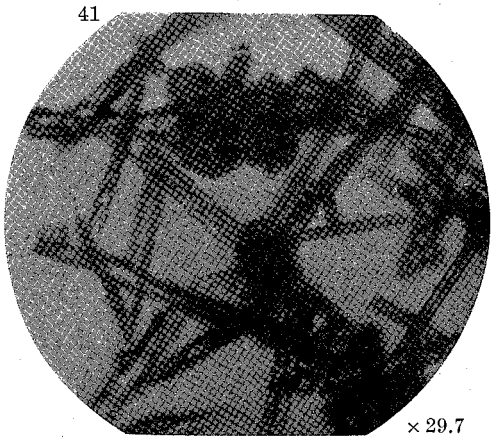

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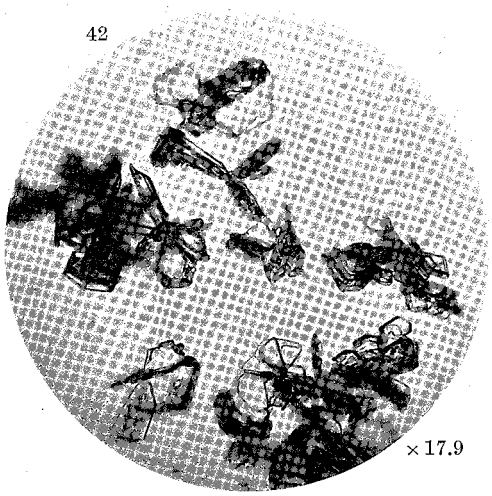

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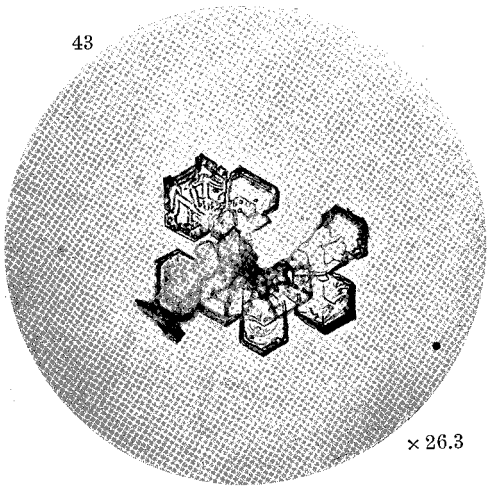

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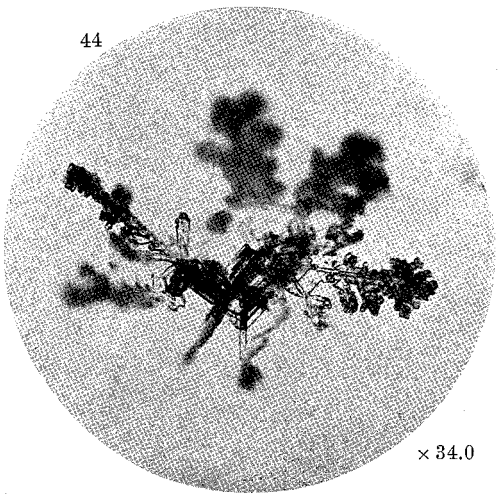

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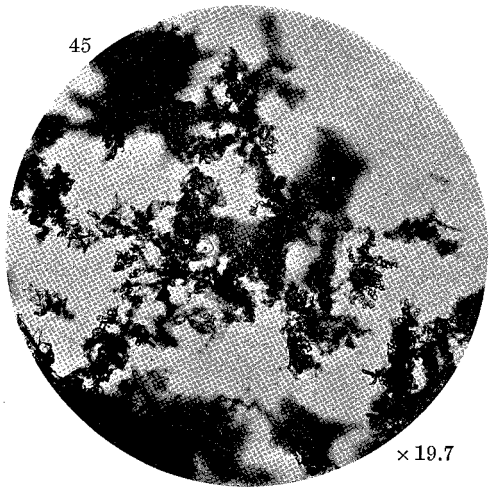

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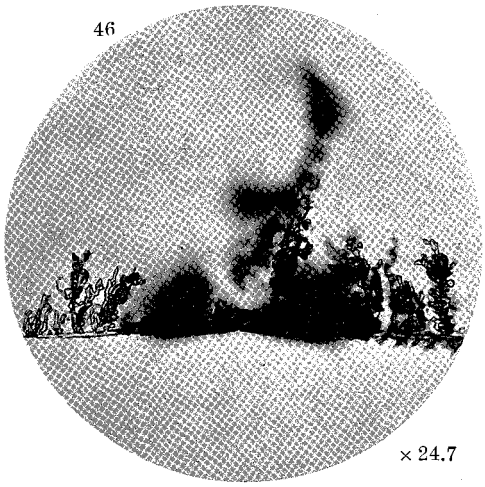

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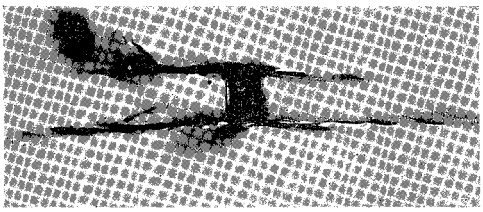

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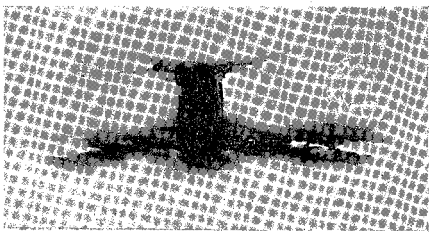

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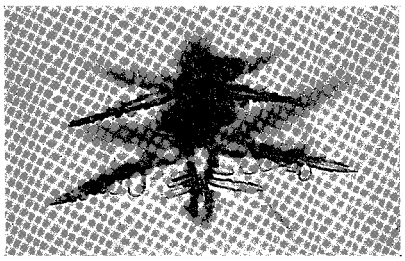

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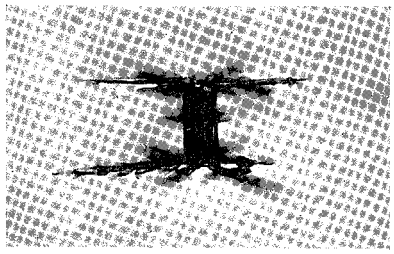

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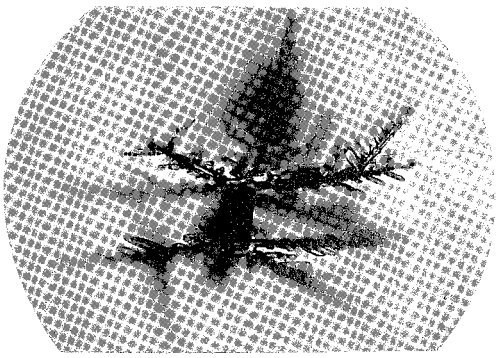

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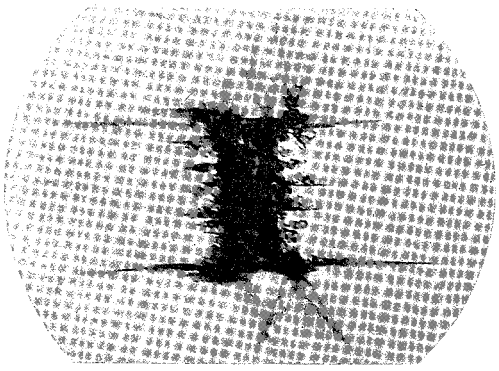

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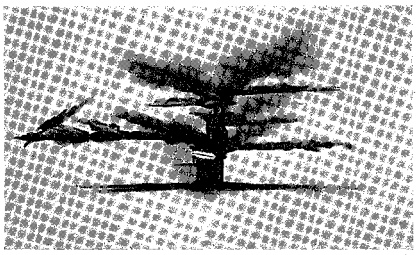

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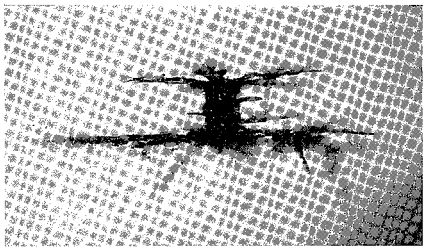

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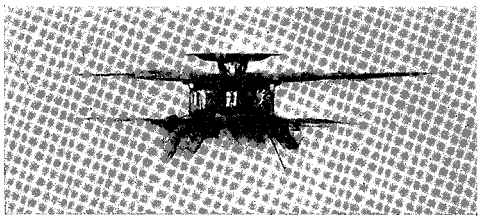

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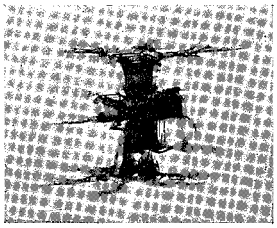

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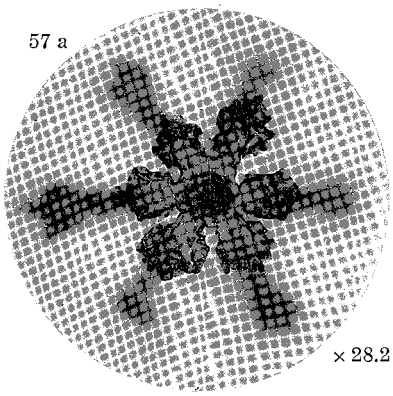

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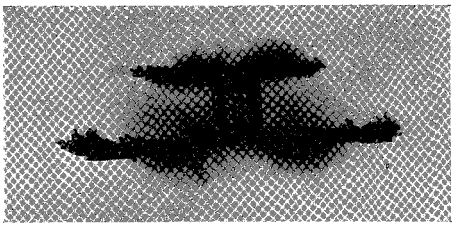

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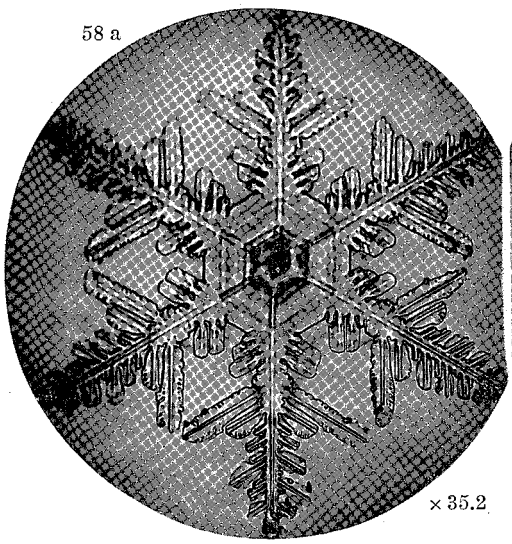

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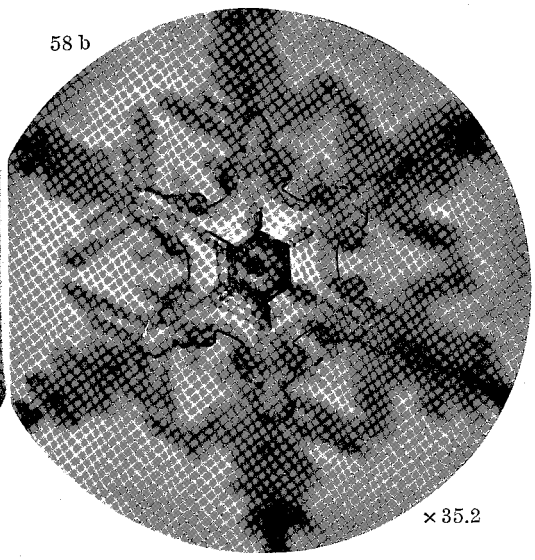

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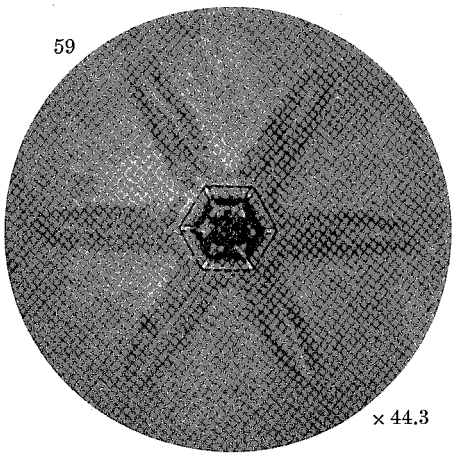

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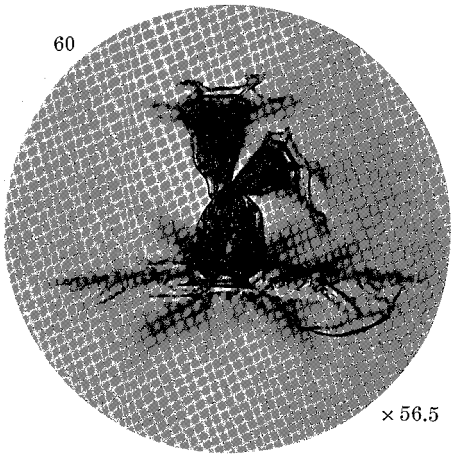

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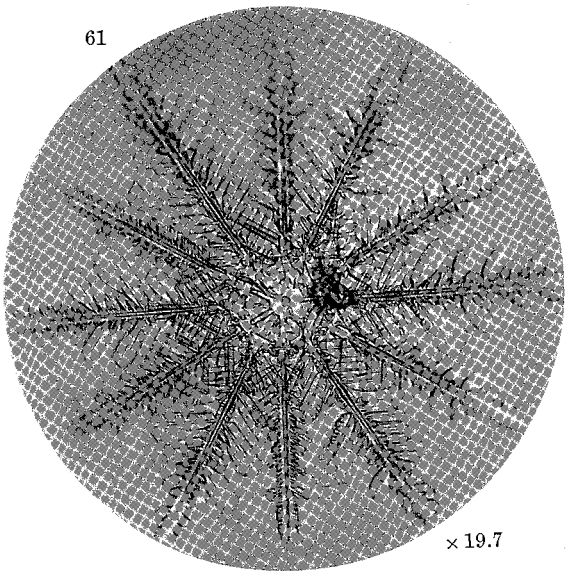

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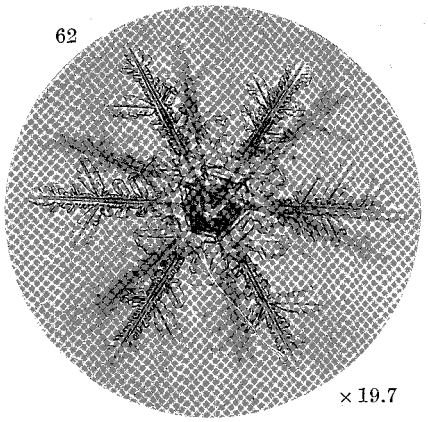

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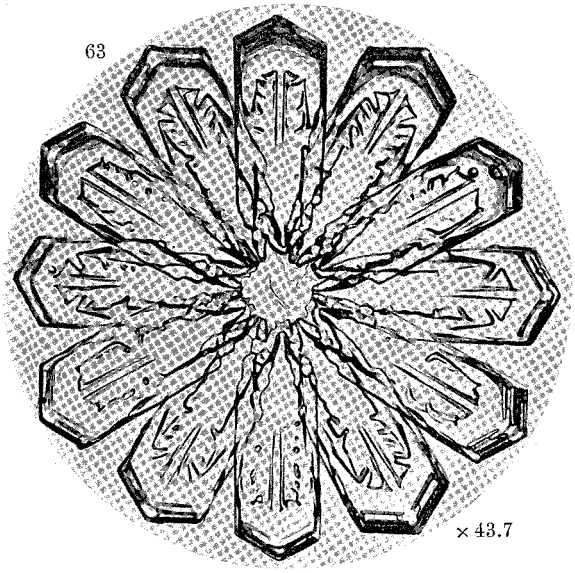

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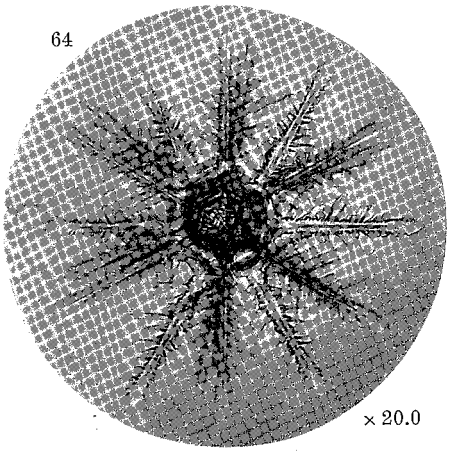

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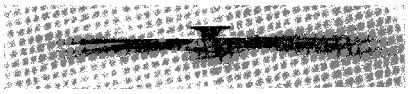

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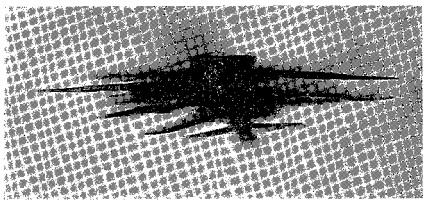

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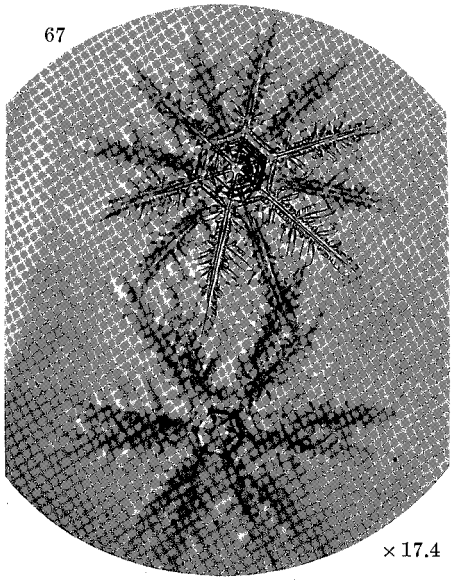

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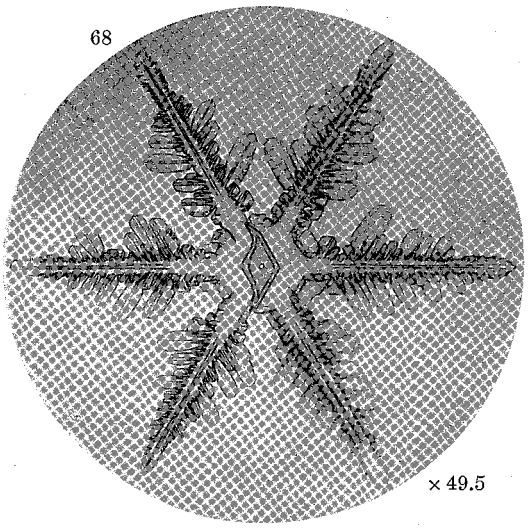

× 49.5

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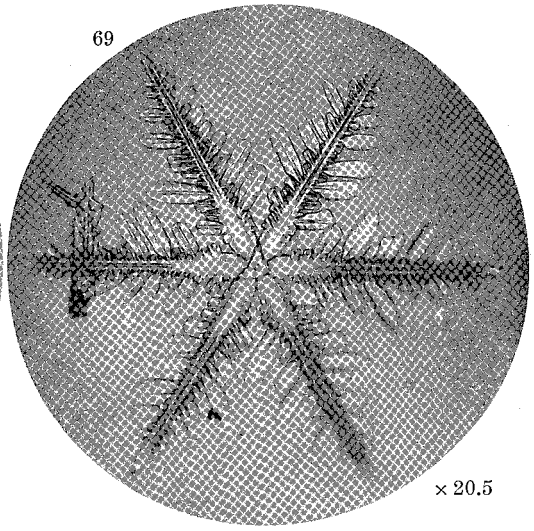

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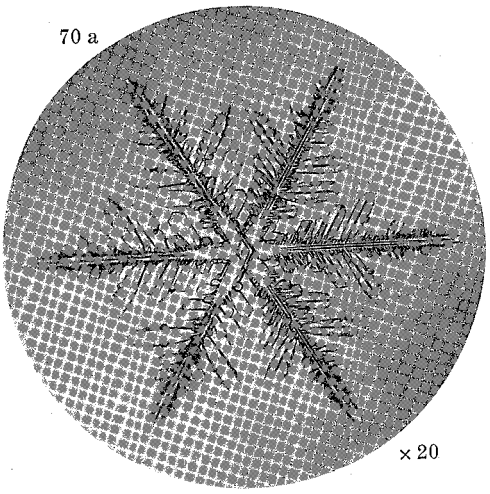

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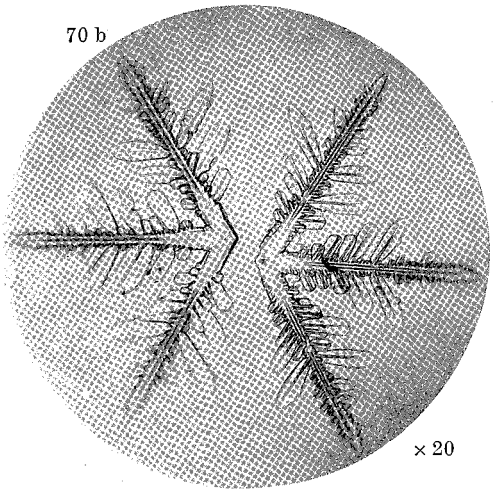

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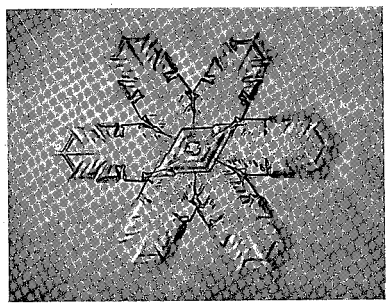

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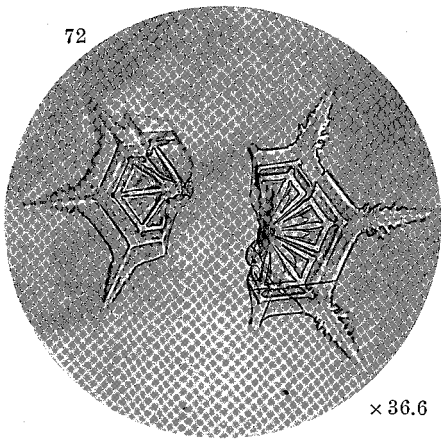

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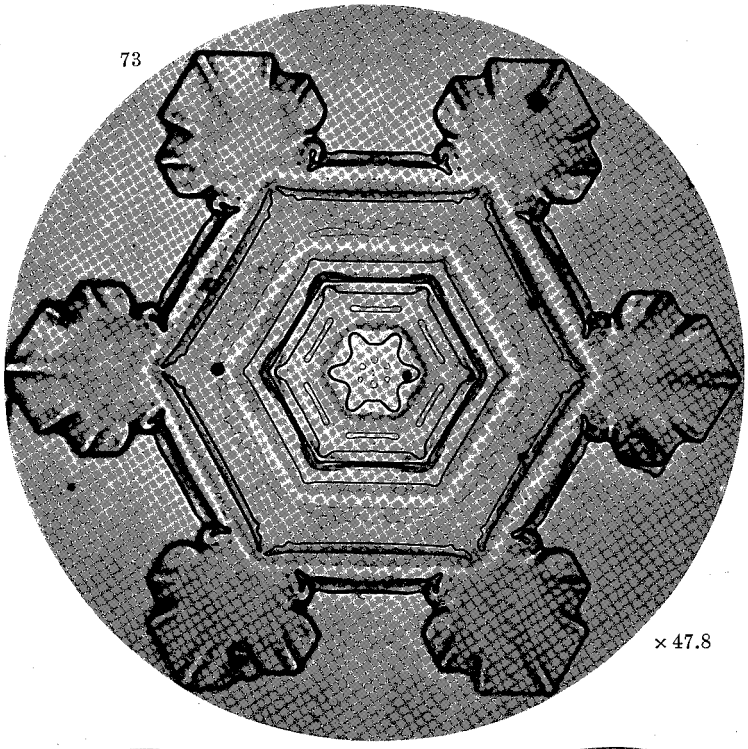

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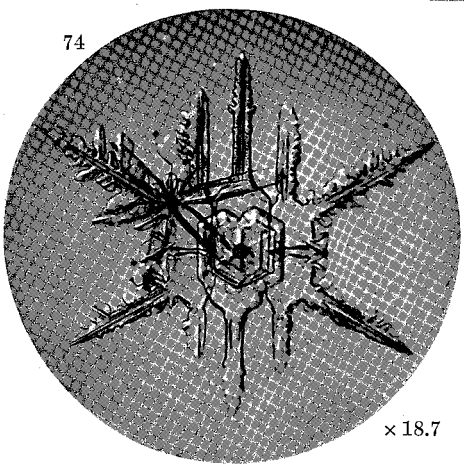

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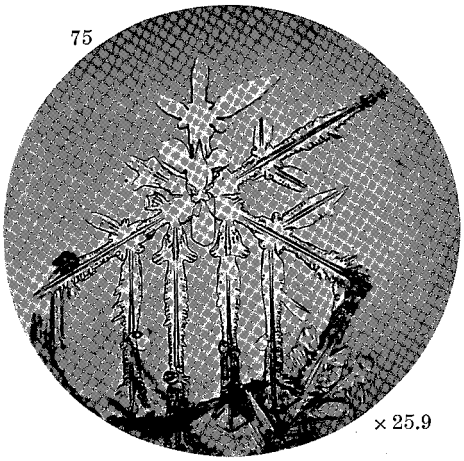

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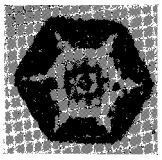

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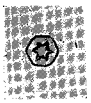

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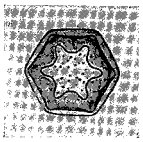

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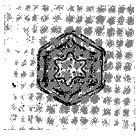

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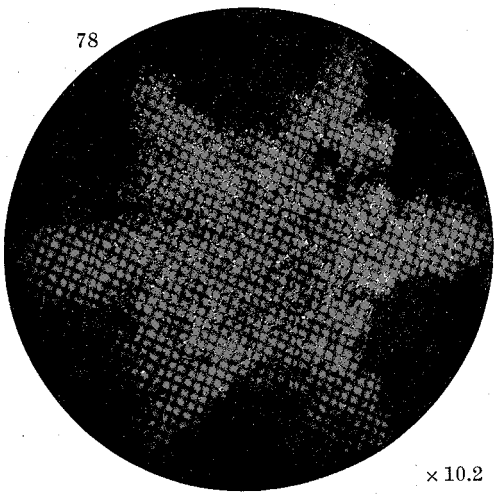

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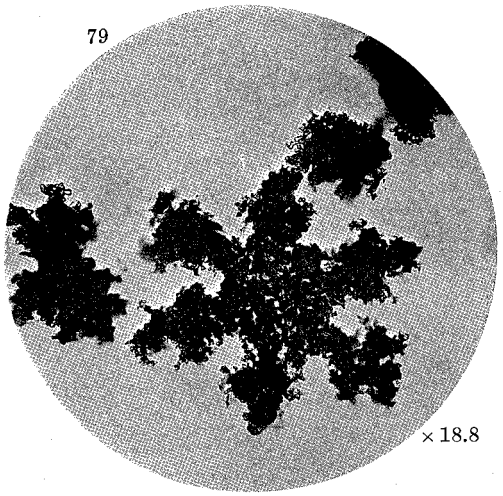

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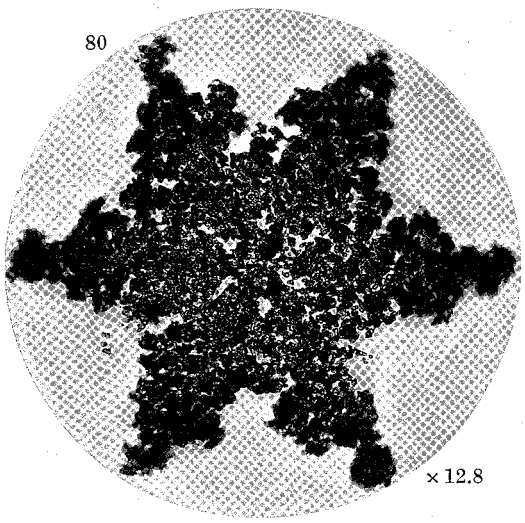

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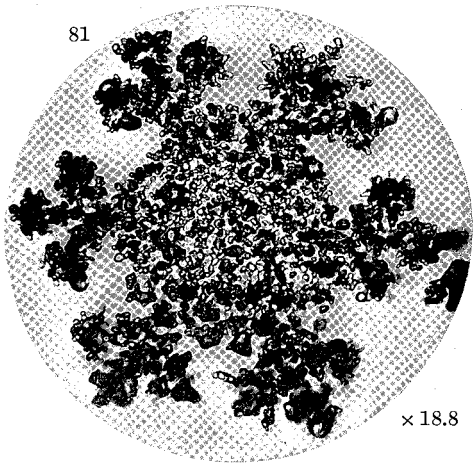

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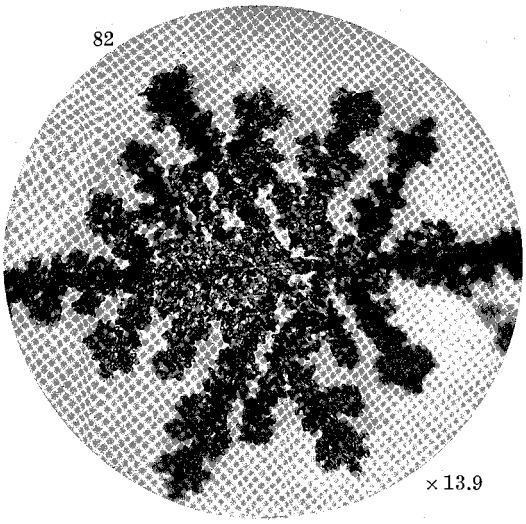

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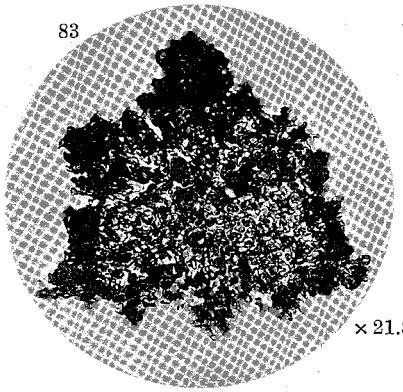

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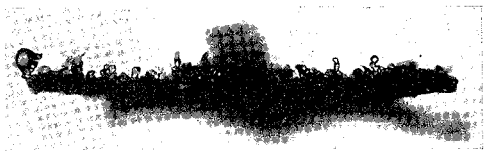

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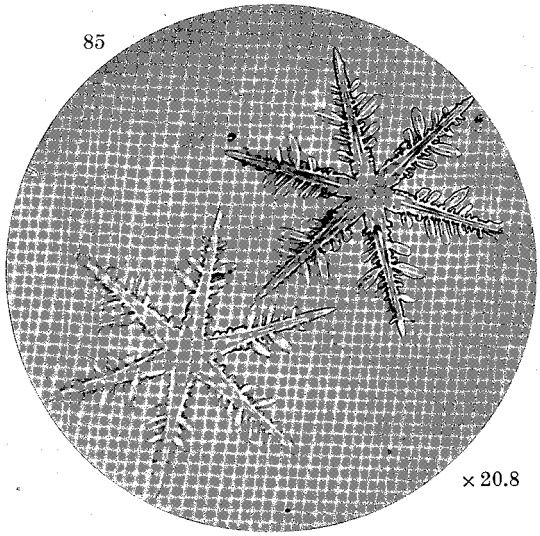

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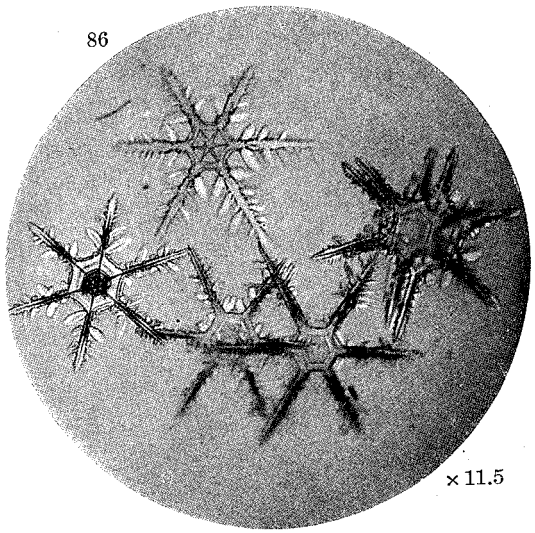

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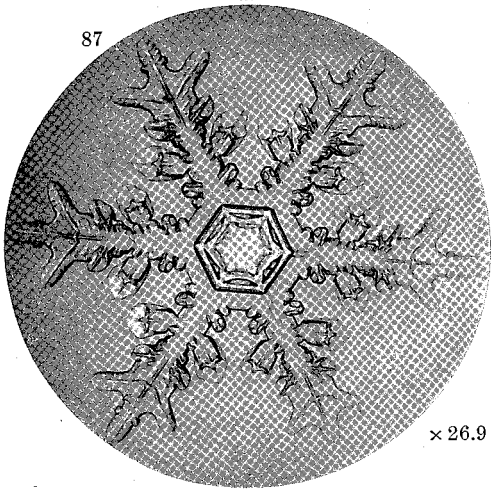

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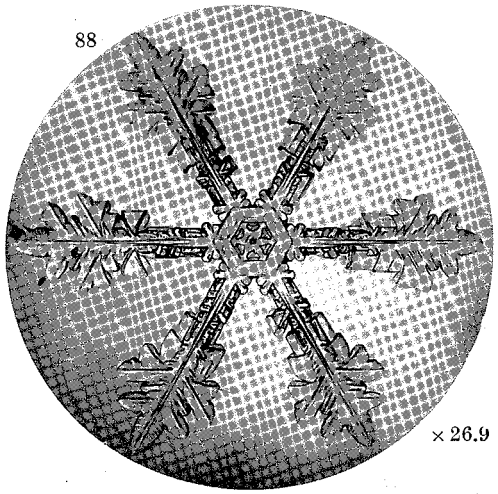

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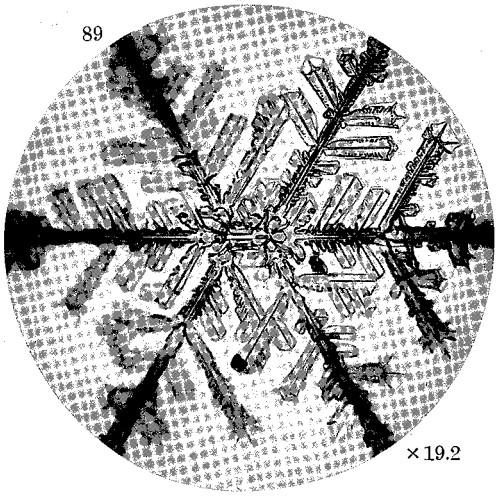

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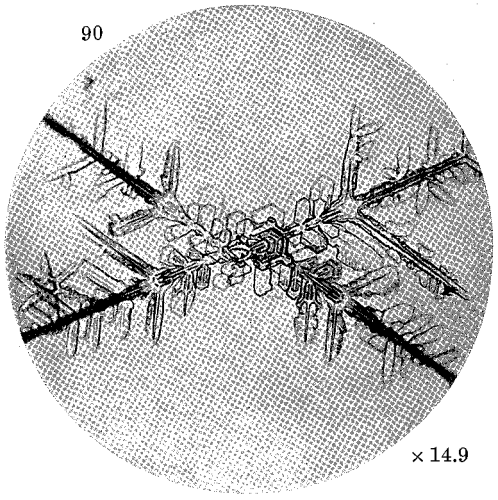

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