STUDIES AMONG THE SNOW CRYSTALS DURING THE WINTER OF 1901–2, WITH ADDITIONAL DATA COLLECTED DURING PREVIOUS WINTERS AND TWENTY-TWO HALF-TONE PLATES.

By Mr. Wilson A. Bentley.

Reprinted from the Annual Summary of the Monthly Weather Review for 1902.

STUDIES AMONG THE SNOW CRYSTALS DURING THE WINTER OF 1901-2, WITH ADDITIONAL DATA COLLECTED DURING PREVIOUS WINTERS.

By Mr. Wilson A. Bentley, dated Jericho, Vt., June 10, 1902.

At the request of the Editor, I gave in the Monthly Weather Review, for May, 1901, a brief sketch of my twenty years of study among snow crystals, illustrating it by about twenty-five examples of photomicrographs of snow forms. He desired me to give at that time a more complete account of my studies and also wished for a much greater number of photomicrographs for illustration. I was unable to accede wholly to his request, but I offered to devote myself during one or more succeeding winters to the gathering of all the data and photomicrographs possible and furnish material for a more complete account; my earnest desire being that I might, in this manner, contribute my mite to the general fund of scientific knowledge. No time, pains, or expense have been spared to make this sketch of the past winter's work as complete as possible.

It is sincerely hoped that the reproduction of the photomicrographs of these marvelously beautiful objects of nature will give great pleasure to many students. Possibly both photomicrographs and text may be of some positive value in an educational way, calling the attention of both the specialist and the general public to these most interesting examples of the handiwork of nature, and to the mysterious laws by which they are evolved from the invisible and seemingly unintelligent particles of matter, called water vapor, floating in our atmosphere.

I am greatly indebted to the Chief of the Weather Bureau, and to Mr. John W. Smith, Weather Forecast Official for New England, for weather maps furnished or loaned to me, and to Mr. E. H. Nash for invaluable services rendered me in changing and numbering exposed plates, so that more time could be devoted to the search for, and the photographing of, the forms.

The endeavor has always been made to secure characteristic sets of photomicrographs from each storm; yet, singularly enough, this proved the most difficult task of all, because the old habit of seeking for the beautiful and interesting, rather than the characteristic types, was very difficult to overcome. For this reason, I fear the winter's photographic record portrays far more fully the general character of the beautiful and interesting than it does the broken or unsymmetrical types. And yet there are few, perhaps, who after viewing the feast of beauty filling these pages will regret our shortcomings in this regard, especially as the general characteristics of the forms, from time to time, are given with some fullness in the accompanying text.

The winter of 1901–2 proved to be extremely favorable for our work and the number of photomicrographs (over 200) was much greater than that secured during any previous winter; the forms also greatly exceeded in beauty and interest the contributions of any other single winter. The dates and characters of the several snowstorms are given in Table 1. Beautiful and perfect forms occurred on twenty-one different days as against ten for the winter of 1900–1901, which was the next most favorable on record.

A list of the dates and serial numbers of selected photomicrographs is given in Table 2; this list includes all that were taken during 1901–2, and some interesting forms photographed in previous years. The data secured during the winter of 1901–2 are very instructive, not only because of the great number of snowstorms and the variety of the weather conditions prevailing therein, but also because our study of the weather maps in connection with the data allowed of the attainment of much more complete and exact results than otherwise would have been possible. It may be noted that, in general, the data and photomicrographs secured tend to further confirm the observations and conclusions arrived at by virtue of the studies of previous years.

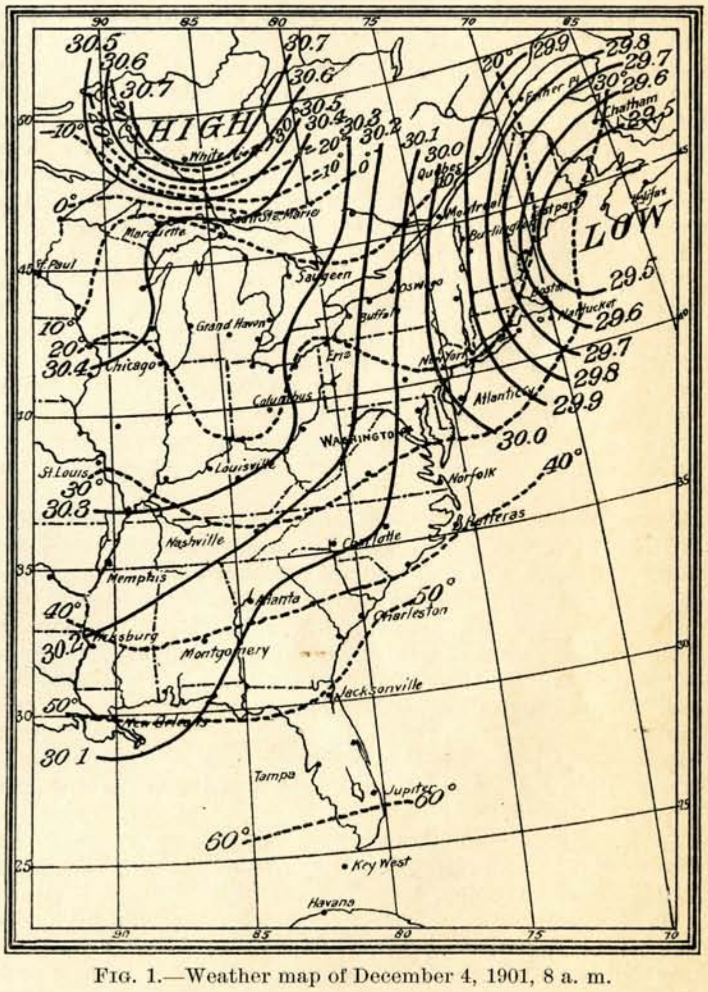


Fig. 1.—Weather map of December 4, 1901, 8 a. m.

We have not yet attained to any positive knowledge, but have been able to frame plausible hypotheses as to the conditions or factors governing the occurrence of the nuclear forms; we are still kept in doubt as to why columnar nuclei are produced at one time and tabular nuclei at other times. In general our data tend to further confirm the conclusions of all observers, that a more or less intimate connection exists

TABLE 1.—*Meteorological data for snowstorms.*

Date.	Numbers of photomicrographs.	Temperature.	Pressure.	Wind.	Clouds.	Portion of the storm field.
1901.		°F.	*Inches.*			
Nov. 25	700-703	29	29.6	nw.	Stratus and detached low nimbus*	Central-western.
Nov. 26	704-721	26, 23	29.6	w.	Stratus and nimbus*	Central-west.
Nov. 27	722-726	9	30.2	w.	Stratus and nimbus	Western edge.
Nov. 28	727-729	7, 13, 8	30.1	w.	Thin stratus above, detached nimbus below	Extreme western edge.
Nov. 30	730-737	18	30.0	wnw.	Thin stratus and nimbus	Undetermined.
Dec. 4	738-765	17	29.8	w, nw.	Stratus above, low nimbus scud below*	Western.
Dec. 5	766	7, 4	30.1	nw.	Thin nimbus	Western edge.
Dec. 15	767-774	25, 20	29.8	ne.	Stratus and nimbus*	Western-central.
Dec. 25	775-779	27	29.8	w.	Dense stratus, detached low nimbus*	West-central.
1902.						
Jan. 1	779¼	—10	30.3	n.	Thin stratus or clear	Extreme western edge.
Jan. 5	780-797	24, 25	30.4	n, nw.	Stratus and few low nimbus	Western edge.
Jan. 10	798-808	15, 25	29.5	w.	Cirro-stratus above, stratus and nimbus below	Southwestern.
Jan. 12	809-833	19, 15	29.4	w.	Clouds hidden by heavy snowfall	Southwest-central.
Jan. 13	834-838	9, 7	29.6	nw.	Stratus and nimbus*	Southwest edge.
Jan. 19	839-842	21, 15	29.9	n, nw.	Low nimbus*	Western.
Jan. 21	843-848	15, 19	30.1	se.	High cirro-stratus, thin detached nimbus	Southwest.
Feb. 7	849-856	12, 18	29.2	w.	Cirro-stratus, few nimbus	Southwest edge.
Feb. 8	857-887	8	29.4	w, nw.	Stratus and nimbus*	Southwest.
Feb. 10	888-896	10, 20, 5	30.0	nw.	Thin stratus, low nimbus	Extreme western edge.
Feb. 13	897-900	9, 14	29.8	n, ne.	High cirro-stratus	Western portion.
Feb. 17	901-905	8, 29	29.8	n, nw.	High cirro-stratus followed by low clouds	Northeast edge at first, central at the last.
Feb. 18	906-922	14, 25	29.1	nw.	Unknown	Central-west.
Feb. 19	923-933	7, 15	29.6	nw.	Low nimbus*	
Mar. 19	934-938	15, 21	29.6	....	Cirro-stratus, stratus, detached low nimbus in the afternoon.	West portion.

*On all these dates Mr. Bentley records "probably high cirrus or cirro-stratus above." As this is an inference drawn by him from the general structure of storm clouds, and the appearance of the forms of the snow crystals, we do not include it in the column of observed clouds.—*Ed.*

between form and size of nuclei, and the altitude and temperature of the air in which the crystals form. There can be no longer any doubt that there is a general law of distribution of the various types of crystals throughout the different portions of a great storm. On this point the data secured, both by direct observation and by a study of the weather maps, are much more complete and satisfactory than has ever before been published. This aspect of our study received special consideration, because it was thought to be most important.

Snowstorms often cover a region of vast extent; crystalization is going on within them over nearly the whole area, and therefore in regions that differ greatly among themselves as to temperature, humidity, air density, electrical conditions, etc. Moreover, the kind, number, dimensions, altitude, and density of the clouds within those various regions differ so greatly one from another that the snow crystals emanating from each region furnish us rare opportunities for observing and studying the effects of each of these various conditions upon the forms.

The accompanying weather map for 8 a. m., December 4, 1901 (fig. 1), shows quite clearly the great extent of our winter snowstorms, and the very various weather conditions prevailing within them. Perfect snow crystals were falling over northern Vermont when this map was drawn, and the location of the low, or storm center, as regards our locality at Jericho, Vt.,[1] was approximately identical with that of the positions of most storm centers when perfect forms have occurred. Perfect crystals emanated from the southwestern portion of this storm, and, in general, the great majority of perfect forms are produced within the western, southwestern, or northwestern portions of such widespread storms.

Table 3 gives the number of occurrences of perfect forms and of other types within the respective quadrants about the storm centers during the four winters 1897–98 to 1901–2, inclusive, so far as shown by photomicrographs. The whole number of such storms depositing perfect forms at our locality was 64.

As will be noted, about five-sixths of the perfect forms occur within the west and north quadrants of great storms. Their appearance within other portions, especially within the south and southeast quadrants, is rare indeed.

The classification by form and structure of the various types referred to in this and the following tables will now be described briefly. Prof. G. Hellmann's fundamental classification is perhaps the best. He divides the forms into two great classes, the *columnar* and the *tabular*. No. 857 is a good example of the columnar; Nos. 716 and 746 illustrate the tabular, while No. 777 presents good examples of both. For convenience these two fundamental types may be divided into subvarieties and the classification adopted by Scoresby and others may be used for this purpose.

The solid tabular forms will be denominated *lamellar*. (See Nos. 746 and 850.) The crystals of more or less open structure possessing solid tabular nuclei, for want of a better name, will be referred to as *stellar*. (See Nos. 709 and 731.) Those possessing centrally open structure and devoid of solid tabular nuclei, resembling ferns, are the *fern-stellar*. (See Nos. 842, 920, and 737.) The columnar forms connecting one or more tabular crystals are classified as *doublets* (see No. 561), the extremely long needle-shaped columnar forms (see Nos. 700 and 227) will be designated as *needle-shaped* or *needilar* (classified by Scoresby as spicular.) It is to be noted that there are other forms whose structures entitle them to be considered as distinct types, but they occur so rarely that excepting the granular forms they will not be considered in the following analysis. (For examples of granular-covered crystals, see Nos. 529, 700, 704, and 807.)

We have now to consider the relative frequency of the appearance of these various types, in both local and general storms; their occurrence and distribution throughout the various portions of great storms; their relation to various cloud strata, their occurrence during various degrees of cold, etc.

Table 4 gives approximately the relative frequency of occurrence of the various types within each quadrant of the general storms, and also of the local snowfalls of the winter of 1901–2.

It is to be regretted that the data regarding local storm types are not more extensive; but as weather maps were only available for the past winter (1901–2) it was thought best to construct tables for the data secured during this one winter.

A comparison of the relative frequency of occurrence of the various types within local and general storms, as given in Table 4, reveals great differences. The preponderance of the branching open structure crystals and granular forms will be noted, and it may be added that such types actually form a larger percentage of the total mass of the crystals than is indicated by the figures of the preceding table.

Most of the earlier observers mention the doublets as occurring very rarely. This seems to be not true as regards our locality. I have observed them quite frequently. A number

[1] Jericho is about 15 miles east of Burlington, Vt.

TABLE 2.—*Chronological list of dates of photomicrographs, with corresponding serial numbers.*

No.	Date.	No.	Date.	No.	Date.	No.	Date.
10	Feb. 26, 1886	732	Nov. 30, 1901	801	Jan. 10, 1902	870	Feb. 8, 1902
19	....do	733	....do	802	....do	871	....do
47	Mar. 12, 1888	734	....do	803	....do	872	....do
64	Dec. 14, 1889	735	....do	804	....do	873	....do
76 *a* ‡	Jan. 5, 1892	736	....do	805	....do	874	....do
92	Feb. 12, 1892	737	....do	806	....do	875	....do
108	Feb. 16, 1893	738†	Dec. 4, 1901	807	....do	876	....do
198	Feb. 15, 1896	739	....do	808	....do	877	....do
227	Jan. 23, 1897	740	....do	809	Jan. 12, 1902	878	....do
257	Jan. 5, 1898	741	....do	810	....do	879	....do
270	Jan. 26, 1898	742	....do	811	....do	880	....do
342	Nov 27, 1898	743	....do	812	....do	881	....do
359	Jan. 6, 1899	744	....do	813	....do	882	....do
405	Feb. 13, 1899	745	....do	814	....do	883	....do
433	Mar. 18, 1899	746	....do	815	....do	884	....do
482	Feb. 18, 1900	747	....do	816	....do	885	....do
488	....do	748	....do	817	....do	886	....do
493	Feb. 19, 1900	749	....do	818	....do	887*	....do
503	Mar. 2, 1900	750	....do	819	....do	888	Feb. 10, 1902
504	Dec. 5, 1900	751	....do	820	....do	889	....do
513	Dec. 27, 1900	752	....do	821	....do	890	....do
529	Jan. 7, 1901	753	....do	822	....do	891	....do
547	Jan. 28, 1901	754	....do	823	....do	892	....do
561	....do	755	....do	824	....do	893	....do
562½	Jan. 31, 1901	756*	....do	825	....do	894	....do
564	Feb. 5, 1901	757	....do	826	....do	895	....do
565	....do	758	....do	827	....do	896	....do
580	....do	759	....do	828	....do	897	Feb. 13, 1902
581	Feb. 13, 1901	760	....do	829	....do	898	....do
582	....do	761	....do	830	....do	899	....do
583	....do	762*	....do	831	....do	900	....do
584	....do	763*	....do	832	....do	901	Feb. 17, 1902
585	....do	764*	....do	833	....do	902	....do
587	....do	765	....do	834	Jan. 13, 1902	903	....do
591	Feb. 15, 1901	766	Dec. 5, 1901	835	....do	904	....do
593	....do	767	Dec. 15, 1901	836	....do	905*	....do
594	....do	768	....do	837	....do	906	Feb. 18, 1902
598	....do	769	....do	838	....do	907	....do
700	Nov. 25, 1901	770	....do	839	Jan. 19, 1902	908	....do
701	....do	771	....do	840	....do	909	....do
702	....do	772	....do	841	....do	910	....do
703*	do	773	....do	842	....do	911	....do
704	Nov. 26, 1901	774*	....do	843	Jan. 21, 1902	912*	....do
705	....do	775	Dec. 25, 1901	844	....do	913*	....do
706	....do	776	....do	845	....do	914*	....do
707	....do	777	....do	846	....do	915*	....do
708	....do	778	....do	847	....do	916*	....do
709	....do	779	....do	848	....do	917*	....do
710	....do	779½	Jan. 1, 1902	849	Feb. 7, 1902	918*	....do
711	....do	780	Jan. 5, 1902	850	....do	919*	....do
712	....do	781	....do	851	....do	920	....do
713	....do	782*	....do	852	....do	921	....do
714	....do	783	....do	853	....do	922*	....do
715	....do	784	....do	854	....do	923	Feb. 19, 1902
716	....do	785	....do	855	....do	924	....do
717	....do	786	....do	856	....do	925	....do
718	....do	787	....do	857	Feb. 8, 1902	926	....do
719*	....do	788	....do	858	....do	927	....do
720	....do	789	....do	859	....do	928	....do
721*	....do	790	....do	860	....do	929	....do
722	Nov. 27, 1901	791	....do	861	....do	930	....do
723	....do	792	....do	862	....do	931	....do
724	....do	793	....do	863	....do	932	....do
725	....do	794	....do	864	....do	933*	....do
726*	....do	795	....do	865	....do	934	Mar. 19, 1902
727	Nov. 28, 1901	796	....do	866	....do	935	....do
728	....do	797	....do	867	....do	936	....do
729*	....do	798	Jan. 10, 1902	868	....do	937	....do
730	Nov. 30, 1901	799	....do	869	....do	938	....do
731	....do	800	....do				

*Omitted. Photomicrographs unsatisfactory.
†The negative was injured, but has been repaired, as will be apparent to the reader.
‡This photomicrograph is, by mistake, numbered 100 on Plate I.

TABLE 3.

Storm portion.	Number of occurrences of perfect forms.	Columnar.	Solid tabular.	Stellar or solid nucleus.	Fern stellar.	Doublets.	Long needle-shaped.	Granular.
N	10	8	7	9	6	1	2	3
NE	5	3	4	5	2	3	1	2
E	3	3	1	3	6	1	2	3
SE	1	1	1	1	1	0	0	0
S	1	0	1	1	6	1	2	3
SW	16	10	14	15	14	6	2	8
W	20	9	19	20	17	2	5	8
NW	10	3	10	10	9	3	0	7
Total occurrence of each type	66	37	57	64	61	17	14	34
Deduct from the above the forms emanating from the central portions of these storms that passed across our locality	14	7	9	12	11	9	3	6
Balance	52	30	48	52	50	8	11	28

TABLE 4.—*Frequency of types of snow crystals in 53 general storms.*

Storm segments.	Columnar.	Lamellar-solid crystals or solid tabular.	Stellar nuclei.	Fern-stellar.	Doublets.	Needle-shaped.	Granular.
N	0	0	0	0	0	0	0
NE	0	0	0	0	0	0	1
E	3	2	1	1	0	1	0
SE	0	0	0	0	0	0	0
S	0	0	1	2	0	0	2
SW	2	1	3	7	1	1	9
W	1	3	7	7	3	0	6
NW	0	1	3	3	1	1	4
Total number	6	7	15	20	5	3	*22
Forms from central region	6	5	7	9	3	6	12
Forms whose location is undetermined	4	8	13	10	0	1	13
Total number of forms from all portions of the 53 general storms	16	20	35	†43	8	10	47
Fourteen local snowfalls	1	0	2	4	0	0	8
Total number for both local and general storms	17	20	37	47	8	10	55

*14 of all these cases came from the central portions. †So in Mss.

of instances have come under my own observation, where nearly the whole snowfall, for many hours together, consisted of such forms. Prof. James C. Shedd, of Colorado College, Colo., who made a study, during the winter of 1901–2, of the snow forms occurring at his locality, mentions finding doublets on two occasions during this winter.

The apparent connection between the temperature of the air and the frequency of the appearance of the various forms is plainly indicated in Table 5.

TABLE 5.

Temperature of storms.	No. of storms.	Columnar.	Solid lamellar.	Stellar.	Fern-like.	Doublets.	Needle-like.	Granular.
Medium cold storms, temperature +15° to +5° F	21	15	13	11	9	3	2	13
Very cold storms, temperature +5 to —10°	5	8	18	21	19	4	3	9
Total occurrence of each type	26	23	31	32	28	7	5	22

It is worth noting that during "cold" snowfalls the solid columnar and tabular forms appear in nearly equal numbers with the more open stellar and fern-like varieties, and considerably outnumber the granular forms.

A comparison of the frequency of occurrence of the forms during various milder temperatures is most interesting and instructive.

The results, as given in the preceding tables, arrived at by a study of the data secured during the four winters of 1898–99 to 1901–2, inclusive, in regard to the relative frequency of occurrences of the various types and the apparent connection between size and form and the air temperatures, agree in general with the results arrived at by many other meteorologists and observers, both in Europe and America, as set forth in the work Schneekrystalle, by Dr. G. Hellmann, Berlin, 1893.[2]

Doubtless the actual connection between forms and sizes of snow crystals and the temperature and density of the air is much more intimate than our present knowledge would indicate, because our studies are based on air temperatures at the earth's surface, instead of in the cloud strata where the snow crystals form. The temperature may often be mild at the earth's surface when the crystals are developing at high alti-

[2] G. Nordenskiold. Preliminart meddelande rorande en undersokning snokristaller. Af G. Nordenskiold. Foren. i Stockholm Forhandl. Bd. 15. Haft 3. 1893. (Geol. Society of Sweden 146–158 und Tafel 5-26.)

tudes where the cold is intense, and such crystals should be classed with those deposited during extreme cold.

The frequency of the occurrence of each type within each cloud stratum, one above the other, is given in Table 6. This table gives only the results obtained during the past winter, and it will be noted that the cirrus and cirro-cumulus clouds have deposited no snow crystals. These clouds, when occurring alone, very rarely if ever deposit crystals of sufficient size to fall to the earth.

Table 6 gives but approximate results and may be sometimes misleading, because when nimbus or stratus clouds are present the existence of cloud strata lying above the lower clouds can not be certainly determined, but have been inferred from general considerations.

TABLE 6.—*General frequency of occurrence of the various types of snow crystals during 67 snowfalls in the winter of 1901–2.*

Kind of clouds.	Total number of snowfalls from each cloud.	Columnar.	Solid lamellar.	Stellar.	Fern-like.	Doublets.	Needle-shaped.	Granular.	Totals.
Cumulo-nimbus	25	1	0	7	16	0	3	19	46
Stratus and nimbus	5	3	2	3	4	2	1	0	15
Cirro-stratus and nimbus	25	5	13	16	16	3	5	22	80
Cirro-Cumulus	0	0	0	0	0	0	0	0	0
Stratus	2	1	2	2	0	0	0	1	6
Cirrus	0	0	0	0	0	0	0	0	0
Cirro-stratus	7	7	5	5	4	0	1	0	22
Cirrus and cumulus	3	1	1	2	2	1	0	2	9
Totals	67	18	23	35	42	6	10	44	178

In general the snow forms are most frequently precipitated when two or more cloud strata exist.

During great storms, especially whenever perfect forms are being produced, such as are portrayed in the following pages, the presence of two-cloud strata is almost always indicated; and much more frequently might these be inferred from Table 5, which gives cloud data for both local and miscellaneous snowfalls, rather than for great storms producing perfect forms.

ANALYSIS OF CLOUD DATA.

It may be of interest to briefly describe the probable numbers and characters of the various cloud strata and the types associated with each. In general, there are present two great cloud divisions, lower and upper. The lower clouds are drifting spirally inward toward the storm's center; the upper clouds, which often extend outward far beyond the lower clouds and the area of precipitation, are drifting outward away from the storm center. Within the central regions of the storm, and also within detached portions of the outer regions, the ascension and horizontal expansion of the lower clouds form vast masses of intermediate and upper clouds. In the eastern and southern regions the upper clouds flowing outward, or more nearly with the average eastward drift of the whole atmosphere in our latitudes, naturally move fastest, and extend farther outward than do such clouds within the other segments of the storm. The relatively warm moist air flowing horizontally inward below these upper clouds, does not usually ascend in mass, until it approaches the storm's center; hence, the lower cloud strata within these segments are inconsiderable, consisting usually of but small detached masses of swiftly moving nimbus clouds. It may be assumed that these two widely separated strata will each sparingly shed the types of crystals that seem to be appropriate to each, i. e., the upper clouds will shed the small solid columnar or tabular forms; the lower clouds, the frail branching tabular crystals. It may also be assumed that near the center of the storm, these two varieties will reach a more complete development, and be of larger size and that other varieties (especially granular forms) will be associated with them.

Within the northern segments of a storm the relatively cold, inflowing lower air will be heavier, and will not exhibit as strong a tendency to ascend as do similar lower currents within other portions of the storm; hence, the production of snow crystals will usually be much less here than elsewhere. Probably a portion of the great mass of ascending and subsequently chilled air of the central portions of snowstorms flows outward and downward within the northern portion of the storm and forms a vast cloud, covering intermediate and other altitudes. These various horizontal cloud strata will, it is assumed, allow of the formation of a great variety of medium and small sized crystals of both the columnar and tabular varieties. Within this northern portion of the storm many of the crystals will probably undergo development while slowly drifting horizontally, or slowly descending.

The clouds within the western segment of the storm are not likely to differ greatly from the northern, except in so far as the lower ones exhibit a stronger tendency to ascend, and so far as overhanging upper clouds are sometimes absent. The great variety and vertical depth of the clouds within this segment will, however, conduce to the formation of a great variety of types, and to more complete development. Our data show that perfect forms are most commonly produced in this western segment of the general storm. I would suggest that possibly a partial explanation of this most interesting result of our work may be found in the fact that in this western segment of the storm the tendency of the lower clouds to ascend and the upper ones to descend, may somewhat neutralize each other, producing a calm within the intermediate cloud strata. This calm condition in the intermediate and upper air may be rendered more perfect, because in this segment the outflowing upper air and cloud strata tend to flow westward and meet, or oppose, the general eastward drift of the whole atmosphere in our latitudes.

We have now but to consider the central portions of general storms. We may conclude with much certainty that the convergence of large bodies of moist air, either warm or cold, causes its general, and often violent, ascension at the center. The ascent of this body of vapor laden air around the storm center, especially in its southwest and central portions, causes the formation of immense continuous cloud masses, reaching from the lower clouds up to, and merging into and forming, both intermediate and upper strata. These great ascending cloud masses allow of the formation of nearly or quite all of the various types of crystals. The moist low clouds and the state of violent agitation conduce to the formation of imperfect crystals and granular forms, and to the fractures of the crystals.

STRUCTURE OF SNOW CRYSTALS.

The beautiful details, the lines, rods, flowery geometrical tracings and delicate symmetrically arranged shadings to be found within the interior portions of most of the more compact tabular crystals, and in less degree within the more open ones, have attracted the attention of nearly all observers who have studied snow crystals. That these interior details more or less perfectly outline preexisting forms must have been early recognized, yet the knowledge as to what they actually were remained long in obscurity, and a complete explanation of all of them is yet to be found. The investigations of Dr. Nordenskiold and G. Hellmann enable us to form a general conception as to their true character. These observers discovered that many of the lines, rods, and other configurations within the crystals, that add so much to the beauty of the forms, and which are so plainly revealed in the photomicrographs, are due to minute inclusions of air. This included air prevents a complete joining of the water molecules; the walls of the resultant air tubes cause the absorption and refraction of a part of the rays of light entering the crystal; hence, those portions appear darker by transmitted light than do the other portions. The softer and broader interior shadings may perhaps also be due, in whole or part, to the same cause, but if so, the corresponding inclusions of air must necessarily be much more attenuated and more widely diffused than in the former cases. We can only conjecture as to the manner in which these minute air tubes and blisters are formed. It may well be that some of them are the result of a sudden and simultaneous rushing together of water molecules around the crystal from all sides. This might result in the formation of closely contiguous parallel ledges, or laterally projecting outgrowths that are separated from each other during the initial impact by a narrow groove, or air space, but are soon bridged over by subsequent growth. Similar contiguous parallel growths occur frequently around the angles of very short columnar forms, and lend plausibility to this theory. Air spaces also exist within columnar forms, as noted by Hellmann and Nordenskiold. They seem to occur within such forms as hollow cup-like extensions, projecting perpendicularly within them from each of the ends of the crystals. Their presence is strongly indicated in some of the photomicrographs of such forms illustrating this article. (See Nos. 777 and 857.)

MODIFICATIONS OF FORMS OF SNOW CRYSTALS.

We now pass on to the study of the modifications that the typical forms undergo during their growth within the clouds. This aspect of our study is peculiarly fascinating.

I assume that the configurations of the exterior portions of the crystals surrounding the nucleus must depend largely upon the initial and subsequent movement, or the flights, upward, downward, or horizontally, of the growing crystals within the clouds. We must therefore make a careful study and analysis of the interior portions of the crystals, including the rods, dots, and lines outlining geometrical forms, that add so much to their beauty and interest. These interior details reveal more or less completely the preexisting forms that the crystals assumed during their youth in cloudland. Was ever life history written in more dainty or fairy-like hieroglyphics? How charming the task of trying to decipher them.

By close study of the photomicrographs, we find that the most common forms outlined within the nuclear portions of the crystals is a simple star of six rays, a solid hexagon, and a circle. The subsequent additions assume a bewildering variety of shapes, each of which usually differs widely from the one that preceded it, and from the primitive nuclear form at its center. Bearing in mind, however, the tendency of the crystals evolved within the upper clouds toward solidity, and the tendency of those from the lower clouds to form more branching open crystals, our task of deciphering the hieroglyphics, and of tracing thereby the probable flights of each individual crystal within the clouds, becomes much easier than might be anticipated.

Taking photomicrograph No. 821 as an example, we can picture with some certainty its various flights within the clouds during each stage of its growth. Star shaped at birth, it was probably carried upward by ascending air currents, and at some upper level assumed the solid hexagonal form that we see outlined around the star shaped nucleus. Having now become heavier, it probably descended, and acquired further growth at some lower level, such as that wherein it had its birth.

No. 831 tells a different story. If we may judge of its life history, as written within its face, it originated at a high altitude and completed its growth wholly at low levels.

Conversely, Nos. 920 and 850 each consummated the whole of its development within one cloud stratum, No. 920 in the lower and No. 850 in the upper clouds. In short, if the nuclear portion is surrounded by outline details indicating branch-like development, we assume that it acquired its branching additions at lower levels and consequently must have descended shortly after birth. Conversely, if the nucleus is surrounded by such details as constitute solid or compact additions, we may assume that it acquired these additions after being wafted upward into regions much higher in altitude than were those wherein its birth took place.

MODIFICATIONS OF FORMS DUE TO OTHER CAUSES.

As it is generally conceded that winds play an important part in modifying the forms of snow crystals, let us consider the probable manner in which they operate to accomplish this.

Aside from causing modifications by wafting the crystals upward and downward within the clouds to regions varying in temperature, humidity, density, etc., as previously noted, the winds probably cause modifications in other ways. Violent winds may prevent a perfect and orderly joining of the aqueous molecules, causing imperfections in the forms, or perhaps amorphous, granular aggregations.

Again, they may waft greater quantities of water molecules to one or more portions of a growing crystal, causing abnormal growth to take place around such portions.

More important still, violent winds often cause fractures to occur, especially as regards the branching forms and whenever, as must often happen, subsequent growth takes place around and upon such broken crystals, irregular, unsymmetrical forms result. Doubtless, we may attribute the origin of some of the odd oblong crystals (see No. 565) to the fact that crystallization sometimes takes place around and upon a long broken branch, or other long portion detached by fracture from some preexisting crystal. Other odd forms seem to owe their abnormal character to design rather than accident. Columnar forms and, in a less degree, small solid tabular forms, being relatively so much heavier and more compact than stellar and similar branching forms, are much less likely than these to be wafted about and to receive modifications due to wind action.

Among the other causes of modification of forms, we must mention the close proximity of two or more crystals during one or more stages of their growth. This close proximity while developing, would probably cause a greater growth of those portions of each contiguous crystal that lie farthest away from the crystal closely adjoining, and thus perfect symmetry would be impaired.

Considerable modifications of form are frequently due to the aggregation upon the crystals of amorphous or granular material, contributed by relatively coarse cloud spherules, particles of mist, or minute rain drops. Frail light, branching stellar and other forms are often rendered coarse and heavy by such additions taking place around and upon every angle of the crystals, so that they fall quickly to the earth.

Perfect crystals are frequently covered over and lines of beauty obliterated by such granular coatings. Granulation often proceeds to such a degree, and the true crystals are so deeply coated over and imbedded within it, that the character of the nucleus does not reveal itself, except under the closest examination. Such heavy granular covered crystals possess great interest for many reasons; they show when the character of the snow is due to the aggregation of relatively coarse cloud particles, or minute rain drops and not to the aggregation of the much smaller molecules of water, presumably floating freely about between them. They also offer a complete explanation of the formation and growth of the very large rain drops that often fall from thunderclouds and other rainstorms, if we accept the conclusion that such large drops result from the melting, or merging together of one or more of the large granular crystals. For many reasons (among which we mention the almost invariable presence of low cloud strata when granulation occurs, and the aggregation occurring on perfect crystals, while these are presumably within the low clouds, rather than the occurrence of such aggregations as a distinct identity by itself) we are led to infer that, as a rule, the heavy granular covered crystals are peculiarly a product of the lower or intermediate cloud strata.

The dependence of the granular forms upon the presence of the lower clouds, will be readily seen by consulting Table 5, showing cloud formation in connection with the occurrence of the various types of snow crystals. While most granular forms possess true crystallic nuclei, there is reason to suppose that they sometimes form directly from the particles of cloud or mist.

PROBABLE CHARACTER OF THE MATERIAL, AND MANNER OF JOINING THE MOLECULES OF WATER DURING THE FORMATION OF THE CRYSTALS.

This interesting department of our study is necessarily and largely suggestive in character, as no one has yet or, indeed, ever can actually see the extremely minute water particles rush together and form themselves into snow crystals. While it is true, in general, that snow crystals form within the clouds, yet it does not by any means necessarily follow that the true crystals are built up by the aggregation of relatively coarse cloud particles. Clouds form whenever the air is overcharged with moisture, and often exist for days and weeks together without depositing snow or rain. The individual particles of these clouds are probably frozen into the semblance of crystals when they experience the intense cold of the upper air. The cloud laden air currents that flow upward and outward within and around our great storms, plainly suggest that clouds are the dross or the unavailable waste of crystal building rather than the actual material out of which the true crystals are formed. We seem to have good grounds for assuming that the true snow crystals are formed directly from the minute invisible atoms or molecules of water in the air, without first assuming a coarse, intermediate state as cloud material. While it may be granted that possibly such relatively coarse cloud particles may possess attractive properties for one another strong enough to cause them to unite, yet it seems somewhat doubtful whether even this union could be accomplished in a manner so complete as to leave no trace behind in the interior structure of the crystals when such are examined under powerful microscopes.

The particles forming granular snow may be much larger than the common cloud particles, but may still be compared with them. When these unite together the dotted, stippled appearance of the resulting crystals denotes unerringly the imperfect joining of such particles and the noncrystalline character of the compound crystal. Cloud particles, while very minute, are yet individually visible to the naked eye when viewed under favorable conditions, appearing as a fine, dusty mass. As bearing upon this point, it may be noted that the crystallization of a mineral in solution, such as alum or saltpetre in water, is not first preceded by the aggregation of its molecules into a coarse intermediate cloud-like state, but is accomplished by the direct aggregation of the ultimate molecules of the substance.

CHRONOLOGICAL LIST OF SNOWSTORMS AND PHOTOMICROGRAPHS.

We now pass to the analysis of the photomicrographs of individual snow crystals secured during the remarkably favorable winter of 1901–2. The number of individual crystals is very considerable, and the beautiful or odd and interesting ones form a large percentage of the whole number; many of them deserve special mention and prolonged close study. Considering them in chronological order, the snow forms of the late November blizzards first demand our attention. Many interesting and beautiful crystals were observed on November 25, 26, 27, 28, and 30. (See Nos. 700 to 737.) It is very rare, indeed, that perfect forms occur during so many consecutive days.

1901.

November 25.—Photomicrographs Nos. 700–703 are examples of long columnar forms, some slightly granular, called in Scoresby's classification "spiculæ." No. 702 presents one of the oddest and most remarkable crystals ever photographed. By some extraordinary combination of circumstances, occurring during the latter stages of its growth, the aqueous material of which it was built was apparently brought to it from one direction only, thus greatly augmenting the growth of all parts of the crystal facing in that direction. The general weather conditions and the serial numbers of the photographs of types of crystals are given in Table 1. The center of the storm was over Halifax, Nova Scotia, and the central-western portion was over our locality. The predominant types of crystals were long needle-shaped columnar forms, associated with granular covered tabular forms. Stratus clouds and low detached nimbus covered the sky and the higher cirro-stratus were probably superimposed on them.[3]

November 26.—Continuation of the same storm. Crystal types mostly tabular, both solid and branching, associated sometimes with doublets; in general the crystals were of large size and open structure. The central-western portion of the storm was still over our location, and as the day advanced and the cold increased, the crystals became progressively more and more compact in structure. Some eighteen different forms, 704–721, were photographed on this date and among them, two, Nos. 716 and 718, are very choice and beautiful. These exhibit a rather unusual and notable peculiarity, viz, a plain or delicately lined nucleus contrasted with a brecciated, boldly designed external portion; the latter approaching granulation, as though the nuclear portion was formed in clouds that were less dense and humid than those in which the outline portions were added. No. 712 is a fine example of the star shaped form of crystal, exhibiting an extreme and slender development of the six primary rays without any corresponding development of the secondary rays. Many of the branching forms of this date were observed to be broken as though by the action of violent winds.

November 27.—Continuation of the same storm. Photomicrographs Nos. 722–726. Crystal types small, granular, and irregular, succeeded later by medium sized, rather compact crystalline tabular forms and a few doublets. Nos. 722 and 723 are charming patterns in snow architecture. The crystals of this date dropped from the clouds of the western edge of the preceding prolonged storm of the 25th and 26th.

November 28.—Rather thin stratus clouds lying above thin detached nimbus masses. These last belated cloud legions of the storm of November 25, 26, and 27 furnished a few small but perfect snow crystals. (See Nos. 727–729.)

November 30.—Clouds rather thin stratus and nimbus. Crystal types wholly tabular of both open and stellate structure. (See Nos. 730–737.)

Among the seven forms of this date we find much to admire in the perfect beauty and symmetry of Nos. 731–734. The beautiful starfish design exhibited by No. 735 is somewhat rare. It is noteworthy that Prof. S. Squinabol, of the University of Padua, made drawings of a snow crystal found in Genoa in 1887 that closely resembles this latter one. The star with long slender rays deposited during this same storm, on November 26 (see No. 712), also closely resembles one (No. 4) figured by Squinabol in his work La Navigata. No. 737 is another form that closely resembles some of those secured by other observers; it is very similar to some of the photomicrographs secured by Dr. Neuhaus, of Berlin, during the winter of 1893, and published in Dr. G. Hellman's work.

[3] The forms of the snow crystals seem to show that they must have fallen from high cirro-stratus through the lower stratus to the ground, growing in complexity and size as they fell. When the upper clouds are hidden we may judge whether they were present by the nature of the snow crystals.

December 4.—Clouds stratus, with detached running masses of low nimbus; probably high cirro-stratus above these. The western portion of this cold southern storm passed over our locality and furnished a great number of forms of snow crystrals that were in general rather small and compact; as will be seen by consulting the photomicrographs Nos. 738–765, many of them are rarely beautiful and symmetrical. The snows of this storm exhibited great variety; solid and branching tabular forms, doublets, and columnar forms were each plentiful.

The rare beauty of Nos. 745, 748, 758 will appeal to all; crystallographers will find much of interest in Nos. 740, 749, 752, 754. One can but wonder how No. 740 acquired its two abnormally large points, and No. 752 its strange addition projecting perpendicularly. This singular addition, an exact counterpart of one-half of the basal tabular crystal upon which it rests and from which it projects nearly perpendicularly, shows but imperfectly in the photomicrograph as a dark, broad, shadowy line stretching centrally across its greatest length. Perhaps the most remarkable thing about this projecting addition is its deviation from the perpendicular. No. 562½, of January 31, 1901, portrays a rare crystal, possessing two vertical additions projecting in opposite directions.

December 5.—Thin nimbus clouds on the west edge of the storm afforded minute granular crystals and solid frost-like tabular types. No. 766, secured during the forenoon, is the only photomicrograph taken on this date.

December 15.—Clouds stratus and nimbus, probably upper cirro-stratus above them. This storm afforded a few perfect snow forms and many unusual odd forms. (See Nos. 767–774.) The attachment to No. 769, like a bay window, deserves especial study, and we can but wonder whether this singular addition was the result of the merging together of two distinct forms. The germ crystals and needle-like forms depicted in No. 767 are worthy of study. The general character of the crystals of December 15 is best expressed by the word *diversified,* as columnar and needle-shaped forms, solid and branching tabular forms, and doublets were at one time or other present in the snowfall. Many of the doublets were connected by an extremely long slender columnar form. The snowfall was preceded in the early morning by rain and hail, and relatively high temperature.

December 25.—Dense stratus clouds, with detached masses of low nimbus; probably cirro-stratus above them. The west-central portion of the widespread storm of this date furnished a great variety of snow types, among which we find many most interesting forms. (See Nos. 775–779.) Although lacking in beauty (except No. 779), they are of great value to the crystallographer and student. We wonder how No. 775 came to acquire its three abnormal points; they seem to be the result of design, not accident. No. 778 presents us with another crystallographic problem, even more difficult to solve. How came the triangular nucleus to gather around itself such peculiar and irregular additions? No. 776 is also most unusual. We can offer no explanation as to how the delicate, beautiful, and unique central details of No. 779 were acquired. No. 777 is, if possible of even more interest than the others. The beautiful and perfect columnar forms seen in this crystal exhibit unmistakable evidence of their previous hollow cylindrical character; the large cavities outlined plainly within each end seem to have been covered or bridged over with outline growth. G. Nordenskiold and other observers have asserted that such cavities sometimes exist within columnar forms; this crystal gives a striking proof of the correctness of the earlier observations. Such large cavities, however, seem to be rather rare; this is the only example I have ever observed of one so large and so plainly indicated.

1902.

January 1.—The extremely cold and nearly cloudless skies furnished the very minute frost-like forms to be seen in No. 779½.

January 5.—The clouds of the western edge of the storm of January 5, 1902, furnished a large and splendid set of forms. The general character of the crystals is shown in the photomicrographs Nos. 780–797. Nos. 783, 785, 786, and 788 are exquisite examples of the frail, branching type of crystals, while Nos. 793, 794, and 795 are fine examples of more solid forms. No. 785 is so rarely beautiful that it is the peer of any in my whole collection. No. 796 exhibits the slight granular deposit that at times partly covered some of the forms, and No. 781, whose nucleus is wonderfully beautiful and perfect, exhibits irregularities in outline apparently due to a more rapid growth of the secondary rays from two of the main rays located opposite to each other. It is rare, indeed, that large, frail, branching forms come to us so symmetrical and unbroken, as did many of these. No. 792 of the series needs especial mention. By close inspection it will be seen that its nuclear portion was built outwardly by a succession of alternate abnormal growths taking place from opposite directions, as though by successive impacts of crystallic material, first upon one-half and then upon the opposite half of the growing crystal. The combination of circumstances conducing to such alternate and opposite outgrowths must indeed be remarkable. The almost perfect symmetry assumed by many of the frail, branching forms of this series greatly resembles in ideal perfection the beautiful drawings of the English observers, Scoresby and Glaisher, and leads us to think that, contrary to the conclusions reached by some recent observers, such drawings may be quite true to nature and more reliable than we have been led to suppose.

January 10.—Clouds cirro-stratus, stratus, and nimbus. The southwest portion of the storm of January 10 deposited a unique collection of forms. (See Nos. 798–808.) The forms were rather small and compact; many odd triangular forms and oblong crystals were interspersed among the more common columnar and compact tabular forms of this snowfall. No. 805, or the oblong one, with an addition projecting abnormally, is similar to No. 752 of December 4, 1901. (See that description.) No. 800 is another rare form. Nos. 801 and 808 are two charming examples showing triangular development. If we may judge by the interior nuclear figure of 801, it was at some period of its growth perfectly triangular in outline. No. 807 shows the granular deposit that collected upon the crystals during the late afternoon, after low nimbus clouds had thickly covered over the sky.

January 12.—Clouds obscured by heavy snowfall. A long series of magnificent snow crystals was secured from the clouds of the southwest-central portion of the storm or blizzard of January 12. (See Nos. 809–833.) The snow, as usual whenever it comes from the central-western portion of a storm, consisted of a great variety of types both columnar and tabular, but as the storm's central portion passed farther to the east, during the afternoon of January 12, the columnar forms ceased to be deposited. Nos. 811, 818, 821, 822, and 826 possess much beauty of design and perfection of form. No. 826 exhibits the delicate scalloped hexagonal-shaped design, which we assume to be not a preexisting outline form, but as produced by additions to and upon, but not around, the crystal after its development had proceeded beyond the scalloped addition. Nos. 815 and 833 show abnormalities on one-half of each of these forms that render them very interesting; in No. 812 we see an almost perfect imitation of many of the long tabular crystals of hoar frost. No. 828 is unique in design and is especially interesting by reason of the very minute dotted nuclear features.

January 13.—Stratus and nimbus clouds. Possibly high strata present during the forenoon. A continuation of the preceding storm furnished on this date the interesting set of forms, Nos. 834 to 838. The crystals were wholly of the tabular form with the exception of a few granular forms and were of medium size. The great beauty of No. 837, and the unique and choice design exhibited by No. 836, will appeal to all lovers of the beautiful. The relatively intense degree of cold prevailing while these were formed is worthy of note.

January 19.—Clouds low nimbus; possibly thin stratus above them. The low lying clouds of the western portion of the rather small storm of January 19 deposited the charming examples of the frail, branching forms seen in Nos. 839–842. No. 842 represents quite correctly the general character and outlines of these types from low clouds; during relatively mild temperatures they are common to the low clouds of both local and general storms. Some of these forms bear a striking resemblance to certain of the photomicrographs of snow crystals secured by Herr A. A. Sigson in Rybinsk-Russia during the winter of 1894.[4]

January 21.—Clouds high cirro-stratus and thin detached nimbus. The southwestern portion of the storm of this date, accompanied by strong southeast winds, furnished the photomicrographs numbered 843–848. No. 845 shows a perfect symmetry and beauty. Nos. 844, 847, and 848 are chiefly valuable on account of their oddity. The broken, irregular contour of No. 844 tells eloquently of the severe winds it encountered somewhere during its flight from cloud to earth. The nuclear portion of No. 848 bears evidence of fractures and subsequent recrystallizations. No. 843 exhibits forms that presumably originated within the upper cirro-stratus clouds that covered the sky during this snowfall. Some of these crystals approach as near to the pyramidal form, which Scoresby asserts he saw on one occasion, as do any I have ever observed or photographed.

February 7.—Clouds cirro-stratus, a few nimbus. This storm contributed Nos. 849–856, including a few choice forms, of which Nos. 850, 854, 855, and 853 are exquisitely beautiful. The acorn design exhibited by No. 854 is quite unique, and the interior details within its outlines are faultless. The germ crystal, shown in No. 849, quite correctly portrays the character of the first crystals that fell from the high cirro-stratus clouds of the southwest portion of this prolonged storm, before the presence of lower clouds enabled the crystals to undergo a more complete and complex development. In addition to those mentioned above, the broad, leaf-like additions to No. 851 are worthy of mention.

February 8.—Clouds stratus and nimbus; probably high cirro-stratus superimposed above them. A continuation of the storm of February 7 and its increase in rigor furnished the large and charming set of photomicrographs, Nos. 857–887. This set comprises more forms than were ever before secured by me from any one storm. They fell from the clouds of the southwestern portion of the storm. Both columnar and tabular forms were common throughout the snowfall. Nos. 857, 858, 860, and 861 are beautiful and very interesting examples of the columnar type of crystals; Nos. 862, 863, 864, 866, and 867 are beautiful examples of stellate, tabular forms which partly replaced the columnar forms as the storm progressed. The beautiful branching crystals, Nos. 881 and 883 portray, in general, the characters of the forms that successively replaced both the solid tabular and columnar forms, as the western edge of the storm came nearer. Among other numbers possessing rare interest is No. 859 which presents us with another example of a crystal possessing one small stunted point. No. 884 exhibits a most interesting phase of crystallic evolution; it is composed of four contiguous points, or rather portions, and two somewhat stunted portions, also similar to each other, but differing widely from the other four. No. 885 shows two overlapping additions to two of the points, thus rendering it of more than usual interest, and presenting us with another seemingly unsolvable problem in crystallography. The numerous small but often-recurring additions by which the crystals continue their growth during intense cold are strikingly exemplified in Nos. 864 and 867. For a somewhat brief time during the snowfall many forms similar to Nos. 872 and 873 were common; associated with these for a brief time were many examples of solid tabular forms, possessing radiating interior designs similar to Nos. 869 and 874. No. 875 is a fine example of the star shaped forms; it exhibits a rather extreme and slender development of each of the primary rays, similar to No. 712 of November 26, 1901. A phenomenon that has been quite frequently observed by me, but rarely if ever mentioned by other observers of snow forms, is the occurrence of colors of red or green, or a combination of both, within the well-defined nuclear portions of certain tabular forms. These colors can usually be seen only by reflected light when the crystals are viewed obliquely from a certain angle; very rarely also they are seen by transmitted light. A number of the more solid tabular forms, comprising a part of the snowfall of February 8, exhibited these colors in a remarkable degree, some of them even by transmitted light. No. 859 is one of the latter; the red, green, and purplish hues were plainly discernible within its nuclear portion, while the focussing of the crystal was in progress. Other examples of individual crystals exhibiting this most interesting phenomenon are Nos. 863 and 866 of this series. The colors were confined to the light nuclear portion of No. 863, and to the light colored star-like rays emanating from it. As regards No. 866, the slightly dark plain portions, outlining a hexagonal figure immediately surrounding the delicate long-rayed nuclear star, were of a beautiful green color, when seen at a certain angle by reflected light. The colors seem to be the result of some peculiar arrangement of the aqueous molecules of the nucleus or central portion immediately contiguous thereto; they appear only in solid, or stellate tabular forms, i. e., those having a well-defined solid tabular nucleus, and are quite frequently met with in some snow falls while they are totally absent in others.[5]

Another interesting peculiarity pertaining to some of the forms of February 8 (and also to a few of those of other dates, see Nos. 837, 744, and 822) is the appearance within them of concentric circular lines or rings encircling the nuclear portion. A study of these curves was made by A. W. Waters[6] in 1877. He called them not inaptly meandering lines, ascribing their formation, doubtless correctly, to a partial melting of the forms by entering a relatively warm air current, and to subsequent recrystallization around the rounded partly melted angles or points of the crystals.

February 10.—Clouds low nimbus and rather thin stratus. (See photomicrographs Nos. 888–896.) The storm of the 7th and 8th continued during the 9th and until noon of the 10th, and furnished, from the clouds of its extreme western edge, many exquisite designs. (The forms collected on the 9th, presumably deposited from near the storm's center, were imperfect or covered with granular accretions.) Nos. 888–896 give ample proof of the beautiful designs of the crystals from this portion of the storm. In addition to the exceptional beauty of the intricate design of No. 890 it exhibits such remarkable symmetry in its arrangement that it is entitled to rank with the finest of this and other winters.

It is worthy that many of the forms are filled in with a multitude of internal details and the coincidence of this feature with relatively low temperatures is once more established.

February 13.—Clouds high cirro-stratus. Photomicrographs Nos. 897–900. This snowstorm was accompanied by low temperatures and evolved the characteristic cold weather types of

[4] See Hellmann in Meteorologische Zeitschrift. 1894. Vol. VIII, p. 281.

[5] This must be an illustration of the colors of thin plates.—*C. A.*

[6] See Hellmann Schneekrystalle, p. 59.

crystals, i. e., solid columnar and solid tabular forms. Examples of the latter are shown in Nos. 897–900. No. 900 is a charming example of the solid tabular type.

February 17.—Clouds high cirro-stratus, also low clouds during latter part of day. Photomicrographs Nos. 901–905. The high cirro-stratus clouds, accompanied by low temperature, that marked the beginning of the storm of February 17 and 18 furnished the usual small, compact, solid columnar and solid tabular forms so common with each. The rapid rise in temperature, and the subsequent formation of lower cloud strata as the storm center approached our location, caused a gradual progressive metamorphism in the character of the forms. Nos. 901 and 902 are typical of forms evolved near the storm's northeast edge, while Nos. 903 and 904 exhibit those prevailing during the afternoon of February 17. No. 904 is very beautiful. No. 903, which is but a central section of a crystal, portrays the perfection of the nucleus contrasted with the broken unsymmetrical exterior portions of the crystal, a peculiarity common to many of this date.

February 18.—Clouds unknown. Photomicrographs 906–922. A continuation of the storm of February 17 brought the central-western portion of this storm over our locality and the somewhat dense clouds of this portion of the storm furnished a large and charming set of forms. The forms, mainly tabular, exhibited both close and open structures, as shown by Nos. 910 and 920, respectively. There were many twin crystals in the early morning, similar to No. 19. No. 920 is exquisitely beautiful in outline, surpassed by few, if any, in our whole collection.

February 19.—Clouds were low nimbus, probably higher stratus present during the early part of the day. In the morning the crystals were small granular balls; these were succeeded by small granular somewhat solid tabular crystals; these in turn were followed by tabular forms free from granulation; during the afternoon the tabular forms of closer structure were replaced by crystals of open structure. As the last belated cloud legions of the prolonged storm of February 17 and 18 were passing overhead, during the forenoon of February 19, they contributed a few more choice examples of snow crystal architecture, as souvenirs of the skill of the Divine Artist, and these may be seen in Nos. 923–933. The design within the interior of No. 929 is unique and choice.

Columnar forms were missing among the snows of this portion of the storm, but granular snowballs (roundish granular snow) were somewhat common.

March 19.—With the storm of March 19, the snow crystal season of 1902 closed, yet even this belated storm furnished its quota of new and choice designs. (See Nos. 934–938.) The bold but graceful design exhibited by No. 935 is well worth study; the perfect symmetry of Nos. 936 and 937 appeals to our artistic sense and causes the eye to linger long upon them. The clouds on this date consisted mainly of cirro-stratus and stratus; detached low nimbus also present, sometimes thinly, at other times thickly, except during the early morning. The photomicrographs show various types of snow crystals; in the morning minute columnar and frost-like forms predominated; during the day tabular forms predominated, but there were at times doublets and long needle-shaped forms with some granular forms. Doublets were connected by extremely long columnar bars. In the afternoon large open fern and stellar forms appeared.

In concluding this mention of individual forms, it is worthy of note that, as during previous winters, occasionally single individual crystals, and more rarely larger numbers of such, produced during the storms of this winter, resembled closely, in outline or interior details, or oddity, one or more of the individual forms found among the snows of previous winters. The recurrence of similar types, after perhaps long intervals of time have elapsed, is a phenomenon of great interest.

It may be worth noting that by the addition of over 200 plates during the past winter, the number of individual photomicrographs of crystals in our collection is brought up to somewhat over 1000, no two of which are alike. This completes also our seventeenth year of photographic work among the snow crystals.

In view of this large collection, each individual crystal of which varies in one or many particulars from any other, the question now naturally arises: Is there no limit to the number of distinct forms, or may we assume that, if our study be sufficiently prolonged, there will come a time when new patterns will rarely or never be found, most of the designs being merely reproductions or duplicates of those already photographed? A partial answer to this query seems to be indicated by the vast number of new patterns that were obtained from the past winter's storms, greater than any previous single winter has furnished. This fact, coupled with the certainty that the number of individual crystals that go to form the snowfall of even one storm, is so vast that one, or many observers, may never hope to find and see anything more than an absolutely insignificant fraction of the whole, leads us to the conclusion that, during all future time and so long as there shall be observers to search for them, new designs will continue to be found to delight the eye with their beauty.

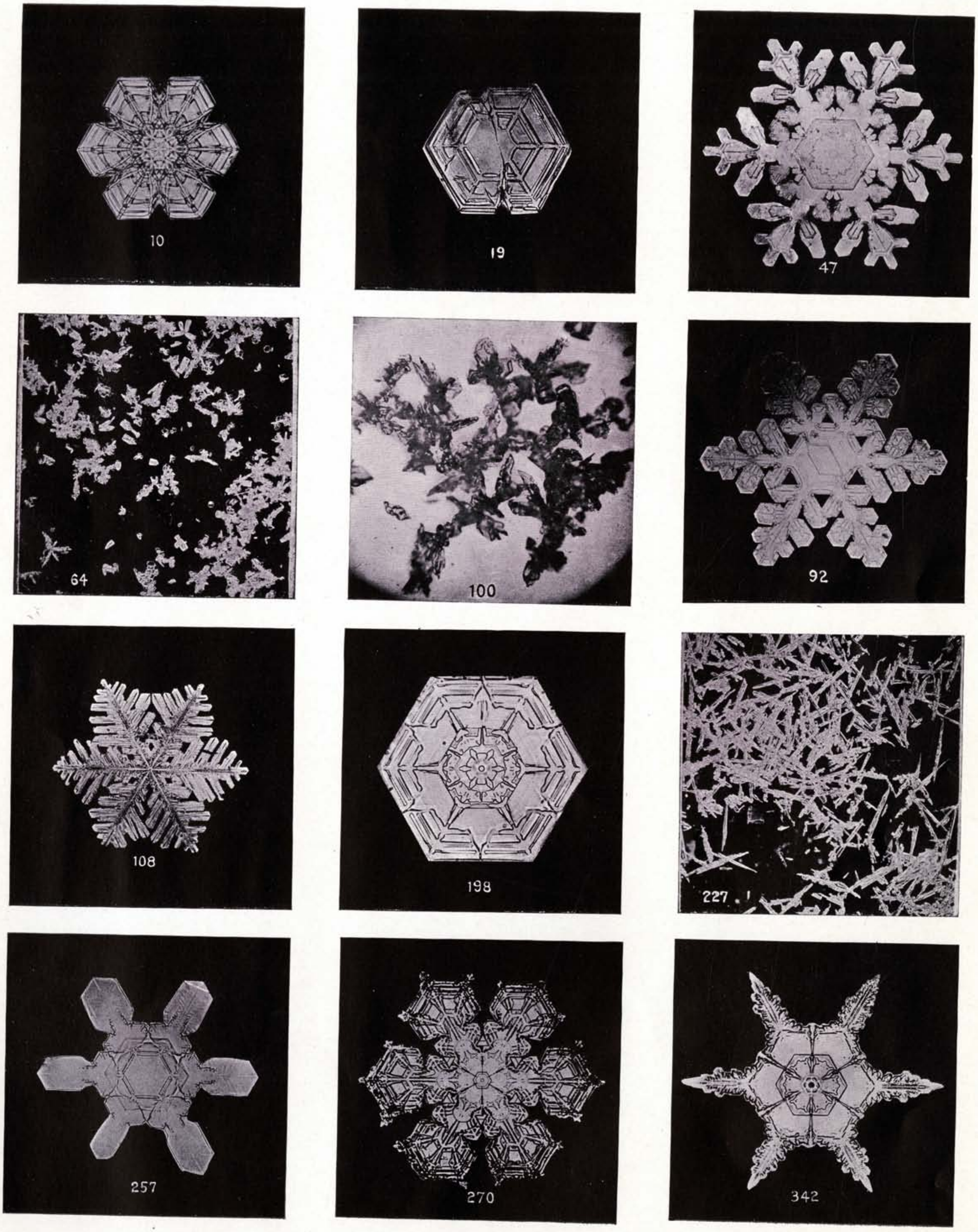
Another interesting thought that arises is: That it is extremely improbable that anyone has as yet found, or, indeed, ever will find, the one preeminently beautiful and symmetrical snow crystal that nature has probably fashioned when in her most artistic mood.

In closing, it seems hardly necessary to add that this most charming and delightful branch of nature study is as yet at its beginning; it still possesses the charm of novelty; many of its problems are unsolved, and many will find its pursuit a source of great pleasure and instruction.

NOTE.—The photomicrographs above referred to are reproduced by the half tone process on the accompanying twenty-two plates, showing the crystals as magnified about twenty diameters.

○

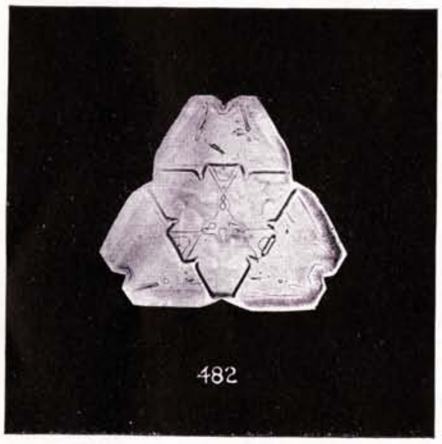
Photomicrographs of Snow Crystals.



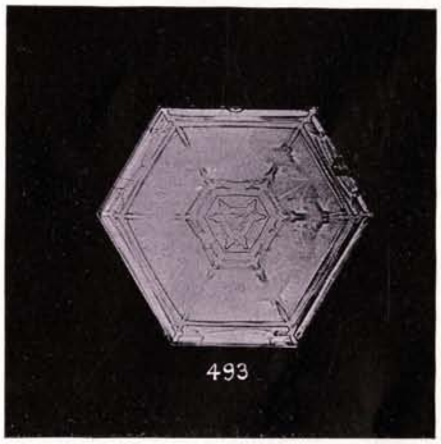

359

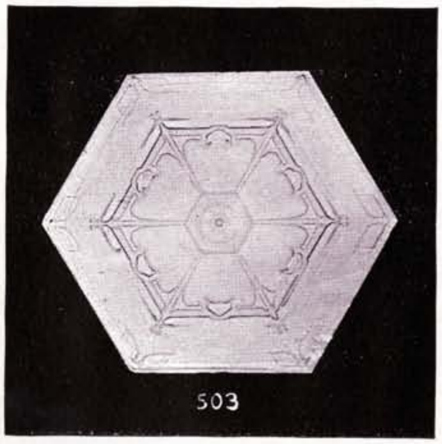

405


433

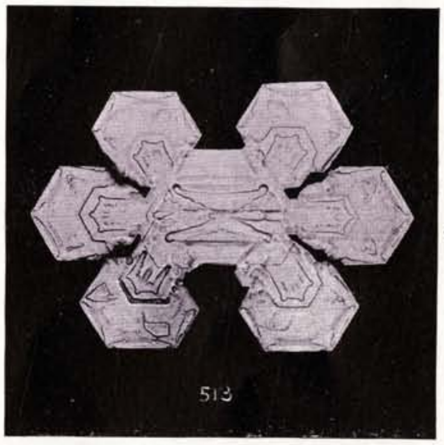

482

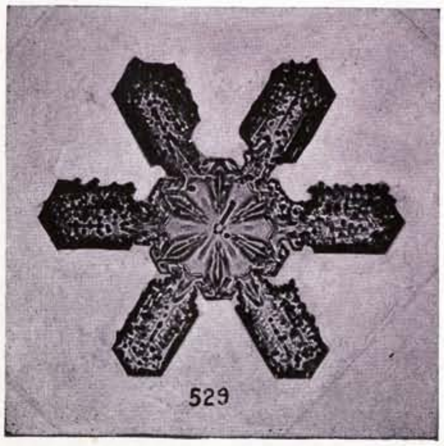

488


493

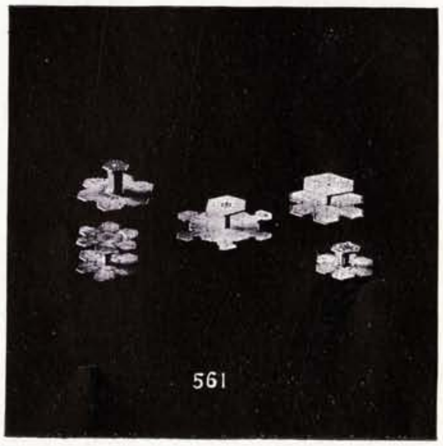

503


504


513

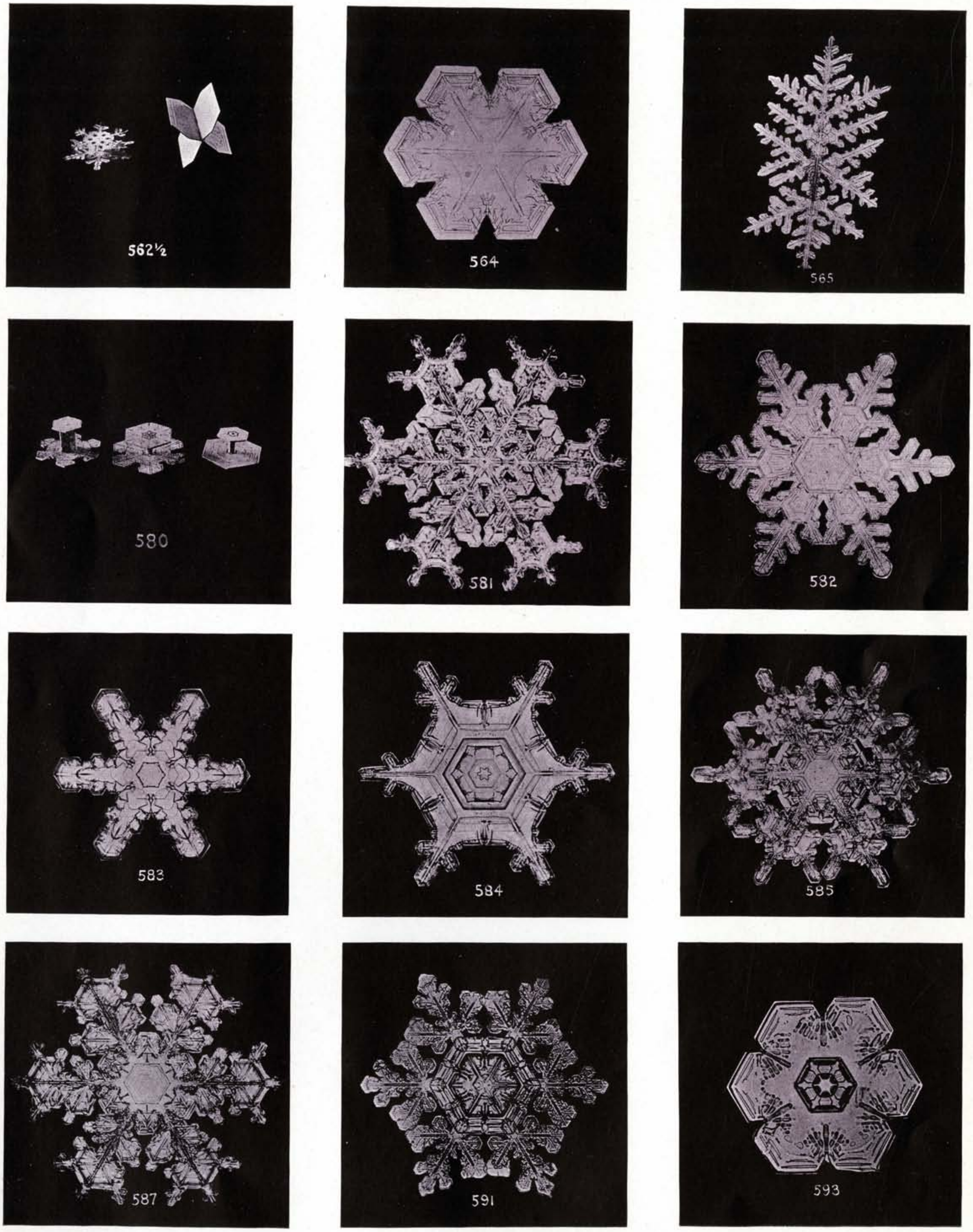

529


547


561

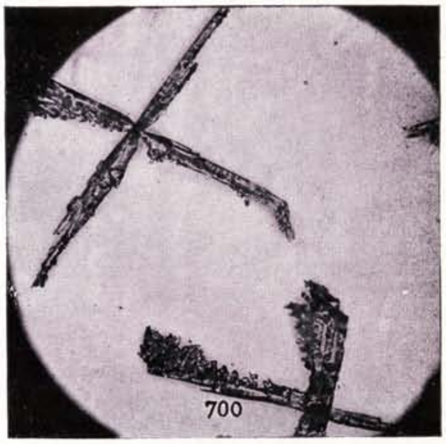
Photomicrographs of Snow Crystals.

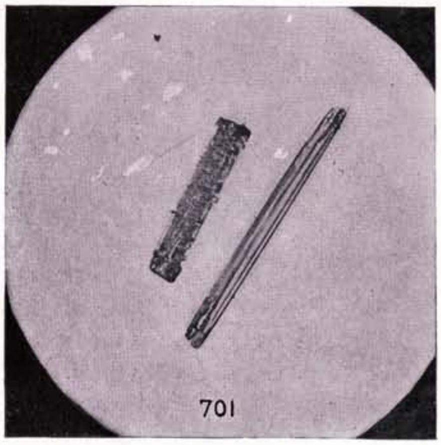
Plate III.



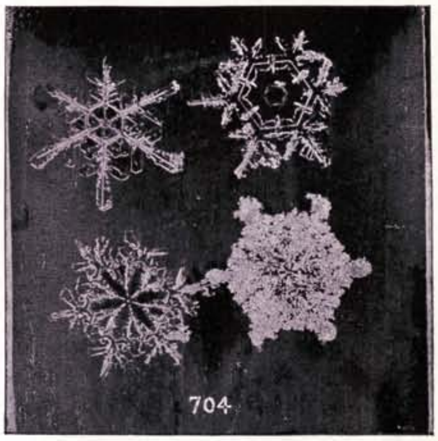

594


598


700


701

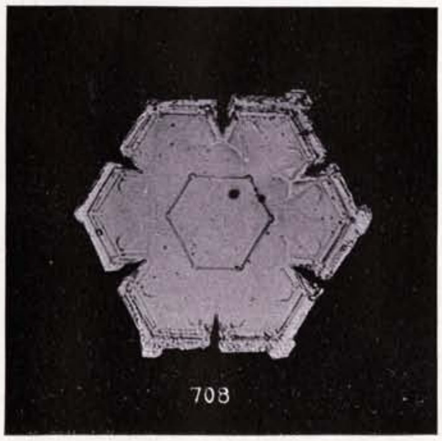

702

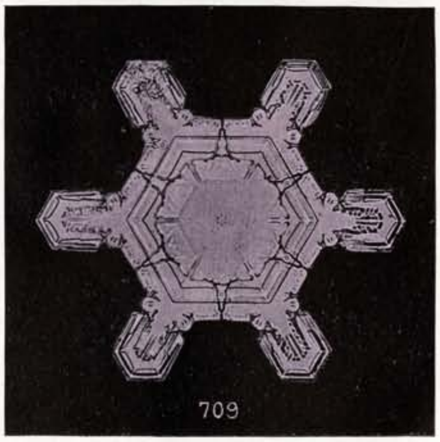

704


705

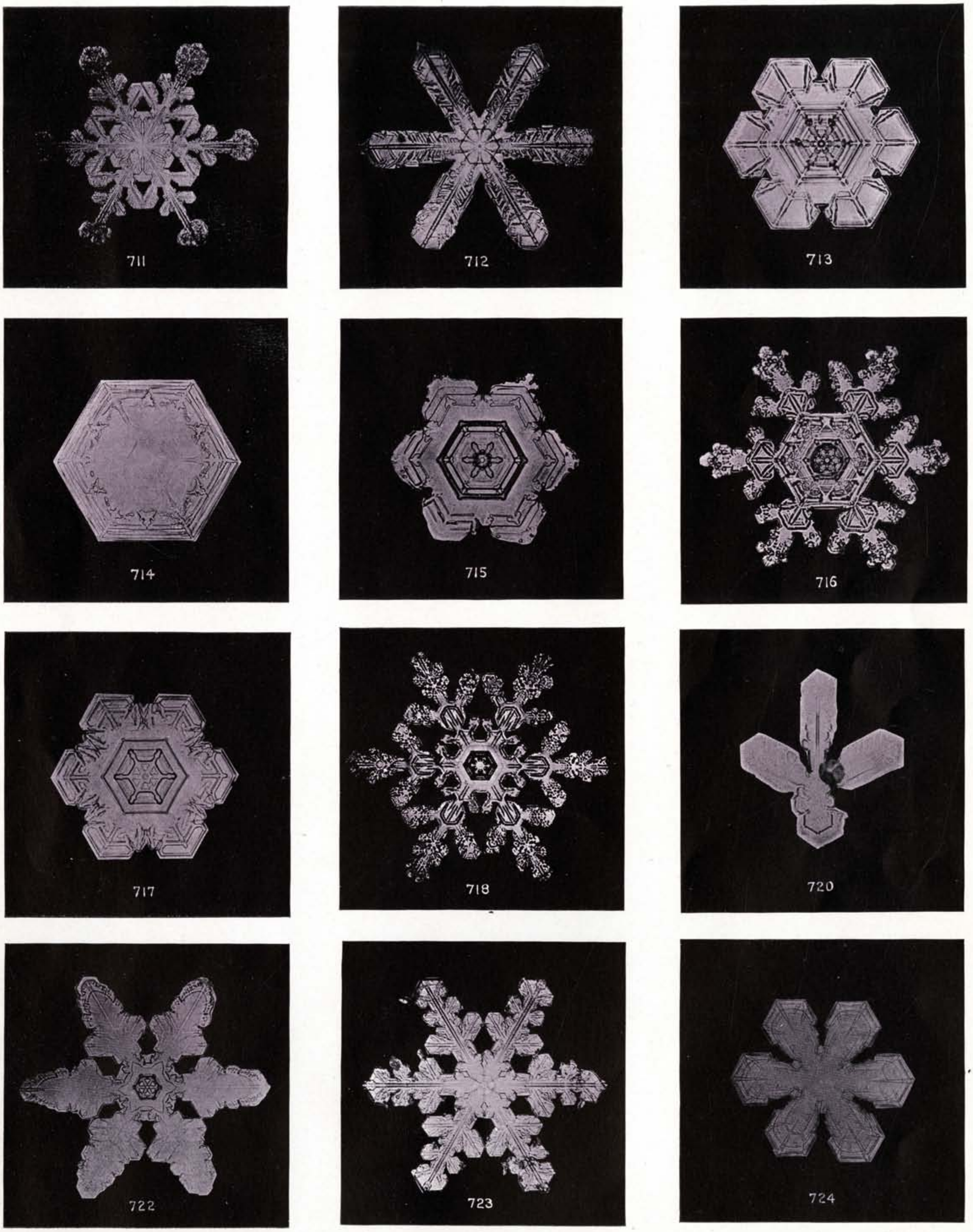

706


707

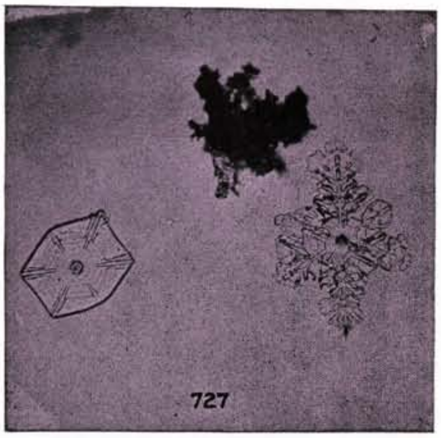

708

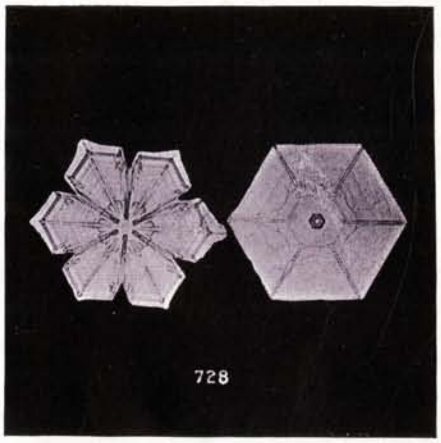

709


710


711
712
713
714
715
716
717
718
720
722
723
724


725


727


728


730

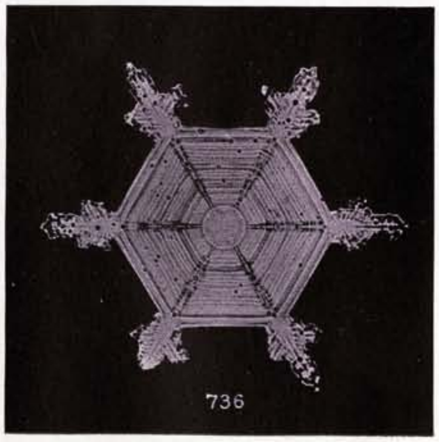

731


732


733


734


735


736


737


738


739


740

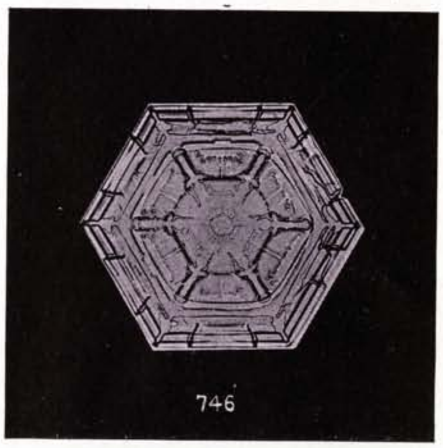

741


742


743


744

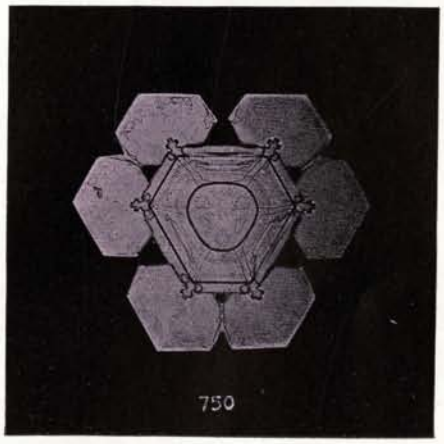

745

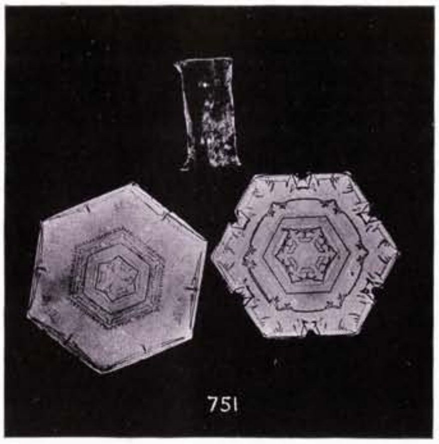

746


747

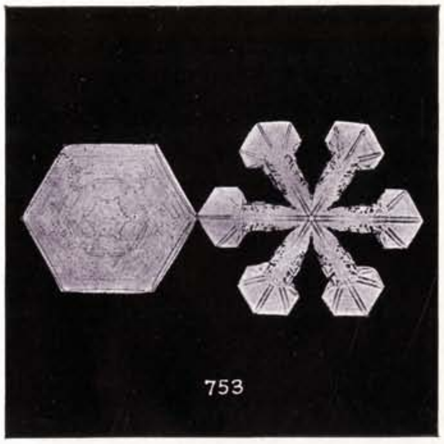

748


749


750


751


752


753


754


755

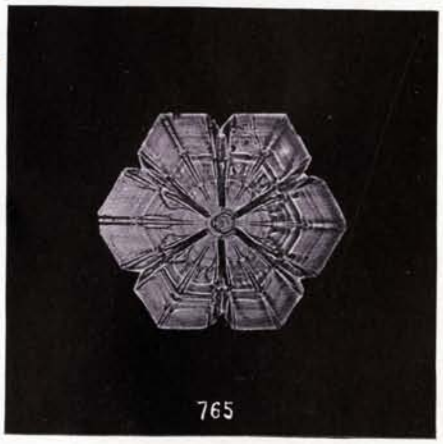

757

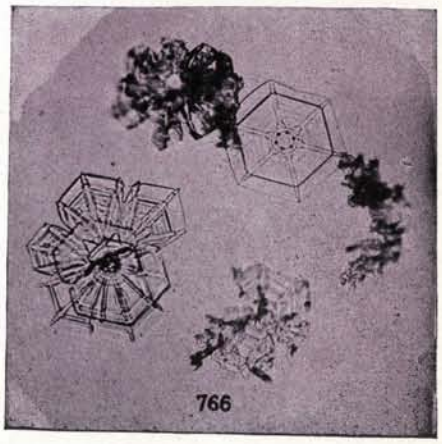

758

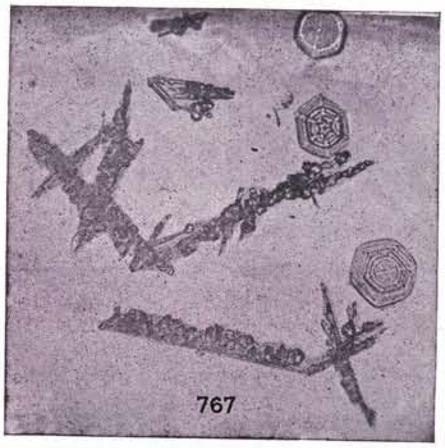

759

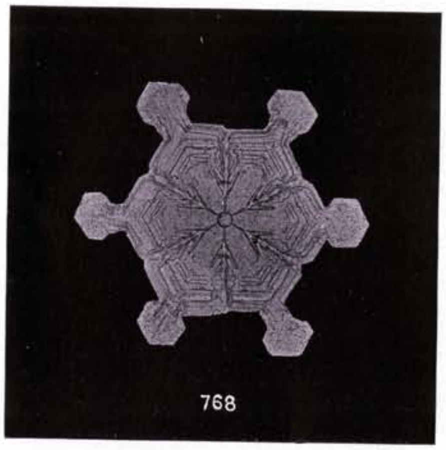

760

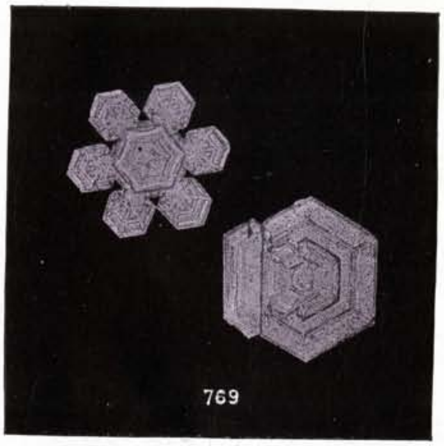

761


765

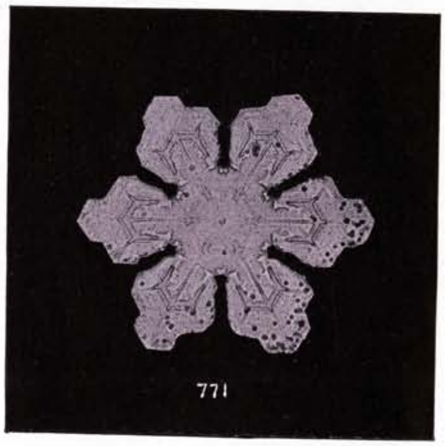

766

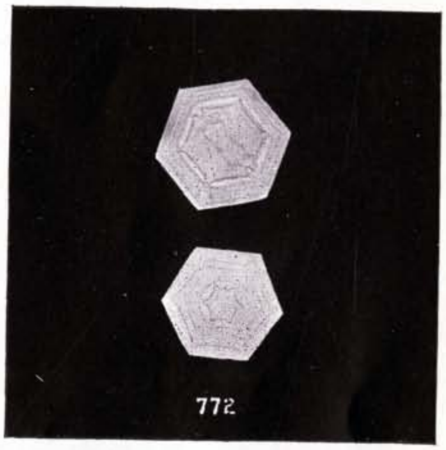

767


768

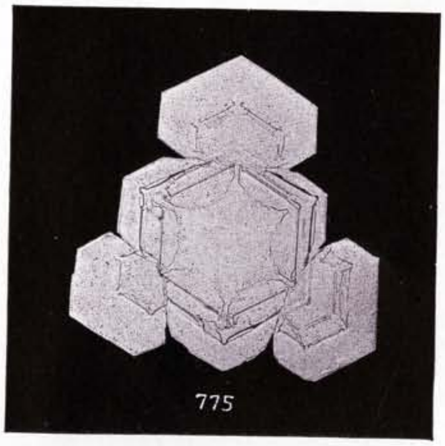

769


770

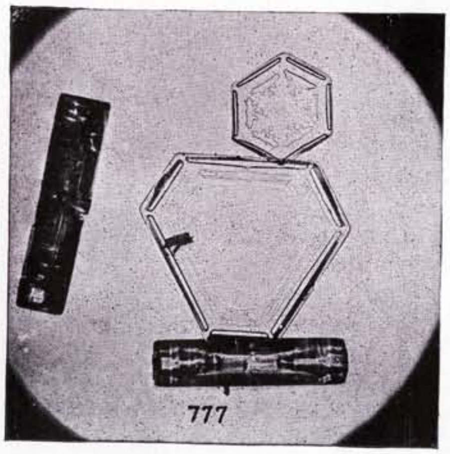

771


772


773

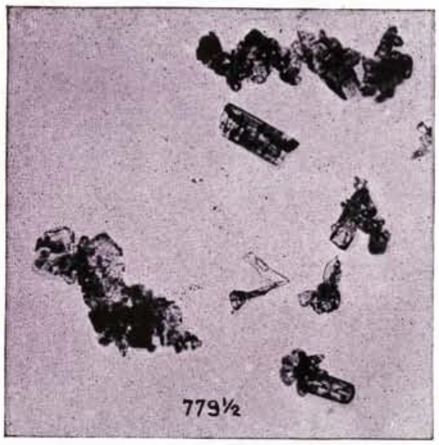

775

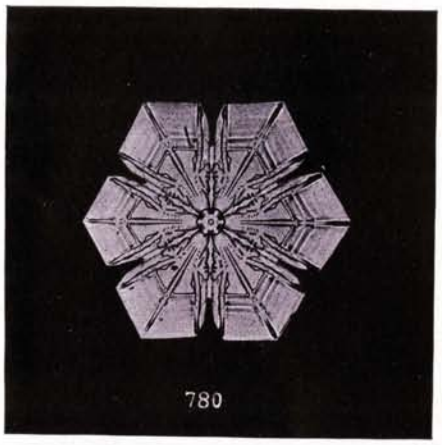

776


777


778


779


779½


780

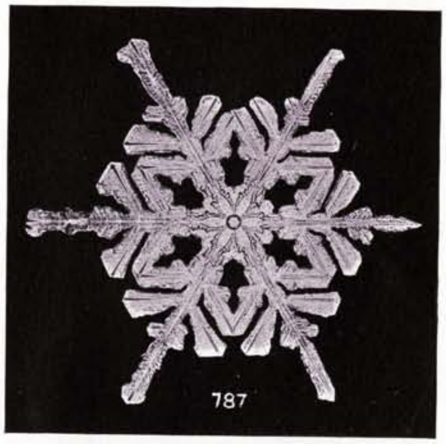

781


783


784


785


786


787


788


789


790


791


792

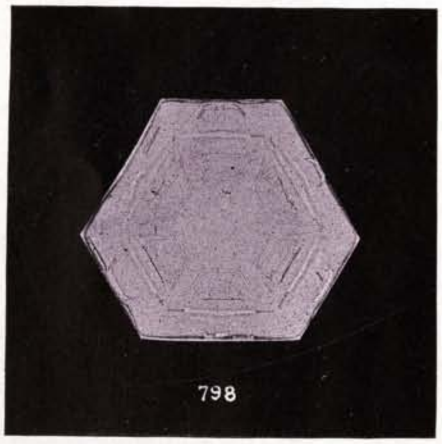

793

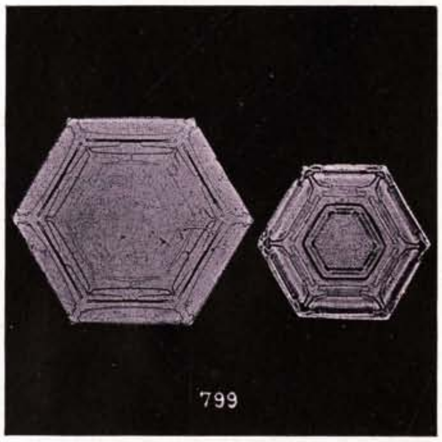

794


795

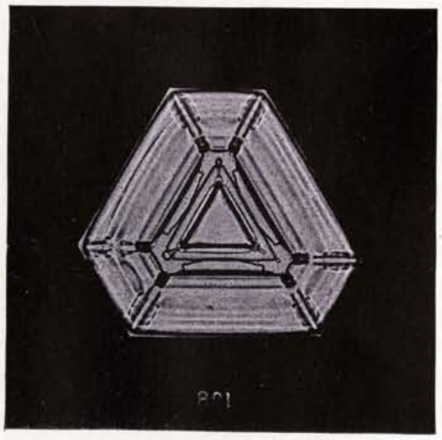

796


797

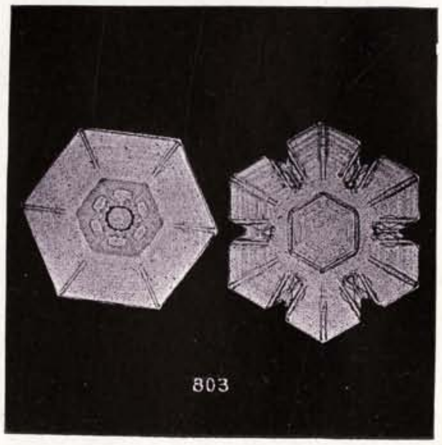

798

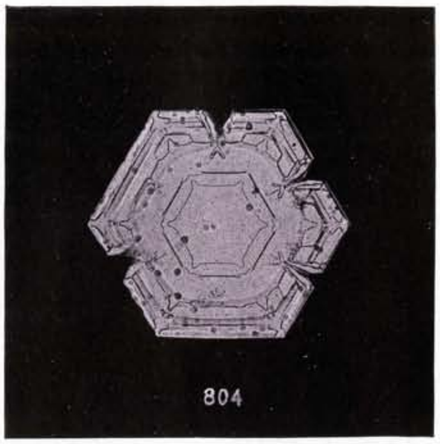

799

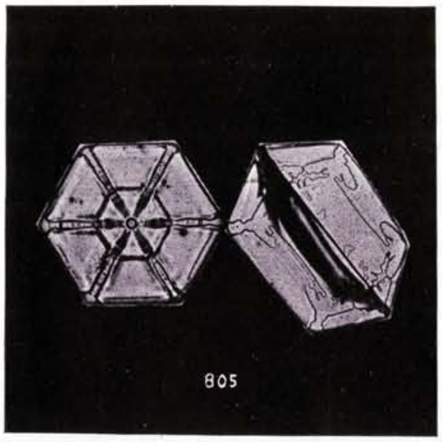

800

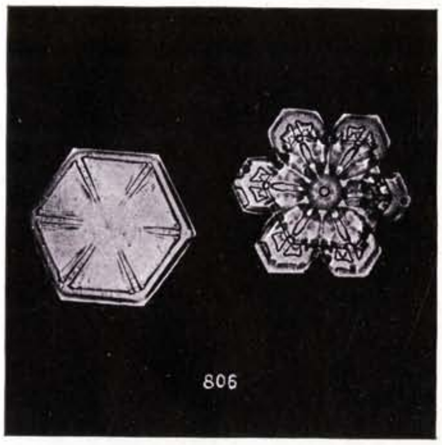

801

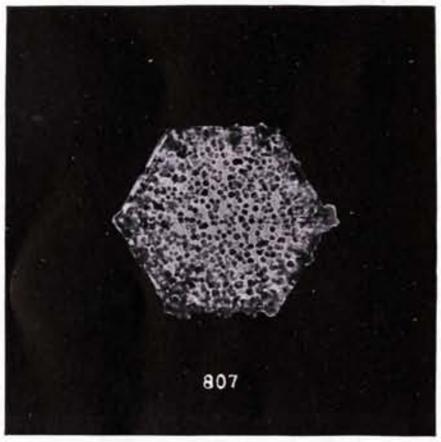

802

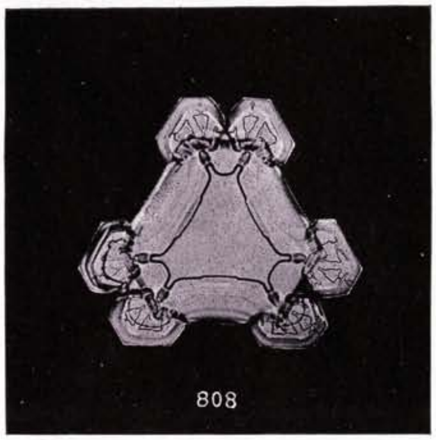

803


804


805

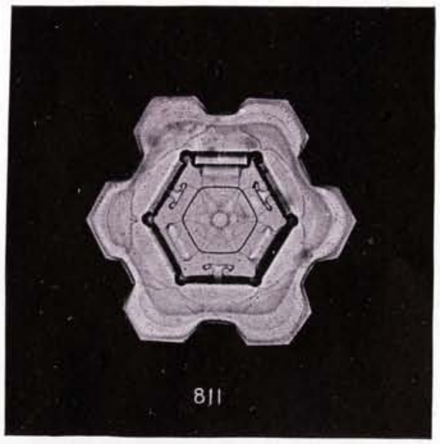

806


807


808


809


810

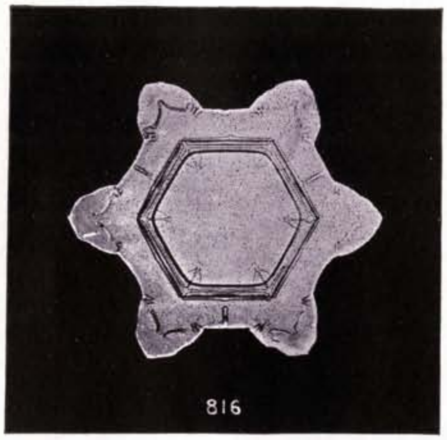

811


812


813


814


815

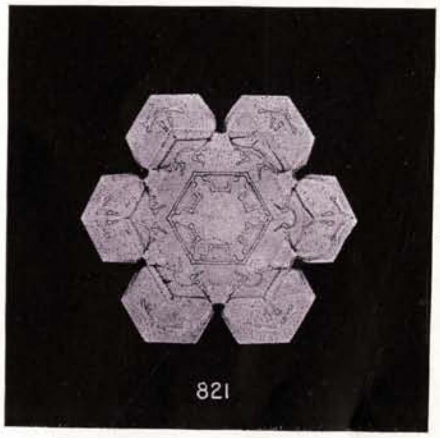

816


817

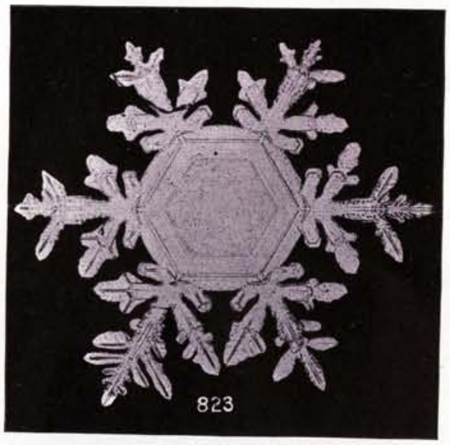

818

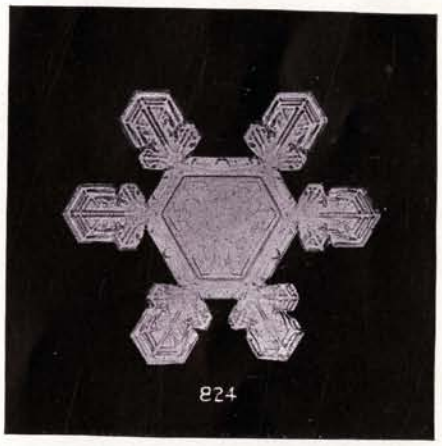

819


820


821


822


823


824

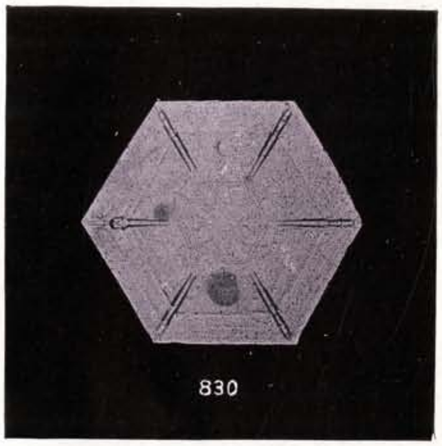

825


826


827


828

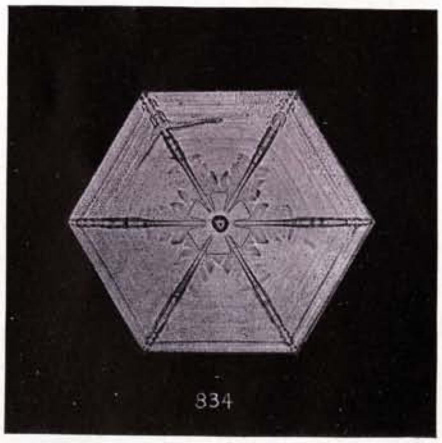

829


830


831

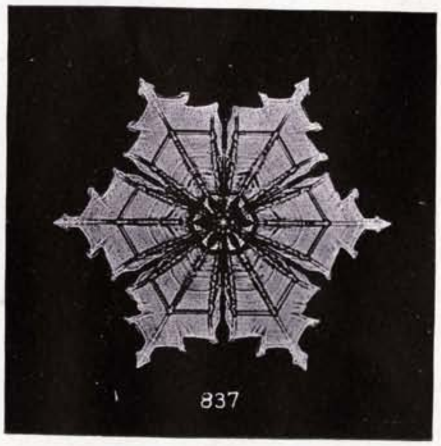

832


833


834


835


836


837

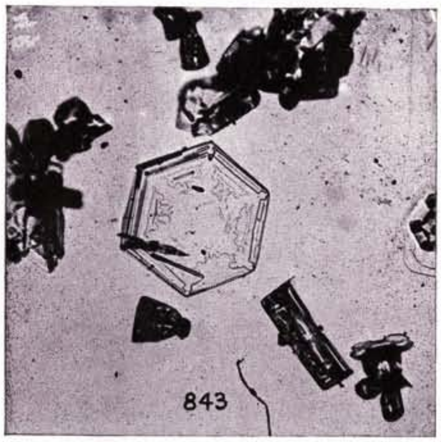

838

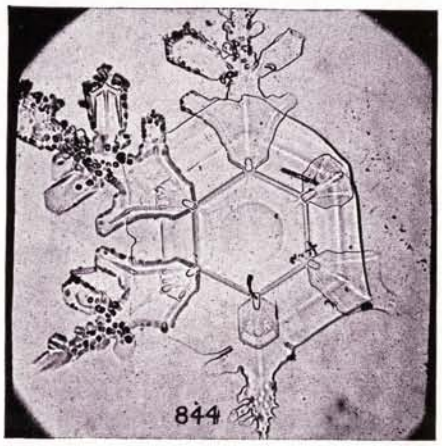

839


840


841

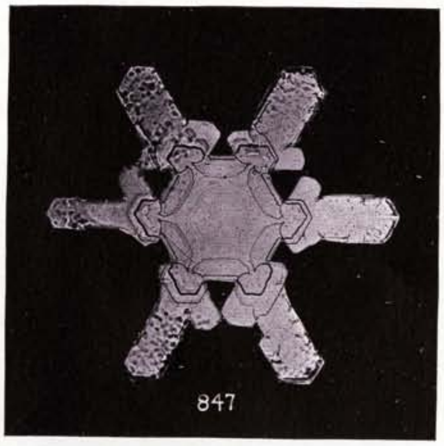

842

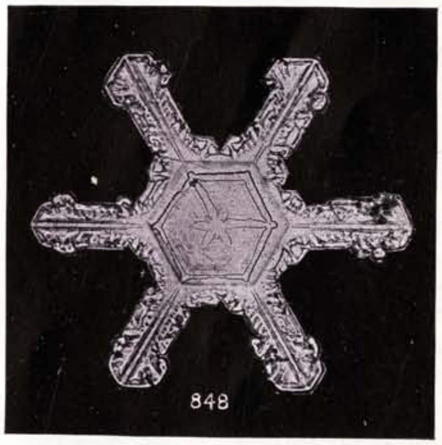

843

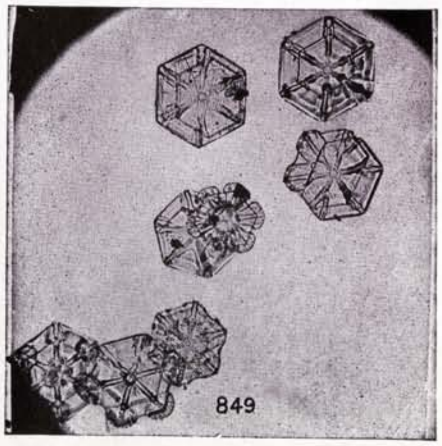

844

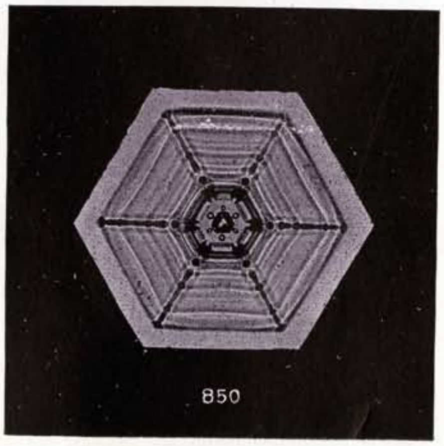

845

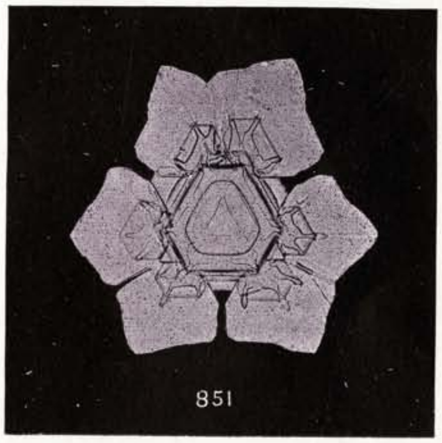

846


847

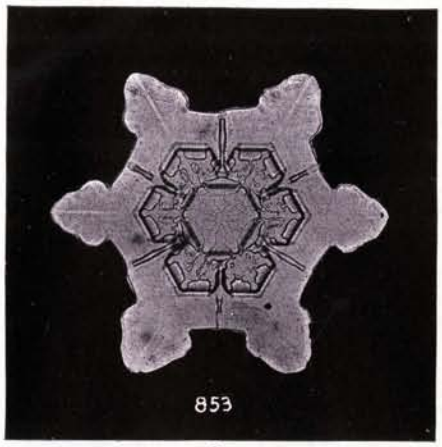

848


849


850

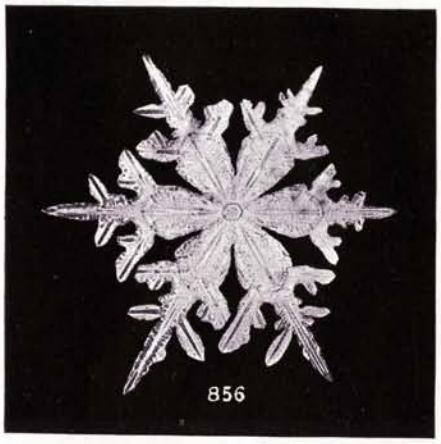

851

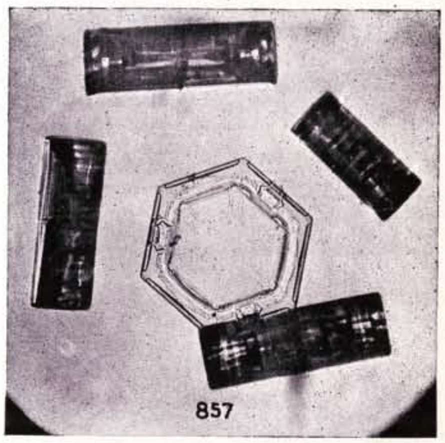

852

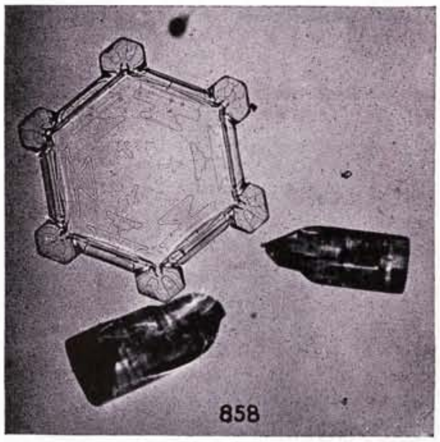

853


854

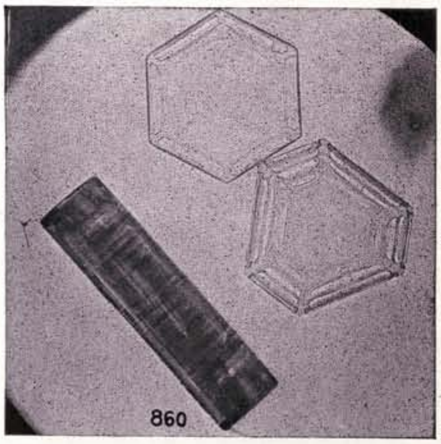

855

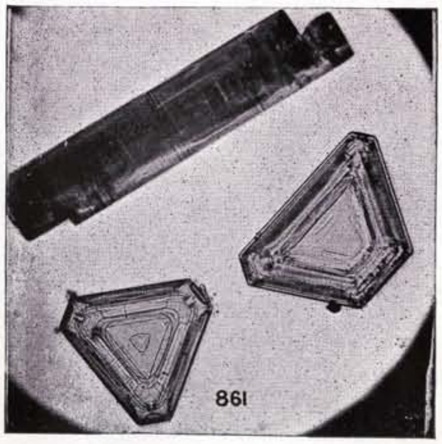

856


857


858

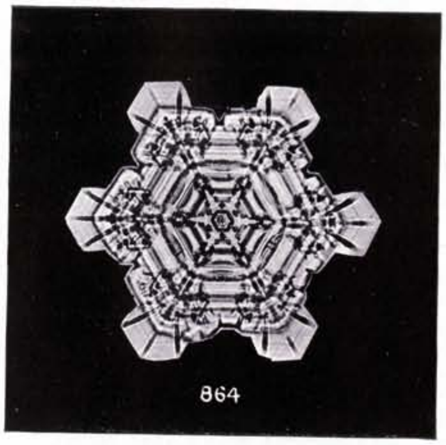

859

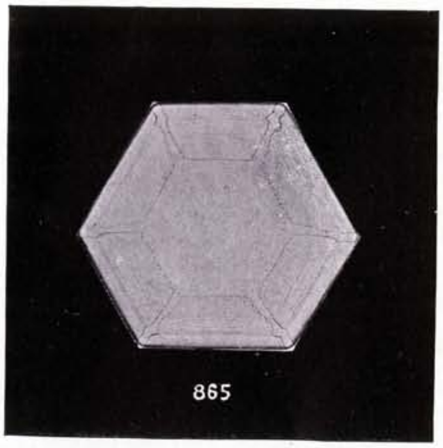

860


861

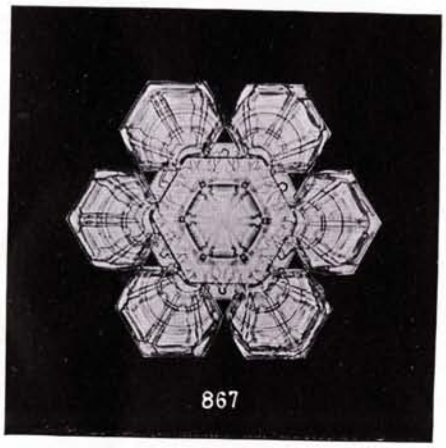

862

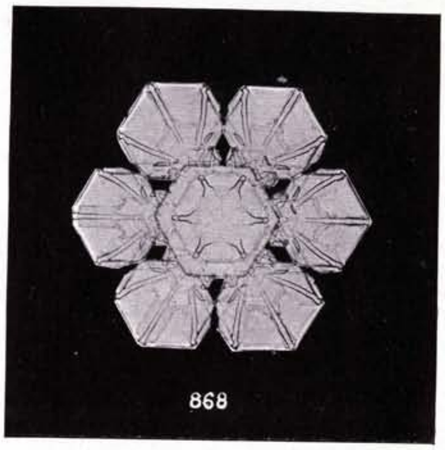

863

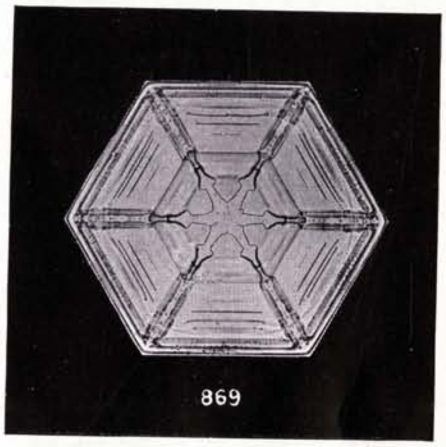

864


865


866


867


868

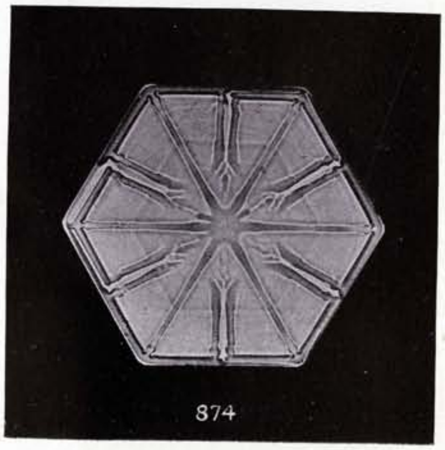

869

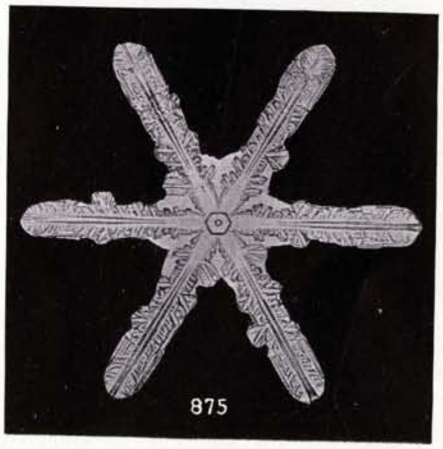

870


871


872


873


874


875

Photomicrographs of Snow Crystals.

Plate XVIII.


876


877


878


879

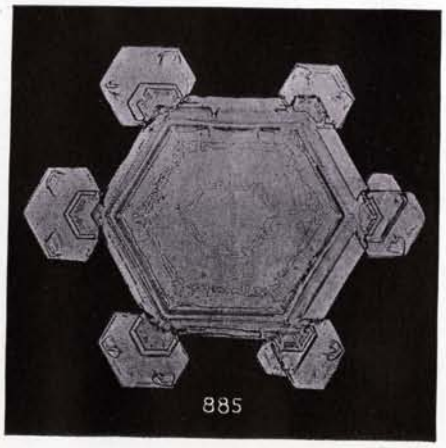

880


881

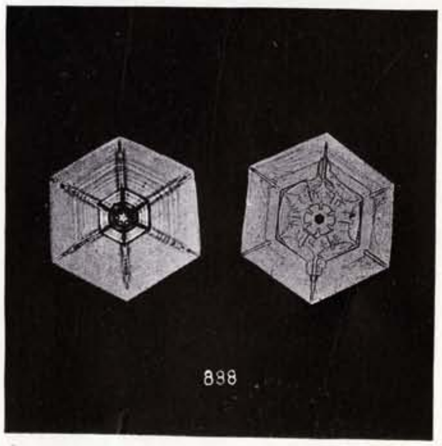

882

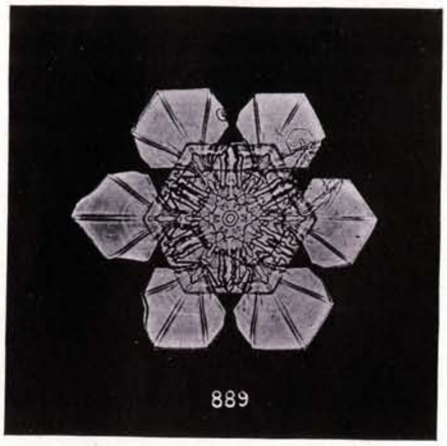

883


884

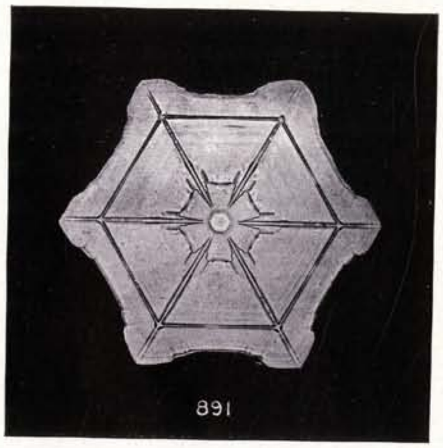

885


886

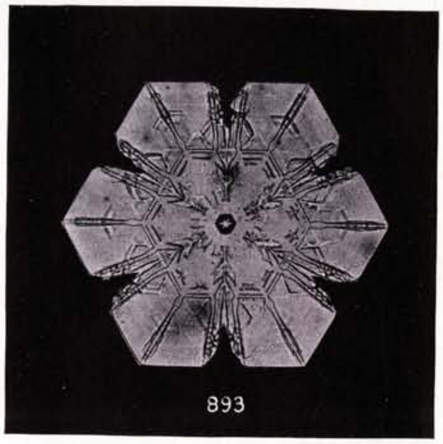

888


889


890


891


892


893


894

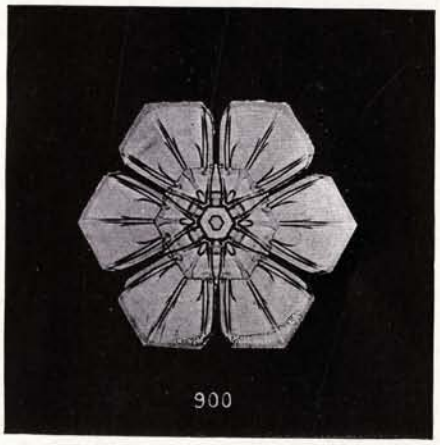

895

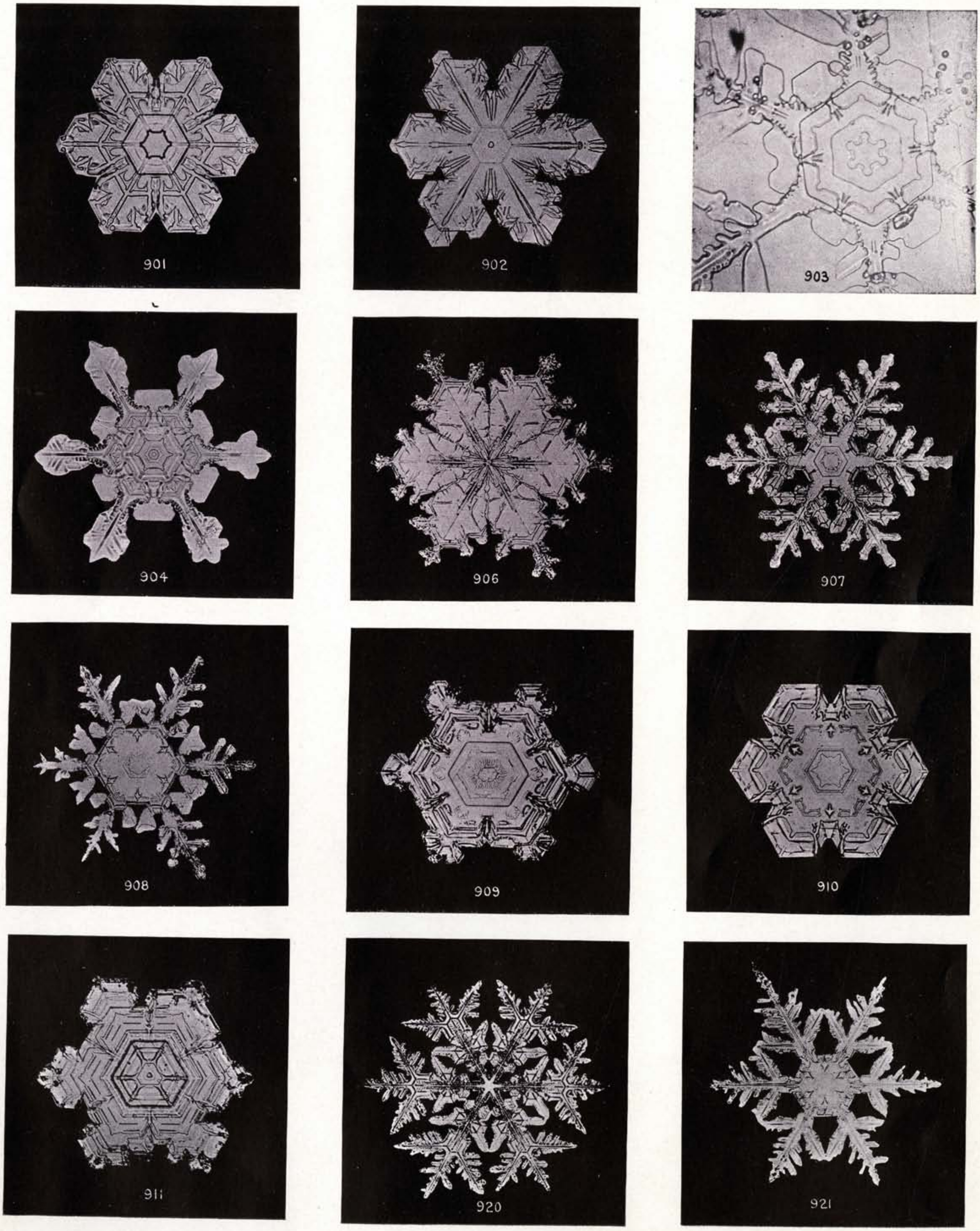

896


897

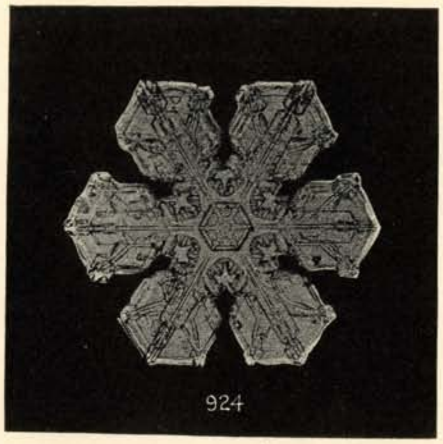

898

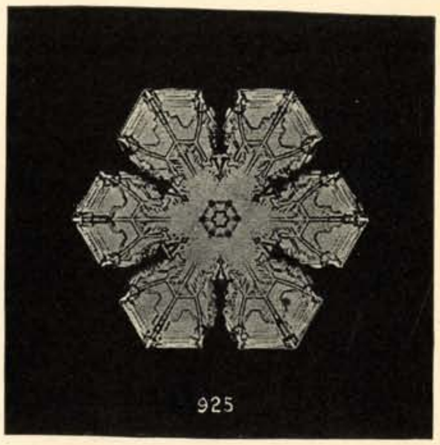

899


900


901
902
903
904
906
907
908
909
910
911
920
921


923

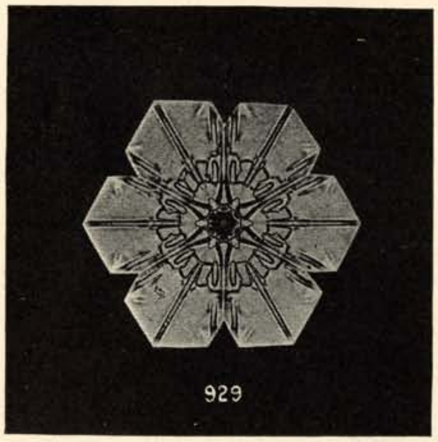

924


925


926


927

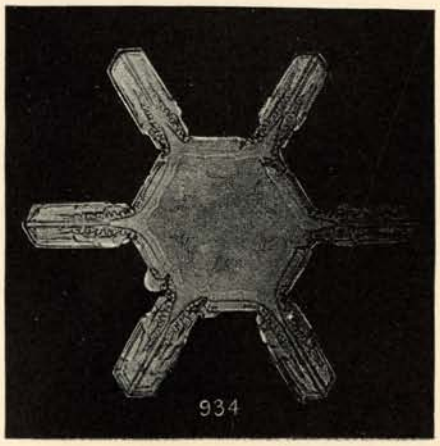

928


929


930


931


932


934


935

Photomicrographs of Snow Crystals.

Plate XXII.