On the Electrical Nature of Snow Particles.

By

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1. Introduction.

Since the appearance, in 1909, of Simpson's theory which attempted to explain the origin of thundercloud electricity by the cascade effect, the electrical nature of snow, along with that of rain, has attracted the attention of many physicists and meteorologists. SIMPSON's measurement[1] on the charge of snow was done at Simla. He observed more positive snows than negative, the ratio of the total positive to the total negative charges observed having been 3.6. MACCLELLAND and NOLAN[2] made a similar observation at Dublin and they found that larger flakes tend to be positively charged and smaller particles negatively. On the other hand, KÄHLER's observations at Potzdam[3] showed that negative snow particles were more frequently observed than positive. All these measurements were done with a collector and an electrometer and the charge recorded was a mean of the charge of many snow particles. Then, this kind of measurements may be called macroscopic. The present authors tried to treat this problem microscopically, that is to measure the charge of individual snow particles. By a snow particle a snow flake is meant as well as a snow crystal, which usually fall intermixed under the climatic conditions of this country. In this series of measurements no attempt was made to distinguish between them, they were treated as of the same weight. Some ambiguity, therefore, may be introduced in the explanation; for example, a small particle may be a small flake or a separated crystal.

Measurement of the charge of individual snow particles was done by GSCHWEND[4] at Freiburg. He received one or few particles of snow in a vessel and measured the charge with a Saiten electrometer. In his observation it was noticed that larger flakes were more frequently observed to be

1) G. C. SIMPSON, Proc. Roy. Soc. A, 83 (1910) 394.
2) MACCLELLAND and J. J. NOLAN, Proc. Roy. Irish Acad., 29 (1912) 81, 30 (1912) 61.
3) K. KÄHLER, Met. Zeit., 40 (1922) 203.
4) GSCHWEND, Jahrb. d. Radioaktivität u. Elctronik, 17 (1920) 62.

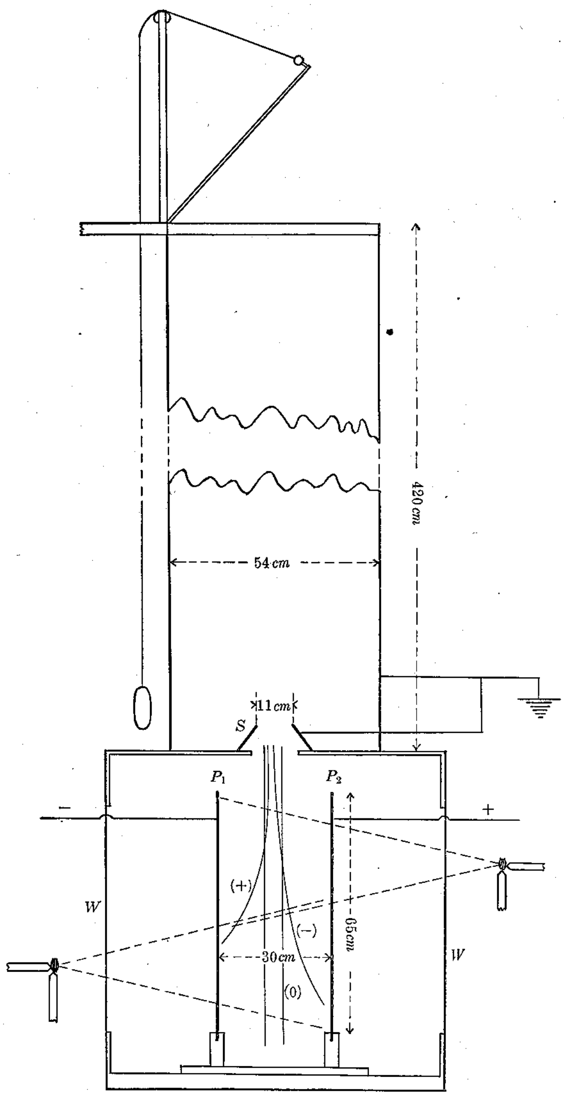
charged positively and smaller particles negatively, in a calm weather snowfall. The authors' method of observing the charge of individual particles was an electric deflection method, which was considered to be most convenient for the continuous observation. It is difficult to measure the quantity of charge accurately by this method, but the sign of charge is very nicely observed. In this measurement importance was attached to the sign of charge and the quantity of electricity was only qualitatively measured.

2. Explanation of the Apparatus.

The apparatus is illustrated in Fig. 1. It consists of a chimney and a wooden box containing the electrode plates, and the whole system is set in the open air. The chimney is made of galvanized sheet-iron and is 54 cm. in diameter and 420 cm. in length. It is provided with a movable cover on the top and a square stop S at the base. For the deflection method it is important to let the snow particle fall in a vertical line, and the dimensions of the chimney were found to be sufficiently suitable for the purpose. The wooden box was made air tight in order to prevent an upward air current which would disturb the free fall of the particle. Three glass windows were fitted in the walls of the box; one in the front for the purpose of observation or photography and two on the sides for illumination. The electrode plate was a brass plate 65 cm. $\times$ 30 cm. in dimension, which was provided with a long slit of 4 cm. in width. This slit was opened lengthwise along the middle line of the plate and used for the purpose of illumination. The distance between the plates was kept at 30 cm. throughout this series of observations. The electric strength applied to the field was the order of 1300 V/cm, which was found to be suitable for giving a moderate deflection to the path of snow particles. As the high tension source a Wommelsdorf's influence machine was used together with a condenser and water resistances for the purpose of stabilizing the voltage. The chimney and the stop S were electrically connected to earth.

With this arrangement the neutral particles will fall vertically and the charged ones will be attracted to the electrode of the opposite sign, as shown schematically in Fig. 1. The general mode of the deflection of the path is shown in Photo. 1. It may be seen in the picture that many particles are little electrified, if at all, and some of them are positively and others negatively charged. By this deflection method one may see very nicely that neutral, positive and negative particles fall, intermixed with each other, at almost the same time in a snowfall. A close examination of

Fig. 1.



the photograph reveals that some of the paths are each composed of two or three parallel lines in close contiguity, while the others are each represented by a single fine line. The former is the track of a large snow flake and the latter is that of a separated crystal or a small flake. It will be understood that the charge of a flake and also that of a crystal are both determined by this method. Sometimes it happens that a large snow flake especially of cotton-snow type is divided into several pieces in the field and the separated pieces are deflected in both directions. This phenomenon will be explained by the theory of separating the electrical charge by induction and it is a matter of interest that is worth while further investigation. At present, however, these flakes are not considered and data regarding them is not intermixed with other data in the following discussion.

3. Result of the Observation.

With the arrangement described above observation was made of the charge of individual snow particles for six snowfalls in March of last winter. The size of the particle and the magnitude of the deflection were recorded in a note by eye observation, following the successive snow particles which fall into the field. Particles which looked to be almost neutral, that is those falling vertically, were excluded in this series of observations, because it was the intention as a first step to see the abundance of either positive or negative particles. The number of particles observed was 1474 in total. The magnitude of charge was estimated relatively in the following manner. The deflection and the size were each classified into three kinds, that is large, medium and small. As a qualitative estimation of the amount of charge, it is assumed that the charge of a small particle showing a large deflection is in the same order of magnitude as that of a large one showing a small deflection. Extending this idea a table was constructed as shown in Table I, in which the figures show the order of magnitude of the charge.

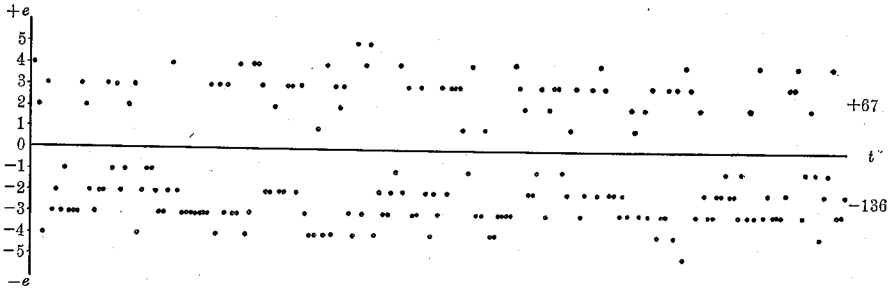
Table I.

size / deflection	large	medium	small
large	5	4	3
medium	4	3	2
small	3	2	1

The charge of particle thus estimated was plotted with a small dot in a diagram, taking time t as x-axis. This time t was chosen on an arbitrary scale, showing only the sequence of the occurrence of the particles. A typical example of the diagram is shown in Fig. 2. This is a record of a continuous observation for 32 minutes, numbering 67 positive particles and 136 negative ones. One can see clearly in the diagram how the positive and negative particles fall intermixed with each other. By the macroscopic method it is possible to measure only an algebraic sum of these positive and negative charges. Sometimes it may happen that the charges of the positive and negative particles received on the collector cancel each other and the electrometer shows no deflection, notwithstanding the fact that individual particles are heavily electrified.

While observing the electrical nature of snow particles, a microscopic investigation of the form of the crystal was carried out in parallel. In the case of Fig. 2, the crystal was the type of thick plate[1]. The frequency of

Fig. 2.
III. 24. 11^h10^m–42^m

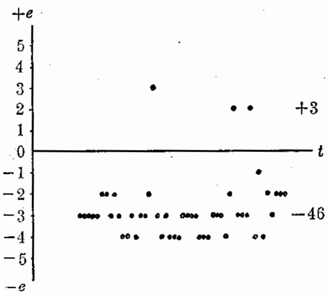


Type of crystals: thick plates.

occurrence of negative snow was observed to exceed that of positive snow in general. Sometimes the phenomenon was met with that more than 90% of total snow particles observed were negatively charged, two examples of which are shown in Fig. 3a, b. The type of crystals in those cases was columnar or dendritic form, both without water droplets. When water droplets are attached to the crystals, the sign of charge tends to be positive. Fig. 3c is an example showing that positive particles were predominant in number, when the crystal was a type of dendritic plane form with many water droplets. Even in the case when positive particles predominate, the negative ones are usually not so few in number. It was very seldom that more than 60% of the total particles observed were positively charged, in the observations of last winter. Sometimes it was observed that only the particles of one sign continued to fall for a short time interval and then those of the opposite sign came down for some time. Fig. 4a is an example of the changing of the sign from positive to negative. At that time the type of the crystal was observed to be a mixture of simple columns with

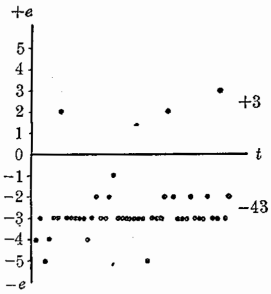
1) The classification and nomenclature of the various types of snow crystals are described in a preceding paper, this Journal, Series II, No. 6 (1934).

Fig. 3 a.
III. 4. $20^{h}20^{m}$



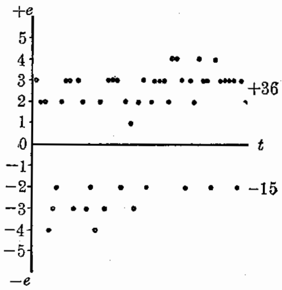
Type of crystals: columns with end plates, simple columns.

Fig. 3 b.
III. 5. $17^{h}20^{m}$–30^{m}



Type of crystals: spacial dendritic crystals without droplets.

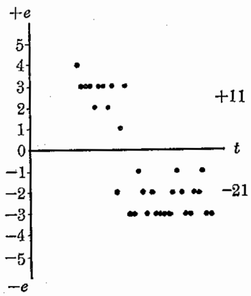
Fig. 3 c.
III. 9. $16^{h}20^{m}$–35^{m}



Type of crystals: dendritic crystals with water droplets.

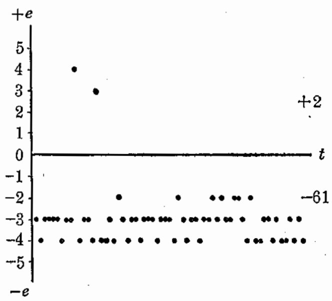
end plates and dendritic crystals with water droplets. The relation between the crystal type and the sign of charge was not determined in this case. It was closely studied in the snowfall of III, 19. Between $2^{h}0^{m}$ and $2^{h}15^{m}$ the snowfall was consisted of dendritic crystals and columns with end plates both without water droplets, when the particles were, almost all of them, negatively charged (Fig. 4b). After half an hour the observation was resumed and it was found that the character of the snow crystals has transformed into a mixture of needles without droplets and dendritic crystals with numerous droplets. It was, then, clearly observed that the needles were negatively charged and that the dendritic crystals with droplets were positively charged (Fig. 4c).

Fig. 4 a.
III. 4. $22^{h}45^{m}$–$23^{h}15^{m}$



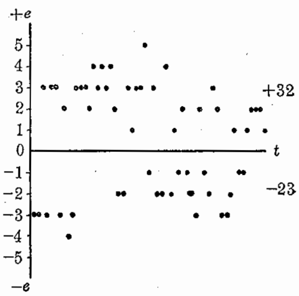
Type of crystals: columns with end plates, needles, dendritic crystals with water droplets.

Fig. 4 b.
III. 19. $2^{h}0^{m}$–15^{m}



Type of crystals: dendritic crystals, columns with end plates, both without droplets.

Fig. 4 c.
III. 19. $2^{h}50^{m}$–3^{h}



Type of crystals: simple columns without droplets(−), dendritic crystals with numerous droplets(+).

The results of the observation are summarized in Table II. In the table it may be seen that among eighteen observations the negative particles predominated numerically in twelve cases and the positive ones in six cases. The number of the negative particles in general far exceeded that of the positive, being 63% of the total 1474 particles observed. The character of the crystal is also noted in the table. When the crystal had no water droplets attached, marked by * in the table, the negative particles were more frequently observed. In seven cases out of the eight observations the negative particles always predominated. One exception was the observation at 11^h on III. 9, when the number of positive particles was 1.6 times that of the negative. When the crystals had attached water droplets, the positive particles tended to be more frequently observed. As will be seen in the table, the positive particles exceeded the negative in number in five cases out of nine observations. From these results it may be considered as a general rule that the ordinary snow crystals are more frequently charged negatively, but when they have attached with water droplets they tend to be positively electrified.

As for the relation between the sign of charge and the size of particles, some investigators report that larger particles are more frequently charged positively and smaller ones negatively, while others did not observe such a relation. In order to clarify this point by their microscopic method, the authors constructed a table showing the ratio of the number of positive particles to that of negative for large, medium and small particles respectively, as in Table III. If all large particles are positively and all small particles are negatively charged, the figure representing the ratio must be infinity for large particles and zero for small ones. One may see in the table that this is not the case. As a mean, the ratio is 0.71 for large particles, 0.77 for medium particles and 0.90 for small ones; that is, the number of the positive particles is smaller than that of the negative for all sizes of the particles. Taking these figures as they are, positive particles are more frequently observed in the case of small particles than in that of large ones. It is quite contrary to the result reported by MacClelland and Nolan. As the present conclusions are deduced from observations carried out only in one month of last winter, no definite conclusion must be attempted yet. It is proposed to continue similar observations next winter.

Table

Number of positive and negative

The time of observation	Number of positive snow flakes and crystals				Number of negative snow flakes and crystals			
	large	medium	small	total	large	medium	small	total
III. 4. 20h	0	3	0	3	21	18	7	46
21	2	3	2	7	7	3	9	19
23	7	3	1	11	9	5	7	21
III. 5. 16h	7	17	3	27	40	14	7	61
17	2	2	1	5	9	22	24	55
III. 9. 11h	7	45	36	88	6	23	26	55
15	3	7	9	19	10	17	10	37
16	16	14	6	36	4	9	2	15
17	18	14	6	38	26	22	2	50
III. 13. 11h	0	2	59	61	0	1	56	57
13	25	50	37	112	26	36	23	85
III. 19. 2h	1	0	1	2	26	16	19	61
3	14	13	5	32	5	9	9	23
5	4	1	11	16	6	1	4	11
6	1	0	0	1	11	6	9	26
III. 24. 11h	36	14	17	67	49	43	44	136
12	2	6	10	18	26	19	20	65
15	1	6	7	14	7	29	64	100
Total	146	194	211	551	288	293	342	923
Per centage	27%	35%	38%	100%	31%	32%	37%	100%

positive particles 551 } 1474 in total.
negative „ 923

II.

snow particles observed.

Character of snow crystals
* Columns with end plates, simple columns.
* ,, , needles, assemblage of plates.
,, , ,, , dendritic crystals with droplets.
Dendritic crystals with droplets, without droplets.
* Spacial dendritic crystals without droplets, cotton snow flakes.
* Assemblage of columnar crystals, spacial assemblege of plates.
Not observed.
Dendritic crystals with water droplets.
* Cotton snow flakes.
Powder snow with droplets.
Cotton snow flakes without droplets, needles with droplets.
* Dendritic crystals, columns with end plates, both without droplets.
Needles without droplets (−), dendritic crystals with droplets (+).
,, , small dendritic with droplets.
* Needles, hexagonal plates with branches.
Thick plates.
Columns with droplets, spacial and plane dendritic crystals without droplets.
* Columns with end plates, simple columns, small plates, all without droplets.

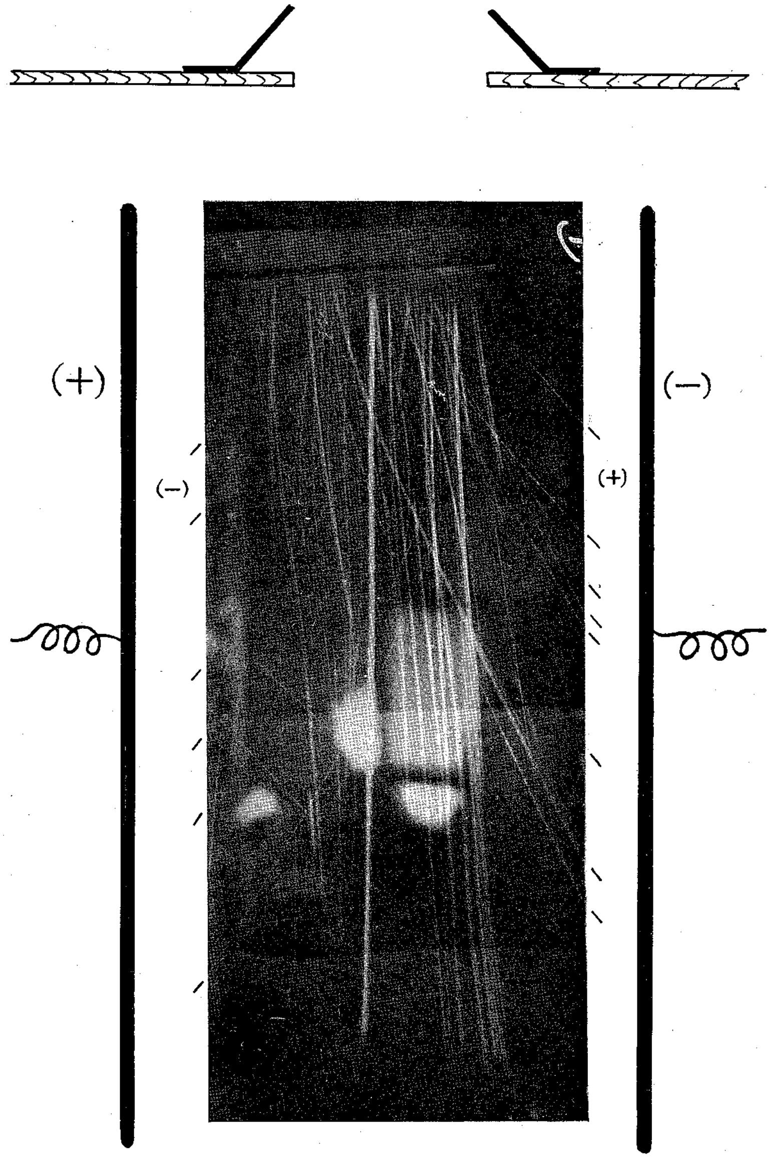
Table III.
The ratio of the number of positive snow particles to that of the negative.

time of fall	large	medium	small	+/− total
III. 4. 20^h	0	0.2	0	0.1
21	0.3	0.4	0.2	0.4
23	0.8	0.6	0.1	0.5
III. 5. 16^h	0.2	1.2	0.4	0.4
17	0.2	0.1	0	0.1
III. 9. 11^h	1.2	2.0	1.4	1.6
15	0.3	0.4	0.9	0.5
16	4.0	1.6	3.0	2.4
17	0.3	0.6	3.0	0.8
III. 13. 11^h	—	2.0	1.1	1.1
13	1.0	1.4	1.6	1.3
III. 19. 2^h	0	0	0.1	0.0
3	2.8	1.5	0.6	1.4
5	0.7	1.0	2.8	1.5
6	0.1	0	0	0.0
III. 24. 11^h	0.7	0.3	0.4	0.5
12	0.1	0.3	0.5	0.3
15	0.1	0.2	0.1	0.1
mean	0.71	0.77	0.90	0.72

4. The Charge of Snow Particles separated by mutual Friction.

KÄHLER and DORNO[1] measured, by a macroscopic method, the charge of snow particles separated by mutual friction, and were led to a conclusion that large particles are positively and small particles are negatively charged by mutual friction. Relating to this problem, the present authors made a preliminary experiment. A small window was opened in the wall of the chimney and a lump of newly-fallen snow that was held on an earthed metal plate was blown into the chimney through that window by using compressed air. The particles of snow thus scattered fell into the space between the electrode plates and were deflected by the electic field. It was found that the separation of the charge was quite remarkable in this case but there were also many particles which were scarcely electrified. No definite relation was observed between the sign of charge and the size of particles, as reported by Kähler and Dorno. It is hoped to continue similar measurement for various types of snow crystals next winter.

1) KÄHLER and DORNO, Ann. d. Phys., 77 (1925) 71.



III, 4. p.m. 10–30. E = 1400 V/cm.
Exposure = 2 sec.