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The Charge on Precipitation Elements and Surface Electric Potential Gradient

Choji MAGONO, Keitaro ORIKASA and Hiroshi OKABE*

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Abstract

The electric charge on individual precipitation elements was simultaneously measured together with the surface potential gradient in Northen Japan, using respectively a vacuum electrometer and a Wulf type electrometer. The size and shape of the elements were also observed by the filter paper and microphotographic method.

The charge on precipitation elements measured was represented simultaneously with the time variation of potential gradient. The following results were obtained.

i) In rain falls, "the reversal relation" between the signs of charge and potential gradient is observed except during the short period when the sign of the potential gradient is changing.

ii) The reversal relation is also observed in general snowfall; however, when graupel or sleet falls, the relation between the charge and potential gradient is very irregular.

iii) The charge on snow flakes is extremely large when the potential gradient was rapidly changing.

Considering those results, it is supposed that the precipitation elements are electrified partially by WILSON's mechanism under fairly intense field, and on that mechanism are superposed certain other effects. If an element is influenced by both positive and negative field during its fall, the effect of the fields will be canceled and the element will carry its original charge to the earth surface without any charge deformation.

§ 1. Introduction

The electric charge on precipitation elements became of interest in connection with the charge separation in clouds and with the balance of the atmospheric electricity. If the charge is measured simultaneously with the potential gradient, it is more useful, because the potential gradient under a cloud base yields an information about the cloud electricity. In the discussion of

* Yokohama National University.

the balance, it is necessary to assume total precipitation currents on the whole earth surface, therefore, it is desirable that the charge on all kinds of precipitation elements should be measured at various regions on the earth. However the observations of the charge on precipitation elements have been almost entirely limited to European or American regions. Therefore, in Japan, the present writers undertook to measure the charge on raindrops, snowflakes and graupel simultaneously with the surface electric potential gradient under clouds through 1954, 1955 and 1956.

§ 2. Apparatus

To avoid artificial electrical disturbances, in winter the authors used an igloo under the snow cover as the site for measuring the charge on snowflakes, as shown in Fig. 1. The igloo was very

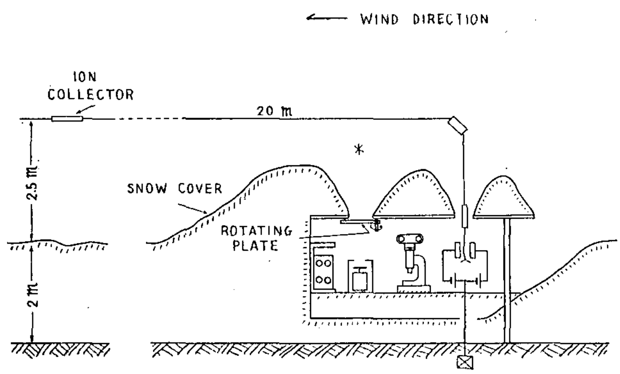


Fig. 1. The vertical section of a snow igloo used in observing the charge on snowflakes.

convenient for the photographing of snowflakes owing to its cold temperature and stagnant air. An ion collector for measuring potential gradient was set up at the height of 2.5 m above the snow surface and to the leeward of the igloo. The potential gradient on the snow surface was measured by a Wulf type string electrometer. Rods of polystyrene or paraffin were very useful as electrical insulators. However, it should be cautioned that snowflakes accreted on the rods often lower the insulation power in the antenna system. A receiving equipment for snowflakes is shown in Fig. 2. At the moment when one snowflake falls through

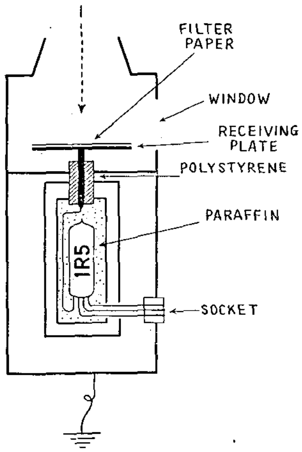


Fig. 2. Receiving plate system.

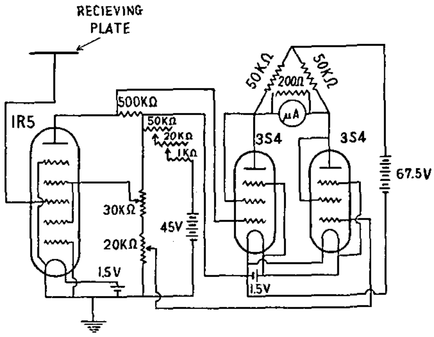


Fig. 3. Electric circuit for measuring the charge on precipitation elements.

a hole of the igloo and falls on the receiving plate, a rotating plate below the ceilig is shut. When a few snowflakes falls at one time onto the receiving plate, the mean charge of the several snowflakes is adopted as the charge of single snowflake. The mass of snowflakes is measured by a filter paper dyed black which is used later as a dark back field to photograph the snowflakes. The charge of snowflakes lying on the receiving plate is measured by an electric circuit as shown in Fig. 3. The apparatus was also used to measure the charge on raindrops.

§ 3. Charge of Raindrops

Kiryu is famous as a city where thunderstorms are very often observed in summer season. Some results in the measurement of charge on raindrops obtained there are shown in Figs. 4 and 5. In the Figures, solid lines show the time variation of potential gradient, and black dots show the value of charge on single raindrops. Numerals suffixed to the dots represent the diameter of the rain drops in mm. At the lowest part of the figures the weather is indicated by International Meteorological symbols.

In Fig. 4, one sees a reverse relation between the signes of drop charge and potential gradient. It is noted that the larger the drop is, the larger the charge on it. The reverse relations

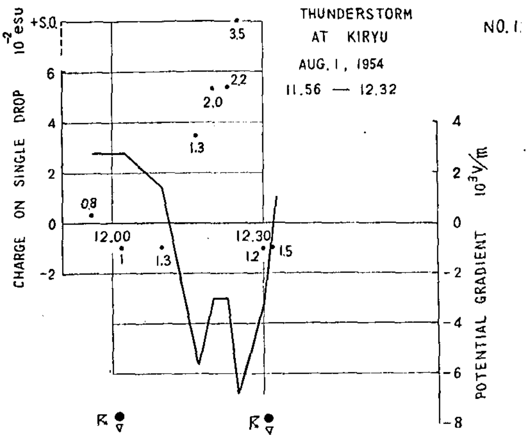


Fig. 4.

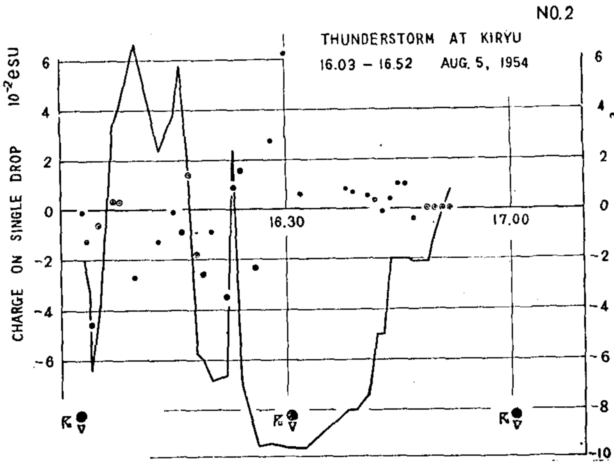


Fig. 5.

Figs. 4 and 5. Time variation of the charge on single raindrops and earth surface electric potential gradient at Kiryu.

are also seen in Fig. 5 except during the short period when the sign of potential gradient is changing. The drops which were observed within 2 minutes before and after the instant when the soild lines showing potential gradient cross the zero-line, are distinguished from other drops by the use of double marks ⊙. The reverse relation has already been found by ELSTER and GEITEL[1] and others[2]. From the relation, one may probably recall WHIPPLE and CHALMERS' calculation[3] based on WILSON's[4] theory. The result of their calculation is as follows,

$$Q = -3Er^2$$

where Q is the maximum charge on a raindrop under a potential gradient E, and r the radius of raindrops in C.G.S. It is considered that the magnitude of electrification of raindrops by ion capture is proportional to the surface of the drops, therefore, in Figs. 6 and 7, the charge per unit area of drop surface is shown to the potential gradient measured at the moment when the drops fell. For comparison, the value of charges obtained by WHIPPLE and CHALMERS' calculation is represented by a solid line. In the figures, one may see that the relation between the signs of the charge and the potential gradient agrees fairly well with that of WILSON's theory, but the magnitude of the charges observed is several times larger than that calculated. The measurement of potential gradient was not accurate; however, this discrepancy may be due to other factors, perhaps to the fact that the potential gradient below cloud bases was much larger than that observed at

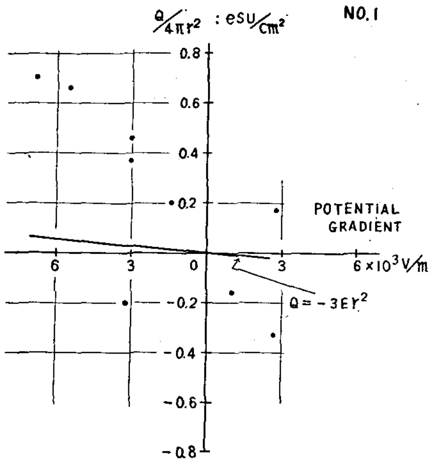


Fig. 6.

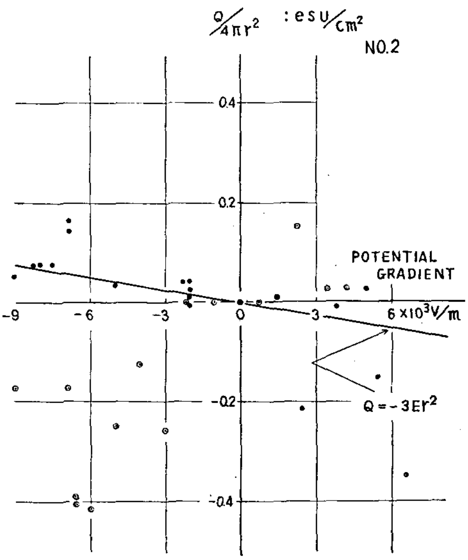


Fig. 7.

Figs. 6 and 7. Relation between the charge per unit surface area of raindrops and potential gradient in Obs. Nos. 1 and 2.

the earth surface. Field potential of the magnitude of several thousand volts per cm is not unusual under active thunderclouds, therefore, one can expect such large charges on drops as shown in Figs. 4 and 5. In this connection, in WHIPPLE and CHALMERS' calculation, a constant potential gradient between cloud base and earth surface is assumed.

On a certain day in September, 1954, charges on raindrops from a frontal thunderstorm were observed at Yokohama. The

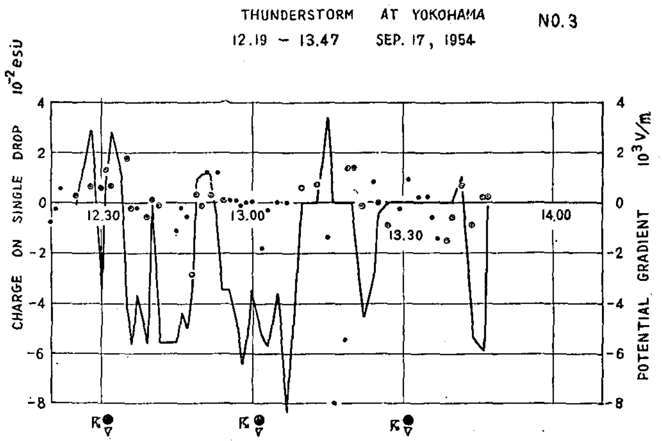


Fig. 8.

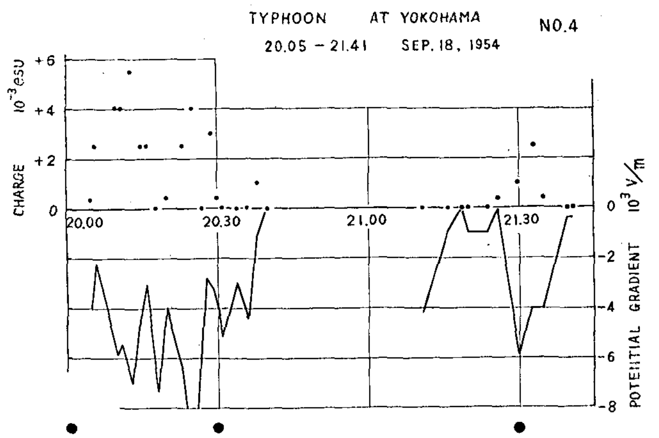


Fig. 9.

Figs. 8 and 9. Time variation of the charge on single raindrops and earth surface electric potential gradient at Yokohama.

reverse sign, the exception and the magnitude of charge were similar to those observed at Kiryu as shown in Figs 8 and 10. On the next day, Typhoon No. 14, 1954 passed through Yokohama. The results obtained then are represented in Fig. 9. In this case also, the reverse sign relation is seen, however, the magnitude of charges shows less than those in thunderstorms. The upper limit of charges measured agrees fairly well with those expected from WHIPPLE and CHALMERS' calculation, as shown in Fig. 11.

Some considerations should be given to the fact that the signs of charges on raindrops were observed near the reverse of the sign of potential gradient, as shown in Figs. 5 and 8. It is questionable whether raindrops carrying such charges of the sign same as that of potential gradient fall actually or whether the authors apparently obtained only such a result near the moment when the sign of potential gradient changed. The lag time between two moments of observing charge and potential gradient was less than a half minute. This time interval is fairly small compared with a few minutes expected from Figs. 5 and 8. The time required for raindrops to fall from the cloud base to the earth surface was probably a few minutes. This time appears to agree with the lag time shown in the figures. If the variation of the field precedes, and the charging of the

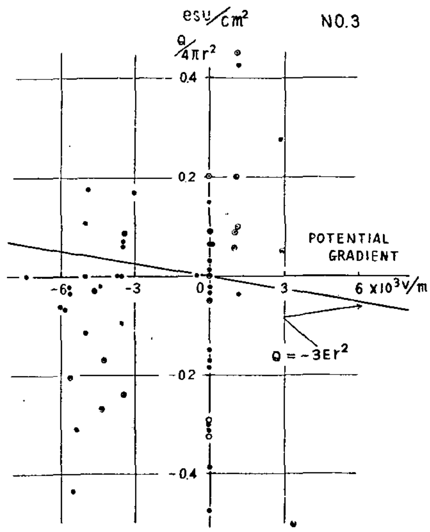


Fig. 10.

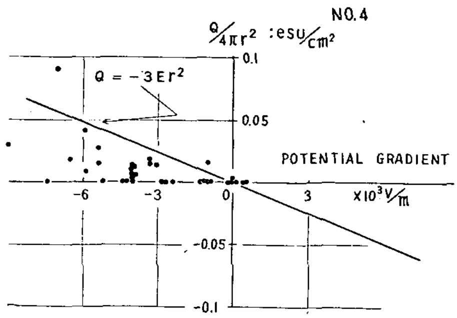


Fig. 11.

Figs. 10 and 11. Relation between the charge per unit surface area of raindrops and potential gradient in Obs. Nos. 3 and 4.

drops under the electric field follows late after the variation, and the drops arrives at the earth surface still later, i. e., if a few minutes elapsed during their fall, then such drops of the same sign as that of potential gradient should be observed only after the reverse of the sign of the potential gradient. However, as one sees in Figs. 5 and 8, the drops which are charged with the same sign as that of the potential gradient are scattered equally before and after the moment when the potential gradient crosses the zero-line. Therefore, the authors believe that the occurrence of such "same-sign" phenomenon is not entirely due to the lag phenomenon which is produced by observation procedures or charging mechanism.

It is supposed that if a drop suffers both positive and negative fields of the same magnitude during its fall, the effects of the fields on the charging of drops will be almost canceled, in other words, the effect of electrification by WILSON's mechanism may be neglected. Thus, the drop observed near the moment of the reverse in the potential gradient's sign will show its original charge obtained within a thundercloud. In considering both the original charge and the deformed one on a raindrop, the authors have reached an opinion essentially the same as that of SMITH[5]. In GUNN's report[6], the relation between the signs of raindrop charge and potential gradient seems almost to be irregular. If the signs are rearranged removing the data observed during the period near the instant of reverse of sign of potential gradient, the relation would become more regular.

§ 4. Change on Snowflakes

In winter season, Northwestern Monsoons bring many squall snowfalls to the western side of Japan. The snow crystals observed there generally form snowflakes which are more or less wet and to which cloud particles are attached. Some results obtained at Sekiyama in Niigata Prefecture are shown in Figs. 12, 13 and 14. The shadowed areas showing potential gradient in the figures mean that within the areas the indicator measuring potential gradient vibrated so violently that instantaneous values could not be read. The rapid change of potential gradient might be due to the local change of air cells near the ion collector, however, it is

Fig. 12.

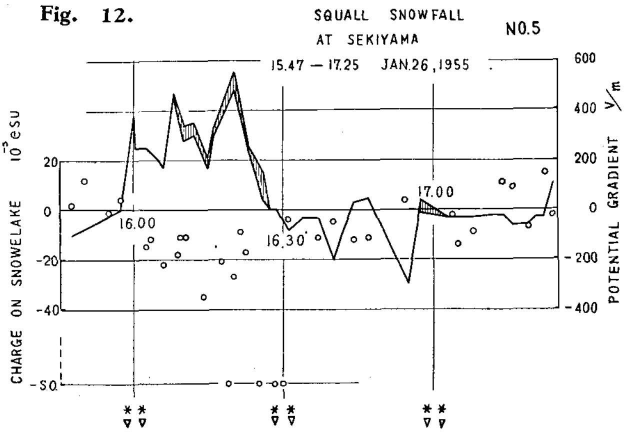


Fig. 13.

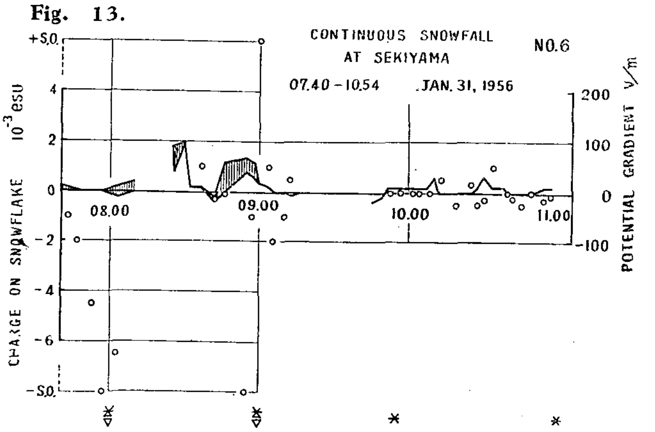
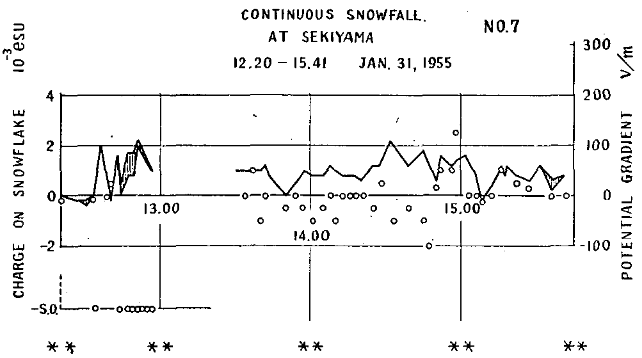


Fig. 14.



Figs. 12, 13 and 14. Time variation of the charge on single snowflakes and electric potential gradient above snow cover at Sekiyama.

noticeable that the charge on snowflakes observed in such periods often showed extremely large negative value, although the magnitude of the potential gradient itsself was not so large.

In those figures also, one may see the reverse relation of signs between the potential gradient and the charge on snowflakes. Considering that the periods of field change are roughly 30 minutes, the rythmical variation in potential gradient may be a part of so-called "wave pattern". When snowflakes are wet, it is easy to measure their charges individually, but in Sapporo when a snowflake breaks up on the receiving plate or many dry snow crystals fall at once, the distinction of charges on individual particles is difficult by means of the writers apparatus. Therefore, Q/r^2 was adopted as the charge on snowflakes, where Q is the charge measured during one period, r the radius of water drop calculated from the total mass of snow particles fallen at one period on the receiving plate. The magnitude of Q/r^2 in mm had usually the same order as that of single flakes even if such a calculation was employed. Therefore, one may use Q/r^2 in esu/mm as the mean charge on single snowflakes, the effect of their masses being eliminated.

In Fig. 15 (Obs. No. 9) and Fig. 17 (No. 12), it will be seen that in steady quiet snowfalls the potential gradient shows positive values similar to that observed usually in fine weather, and even if small depressions of potential gradient owing to the negative electricity of cloud appeared at the same time as shown in Fig. 15 (No. 8) and Fig. 16 (No. 10), the charge on snowflakes was still a small negative one. It has already been found by SIMPSON[7], CHALMERS and LITTLE[8] that in steady quiet snowfalls snow crystals carry negative charge. Findings of the authors is that in such cases, the sign of potential gradient is generally positive. This reversal relation calls to one's mind WILSON's mechanism in the case of snowflakes. On the other hand, CHALMERS[9] has shown that the snow crystals could be electrified by the capture of ions. However, in such steady snowfalls, it is still questionable whether the charge on snowflakes are electrified by the ion capture mechanism or not, because the magnitude of the potential gradient is similar to that in fine weather. Even if the snowflakes are charged negatively by other mechanisms, for example, the mechanism sug-

Fig. 15.

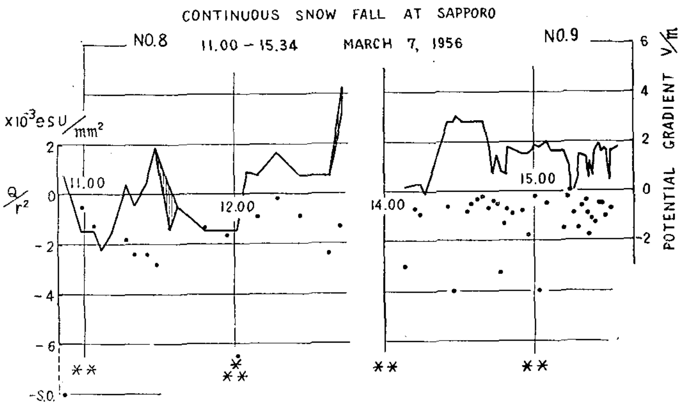


Fig. 16.

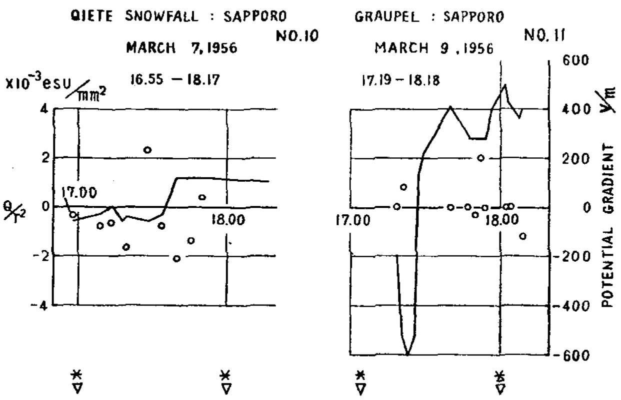
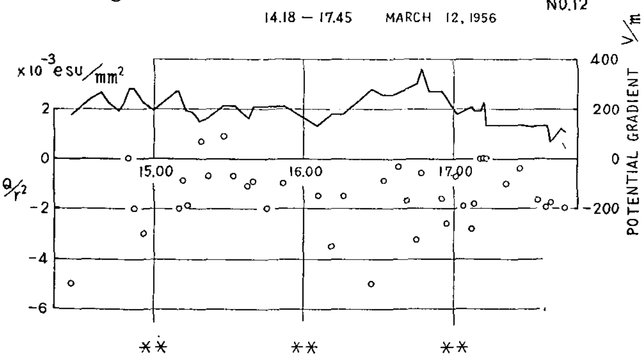


Fig. 17.



Figs. 15, 16 and 17. Time variation of the charge on snowflakes or graupel and electrical potential gradient above snow cover at Sapporo.

gested by FALCONER[10], and the potential gradient is maintained by the mechanism just as in fine weather, a similar reverse relation of sign to those shown in Nos. 9 and 12 may be observed.

Until the positive charge during negative potential is also observed, WILSON's theory of snowfalls cannot be accepted. Unfortunately, the present writers had no chance to make such observations in the period of their study.

§ 5. Special Cases

An example of charges on graupel is shown in Fig. 16 (No. 11). The potential gradient changed rapidly from −600 V/m to +500 V/m, and the charges on graupel were roughly zero or rather positive. From WORKMAN and REYNOLDS' effect[11], it is expected that a graupel is rather negatively charged in a thundercloud. But the authors think that after the fall from cloud base the charge on the graupel may be influenced by other mechanisms, for example, by WILSON mechanism. If the original charge on the graupel is relatively small, the sign of the charge will be reversed during its fall. NAKAYA and TERADA[12] reported that when the snow crystals had cloud particles attached, they were often positive. It is the authors' opinion that more numerous data are necessary in order to learn the relation between the potential gradient and the charge

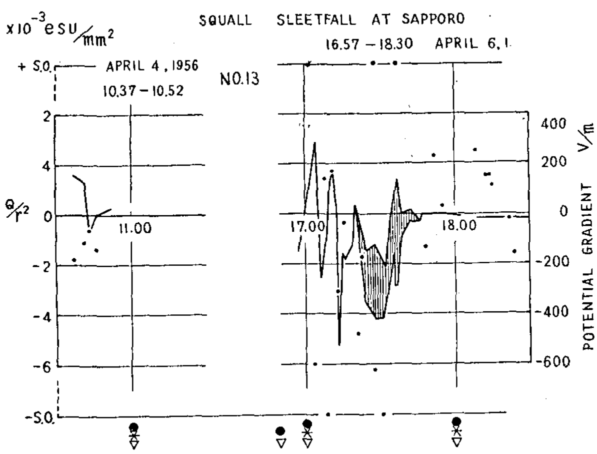


Fig. 18. Time variation of the charge on melted snowflakes and electrical potential gradient above earth surface at Sapporo.

on graupels, because the change of potential gradient under clouds which precipitate graupel is very violent and complex.

Early in April, 1956, some results about sleet (partially melted snowflake) were obtained as shown in Fig. 18. The potential gradient varied violently and the charge on the sleet was also widely scattered.

§ 6. Conclusions

The change of potential gradient and of charges on precipitation elements is so rapid and complex that a vagueness is not avoidable in the discussion if based on the results arranged by the mean values. Therefore, to show the charge on individual precipitation elements simultaneously with the time variation of the potential gradient may be an adequate method clearly to represent the precipitation electricity. The authors believe that using this method of representation they will arrive at a more perfect understanding about the cloud electricity. Considering generally the results obtained hitherto, it is the authors' opinion that the reverse relation of sign between potential gradient and charge on precipitation elements occurs mainly under the cloud base by WILSON mechanism and on that mechanism are superposed other mechanisms.

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References

1) J. Elster and H. Geitel, *Met. Zeit.*, **5** (1888), 95.
2) H. Bendorf, *Wiener Ber.*, **119** (1910), 89,
F. J. Scrase, *Met. Off. Geophy. Mem.*, **75** (1938),
J. A. Chalmers and E. W. R. Little, *Terr. Mag. and Atm. Elec.*, **45** (1940), 451.
3) F. J. Whipple, and J. A. Chalmers, *Quart. Jour. Roy. Met. Soc.*, **70** (1944), 103.
4) C. T. R. Wilson, *Jour. Frank. Inst.*, **208** (1929). 1.
5) L.G. Smith, *Quart. Jour. Roy. Met. Soc.*, **81** (1955), 23.
6) R. Gunn, *Jour. Met.*, **10** (1953), 279.
7) G. C. Simpson, *Quart. Jour. Roy. Met. Soc.*, **68** (1942), 1.
8) J. A. Chalmers and E. W. R. Little, *Terr. Mag. and Atm. Elec.*, **52** (1947), 239.
9) J. A. Chalmers, *Quart. Jour. Roy. Met. Soc.*, **73** (1947), 324.
10) R. E. Falconer, *Final Rep., ONR Project, Rep. No. R. L.-1007, Res. Lab*, G. E. (1953), 97.
11) E. J. Workman and S. E. Reynolds, *Phys. Rev.*, **78** (1950), 254.
12) U. Nakaya and T. Terada, *Jour. Fac. Sci. Hokkaido Univ. Ser. II*, **1** (1934), 181.