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Observation of Electric Charge of Ice Crystals (Diamond Dust) and Atmospheric Electric Potential Gradient in Winter Fog at Inuvik, N.W.T., Canada

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Abstract

Electric charge on ice crystals and electric potential gradient on the ground surface were observed in winter fogs at Inuvik, N.W.T., Canada.

Quantities of electric charge on ice crystals were measured by means of applying ice crystals to a horizontal electric field of alternative high tension, and photographing its trajectories. The sign of them were decided by a specially designed illumination system.

Observed values of electric charge on ice crystals were in a range of 3×10^{-8} esu to 5×10^{-5} esu, while the size of ice crystals measured were in a range of $8 \mu\text{m}$ to $80 \mu\text{m}$.

After the ice fog the potential gradient at the ground surface was enhanced positively to the intensities of several times of fair weather values.

As a whole, ice crystals carried positive and negative charges in nearly equal fractions.

Ice fogs appeared over the observation site in wave like fashion for a period of several tens of minutes, where ice crystals in the early and later stage carried preferentially positive and negative signs of electric charge respectively.

It may be considered that in the early stage ice crystals vigorously grew under plentiful humidity, and in the later stage stopped growing or began to evaporate under poor humidity. It seems that such conditions surrounding ice crystals contribute to the sign of electric charge.

1. Introduction

It is of considerable interest to study atmospheric electricity in winter fog (diamond dust). Especially, the electric charge of individual ice crystals in diamond dust have never been measured exactly, because the values of charge are so small for measurement under severe conditions of low air temperature. This is considered to be related to the investigation of ice crystal electrification in the upper part of clouds such as cirrus clouds. Reiter¹⁾ considered from his observation of field strength that ice crystals in cirrus clouds might carry positive charge. Magono and Iwabuchi²⁾ reported that the shape of ice crystals seemed to be related to the sign of electric charge in

their laboratory experiment, in which hexagonal plates and star type (in -15°C) crystal predominantly carried a negative charge, and column and prism type (in -7°C and -30°C) crystal had a positive charge. Endoh, Iwabuchi and Magono³⁾ previously measured atmospheric electric potential gradient in winter fogs reported that ice crystal appeared to be consequently electrified negatively. The author in the present report carried out measurements of electric charge on ice crystals and snow crystals, and atmospheric electric potential gradient at the surface at Inuvik. The present paper mainly describes the results of the observation of electric charge on ice crystals.

2. Observation site and equipments

The observation site was the Inuvik Research Laboratory at Inuvik, N.W.T., Canada. Instrumentation used for atmospheric electric potential gradient was a specially designed radiation probe, using solid state micro electronics. The electric charge of individual ice crystal was measured by means of Wells and Gerke's method⁴⁾, when an ice crystal falls into a horizontal electric field of alternating current in high tension, it leaves a trajectory of sine wave type. Quantity of electric charge and mass of ice crystal were calculated from the amplitude and wave length of the trajectory, and this method were described by Wells and Gerke⁴⁾ and Magono and Kikuchi⁵⁾. The sign of electric charge was decided by a specially designed illumination system as shown in Fig. 1. The falling ice crystal was illuminated by an upward light beam from two light sources beneath it. One of these was a low pressure mercury lamp which was excited by a half wave current through a diode from alternating current exactly synchronized to high tension field between parallel disks. The other was a continuous light source from a tungsten lamp. The illuminating phase was tested in relation of the electric potential change between parallel disks by a phototransistor and a two channel synchroscope. This is shown in upper part of Fig. 2. If an ice crystal carries a positive charge as shown in the figure, it would be illuminated in the phase hatched as shown in lower part of Fig. 2. This method is more reliable than the deflection method by d.c. high tension under complexly disturbed air motion. The principle of these methods is essentially similar to Twomey's⁶⁾ method. All systems of measuring equipment which are shown in Photo. 1 and 2 were surrounded by four tall walls to avoid wind disturbance as shown in Photo. 2 and 3. Typical examples of pictures are shown in Photo. 4 and 5.

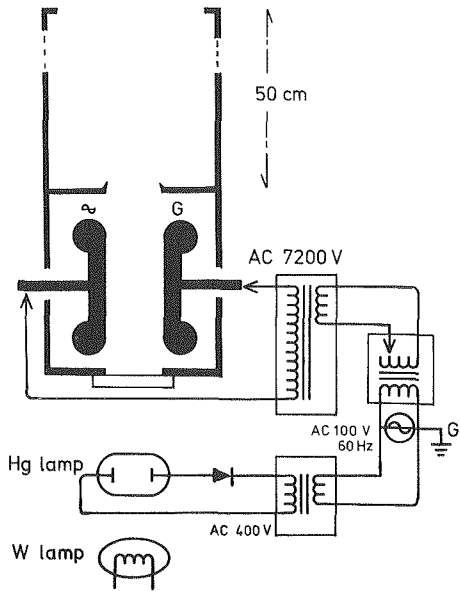


Fig. 1 Schematic of the equipment used for measuring the signs and quantities of electric charge on ice crystals. The shape of electrodes is approximately Rogowski type.

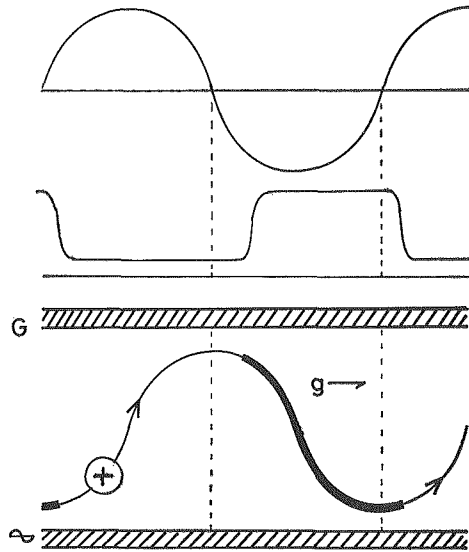


Fig. 2 The relation between the sign of electric charge on the particle and its illuminated phase in falling trajectory, top: applied alternative potential to the electrode against G, middle: illumination phase of Hg lamp, bottom: falling trajectory of a particle carrying positive electric charge.

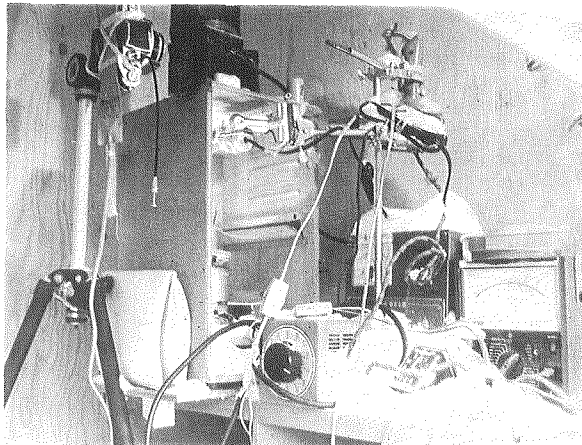


Photo. 1 Real feature of settled equipments.



Photo. 2 Feature of operation taken from upper opening of the observation box.

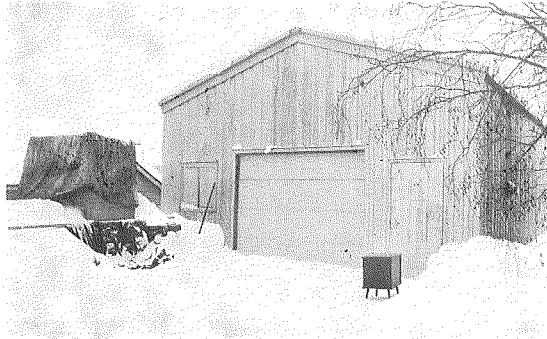


Photo. 3 Whole view of observation box for avoiding wind disturbance.

3. Results

Diamond dust phenomena occurred three times during our stay at Inuvik. Fortunately observation was carried out successfully in the most severe and strong fog on Jan. 31st 1977, which is mainly analyzed in this paper.

A typical example of the pictures taken are shown in Photo. 4 and 5. As seen in the picture, the sign of electric charge carried by the individual ice crystal was easily and exactly determined by the strongly illuminated phase of sinusoidal trajectory. All data taken in that period are shown and plotted in Fig. 3. The abscissa and ordinate are respectively related to electric charge quantity and size of ice crystal, and the figures are separated

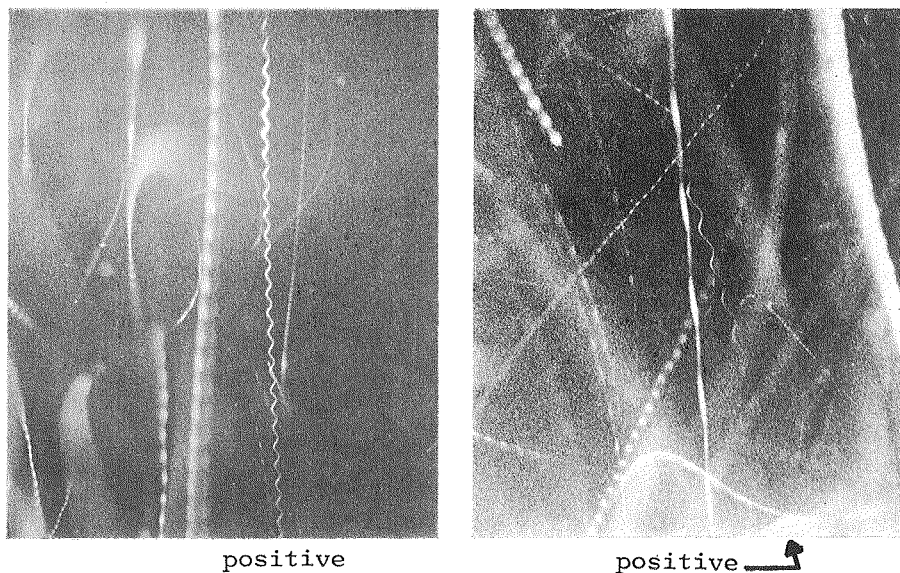


Photo. 4 These picture showing the typical examples of falling trajectory of charged ice crystals. Strongly illuminated phase indicates the sign of electric charge on individual ice crystal.

from top to bottom for positive and negative charge respectively. Solid and open circles indicate the observed time respectively in the early and later half of the observation period of diamond dust. As seen in the figure, the frequency of positive and negative charge are approximately equal.

Observed values of electric charge on ice crystals were in a range of 3×10^{-8} esu to 5×10^{-5} esu, while the size of ice crystals measured were in a range of $8 \mu\text{m}$ to $80 \mu\text{m}$.

It is noted that due to the using this equipment, both ranges were extended to smaller values than that were measured by Magono and Kikuchi⁵⁾ and Magono and Iwabuchi²⁾ as shown in the figure.

The time changes of the sign of electric charge are dramatically shown in Fig. 4. In the figure, the top curve indicates the atmospheric potential gradient at the surface, second, the upward and downward spikes in time series respectively shows only the sign of positive and negative charge of ice crystal measured at the time of spike position on the time axis. Bottom histogram in time series shows the flux of ice crystal fall or intensity of ice fog.

Diamond dust appeared over the observation site in periodically changing

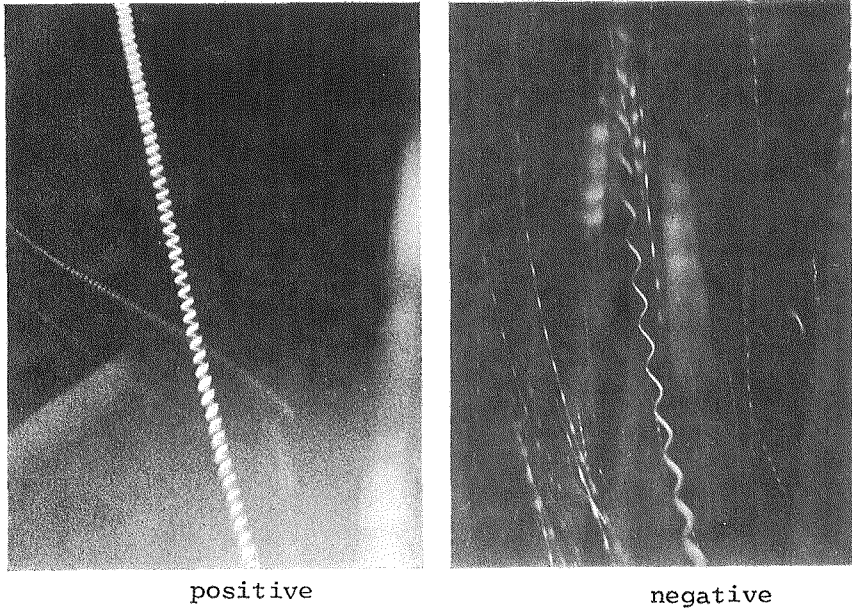


Photo. 5 These picture showing the typical examples of falling trajectory of charged ice crystals. Strongly illuminated phase indicates the sign of electric charge on individual ice crystal.

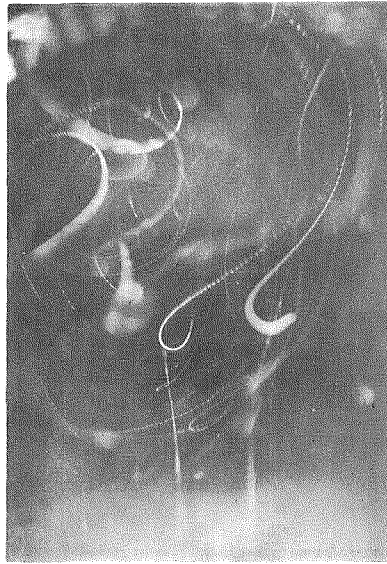


Photo. 6 This picture is one of examples showing complicatedly curved trajectory in the early stage of ice fog.

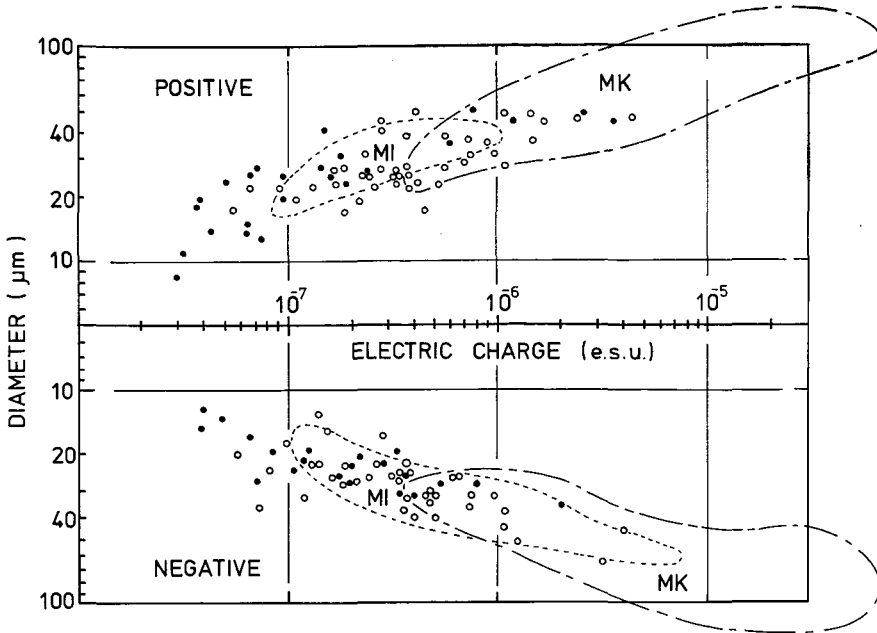


Fig. 3 Relation of the size and electric charge of individual ice crystal. Solid and open circles show respectively the ice crystal observed in the early and later half of the whole diamond dust period, MI: measured in the laboratory by Magono and Iwabuchi²⁾, MK: measured in the cloud at mountain-top by Magono and Kikuchi⁵⁾.

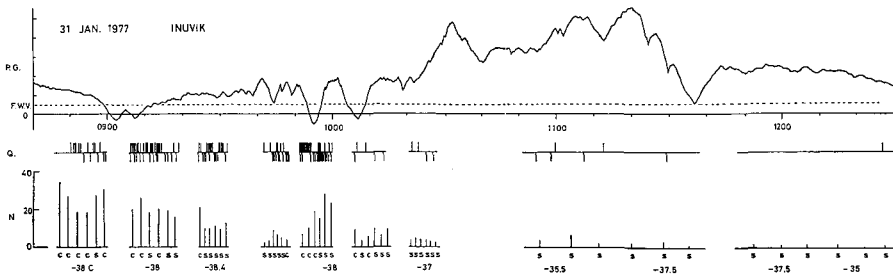


Fig. 4 Time variation in ice fog (diamond dust) on Jan. 31st 1977, P.G.: electric potential gradient at the surface, F.W.V.: fair weather value, Q: the signs of electric charge carried by ice crystals, upward and downward spikes show positive and negative signs alone of electric charge respectively, N: net flux of ice crystal-fall ($1/cm^2 \cdot MIN.$)

intensities of wave like concentrations. It was observed that at an early stage of the wave pattern, electric charges of ice crystals were predominantly positive and the concentration and size of ice crystals were relatively high and small respectively, and that, on the contrary, in the later stages, electric charges of ice crystal were predominantly negative and the concentration and size of ice crystals were relatively low and large respectively. The most representative example in such a case was seen in a period from 0948 to 1000 on Jan. 31st 1977. And this particular time the electric potential gradient were observed to change dramatically. From the pictures of trajectory of falling ice crystals, all cases were divided into two types namely, complicatedly curved as shown in Photo. 6 and in a simple straight trajectory. These are indicated as C and S in Fig. 4. And it may be seen that C and S are related to the above-mentioned early and later stages respectively.

After sunrise around 1130, it was noted that fog was about to disappear, whereupon the atmospheric electric potential gradient was strongly enhanced to large positive values which were not previously seen in any other precipitation during the observation period.

4. Consideration

It may be considered that in the early stage, the moisture of air surrounding ice crystals was high, after which numerous minute ice crystals released their latent heat under fast growth. This was followed by ice crystals and the surrounding air moving complicatedly because of partial convection. While in the later stage, the size of the ice crystals became considerably large and the moisture in atmosphere of ice crystal was considerably lowered. Thus they could no longer release the latent heat, and as a result ice crystals fell vertically following a nearly straight trajectory. The relation between the sign of electric charge of ice crystal and its moisture condition deduced from the difference of growing stage of ice fog seems to be in good agreement with the results of laboratory experiment which were previously performed by the present author, as shown in Table 1, although the conditions of air temperature were different. This observation and the experiment mentioned above were carried out at an air temperature of -38°C and -15°C respectively (c.f. Appendix).

Regarding the abnormally enhanced positive potential gradient immediately after fog disappearance, the following explanation may be considered. First, as a result of fog disappearance, the fully grown ice

Table 1. Comparison with the results of laboratory experiment (see Appendix) and field observation
laboratory experiment at -15°C

		Measuring time	
		early	later
Experimental results	Polarity of ice crystal charge	positive	negative
	Feature of ice crystal	size number shape droplet	larger moderate sharp a few
Consideration	Moisture around ice crystal	plenty	poor

field observation at -38°C

		Measuring time		
		early	later	
Observation results	Polarity of ice crystal charge	positive	negative	
	Feature of ice crystal	falling trajectory	complicatedly curved	simply straight
		size number shape	small too many sharp	large a few soften
Consideration	Moisture around ice crystal	plenty	poor	

crystals preferentially carried a negative charge and fell to earth releasing the charge to the ground, which left the opposite sign of charge in the atmosphere. Whereas those with a positive charge enhanced the normal potential gradient positively. Second, when fog disappeared, it may be considered that the ice fog left a considerable amount small size, low mobility particles e.g. large ions which lowered the atmospheric electric conductivity and this effect in turn caused the normal potential gradient to be highly enhanced because of atmospheric Ohmic law.

5. Conclusion

The electric charges of diamond dust were measured successfully by a specially designed apparatus. It appears that the signs of charge carried by individual ice crystal depend on the growth stage of the ice fog. At the early stage, they were very small in size with a high concentration, and thereafter

they preferentially carried a positive charge. However in the later stage, they were large in size with a low concentration, and thereafter they carried preferentially a negative charge. The sign of the electric charge appeared not to depend on the shape of ice crystal.

In the records of atmospheric electric potential gradient in diamond dust, it may be noted that the effect of residual space charge was caused by leakage of preferential charge which was carried by falling ice crystals.

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Appendix

In order to investigate the mechanism of electrification processes on ice crystals, some experiments were carried out in the laboratory. These are to be published in full in the future but will be described briefly here as follows.

In a cold box filled with fog of supercooled droplets, ice crystals were generated by a seeding method. Ice crystals suspended in the air were all suctioned forcibly by a pump and the ice crystals alone were trapped by a filter, which was electrically isolated from the ground and connected to an electrometer for measurement. It was noted that the signs of electric charge of ice crystals depended to the time elapsed after the seeding until the onset of suction and measurement. Ice crystals in the early and later stage of a life cycle carried preferentially positive and negative electric charge respectively. In the former stage, since there was sufficient humidity, ice crystals grew vigorously. On the other hand in the latter stage, when the humidity was not plentiful, ice crystals stopped growing or in some cases even began to evaporate. The relation of these results are summarized in the upper part of Table 1.

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