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On the Size of Electric Charge Carriers and Their Relaxation Time in the Atmosphere around the Growing Ice Crystals

(Electrification Mechanisms of Snow Crystals: Part III)

Tatsuo Endoh

Department of Geophysics, Faculty of Science
Hokkaido University, Sapporo 060, Japan

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Abstract

Electric charge carriers contained in the atmosphere with the exception of ice crystals in their growing stage were investigated by means of two parallel Gerdien tubes and three kinds of filtration methods in a temperature around −15°C.

Ion current was largely negative in both tubes and in every filtration method. By decreasing the set critical mobility, the negative ion current could be prevented to flow in a positive side inner electrode due to some turbulences. From these critical mobilities, the size of carriers was estimated to be less than 40 Å. The mean relaxation time was deduced to be more than 100 sec according to the concentration of carriers.

1. Introduction

In the investigation of electric charge generation of thunderclouds, recently it is becoming clear that the recombination loss should be considered as an important factor as well as separation. Nevertheless this effect has not been treated hitherto in observations and experiments in the laboratory except for a few theoretical studies by Freier (1963, 1967), by whom relaxation time in thunderstorms was deduced theoretically to be several seconds.

On the other hand, in experimental results by Endoh (1981a, 1981b), the effect of recombination loss was considered qualitatively. In the first experiments where ice crystal charges were measured by forcible separation from their surrounding atmosphere, quantities of ice crystal charges were always detectable. In the second experiments where ice crystal charges were measured *in situ*, namely under a situation of free fall, the quanitities were relatively small or sometimes not detected. Charges of considerably large fractions of ice crystals were frequently too small to be measured. Con-

sidering the duration from the time when ice crystals are charged due to some separation mechanism to the time when they are sampled and their charges are measured, it may be expected that these in the former case are shorter than those in the latter. Therefore these difference are considered to provide an explanation for the experimental results in terms of recombination loss. For the purpose of reducing relaxation time, it is desirable to measure the mobility, size and concentration of the charge carriers.

2. Experimental Methods

An apparatus used in the present experiment is shown in Fig. 1. Ice crystals were produced in a tower with a horizontal areas of 40 cm×40 cm and a height of 240 cm, by introducing supercooled droplets and seeding with a cooled copper rod. Ice crystals were trapped forcibly by three kinds of filtration methods namely filter net, spiral tube and cascade methods. These are described in detail later.

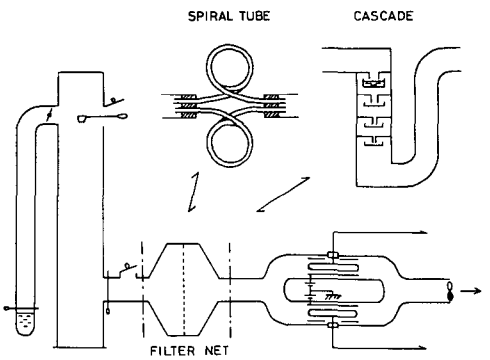

Fig. 1 Experimental apparatus for measurement of ions in the atmosphere around ice cryatsls. Three types of filter are illustrated schematically; filter net, spiral tube and cascade, and the detecting part is constructed by two Gerdien type ion counters in parallel with each polarity of ion.

Filtrated air was introduced into two Gerdien tubes set in parallel with each polarity and measured by means of charging method to each inner electrode, which was connected respectively to two vibrating reed electrometers of the same type. Critical mobility could be decided by selecting the potential of the outer electrode and flow rate.

(*a*) *Filter net method*

This is shown in the lower part in Fig. 1. A sheet of thin nylon cloth with a mesh size of 5~10 μm, was used as a filter net. To avoid early clogging of the pores of filter cloth and to decrease the speed of air flow, tubes were spread from 12 cm to 40 cm in diameter at the position of the filter cloth so that flow speed was decreased from 10 m/sec at the inlet to 10~15 cm/sec. Since such a low speed is nearly equal to the free fall speed of ice crystals examined, it is considered that no secondary charge generation occurred. However, the pores of the cloth were clogged by ice crystals after a few runs.

(*b*) *Spiral tube method*

This is shown in the upper middle in Fig. 1. Eight copper pipes with an inner diameter of 10 mm were given a double spiral with a radius of curvature of 4 cm and bundled and connected in parallel between the tower and Gergien tubes. All ice crystals were examined as they fell out during the passage through the spiral tubes due to the centrifugal force. The pipes were not chocked by icing or riming even after considerable usages.

(*c*) *Cascade method*

This is similar to the usual cascade impactor with four stages as shown at the upper right in Fig. 1. A small dish was placed on each stage and a kind of antifreezing solution was poured in it to completely avoid riming processes caused by supercooled droplets and ice crystals. Although a slide glass was set on the fourth stage and examined for any impacted particles by a microscope, no ice crystals or supercooled droplets were found there.

Experiments were performed in a procedure as follows. First, a lid D in the figure was left open and the air from out of the tower was introduced through the filter and Gerdien tubes continuously by a suction pump. When the measuring system of electrometers became stable and ice crystals were made in their growing stage in the tower, A and B were clogged and C was left open. Then the shutter E and a lid D were opened and closed respectively in turn. Then the air containing ice crystals and vapour in the tower was introduced to the filter and the filtrated air was expected to the measuring system one after another.

3. Results

Experiments were almost performed in a temperature around −15°C and was limited in ice crystals content at their growing stage.

Two records in the experiments by means of filter net method are shown in Fig. 2. Axes of the abscissa and ordinate indicate the time and ion current respectively. At the beginning positive and negative ion currents were seen to be in a balanced state by the air from the cold room. As soon as the shutter E was opened, the ion current went abruptly toward negative values in the records of both polarity tubes. It is noted that although the critical mobilities were set at 1.5 $cm^2/(sec \cdot V)$ even the record of the tube for positive ion indicated negative values.

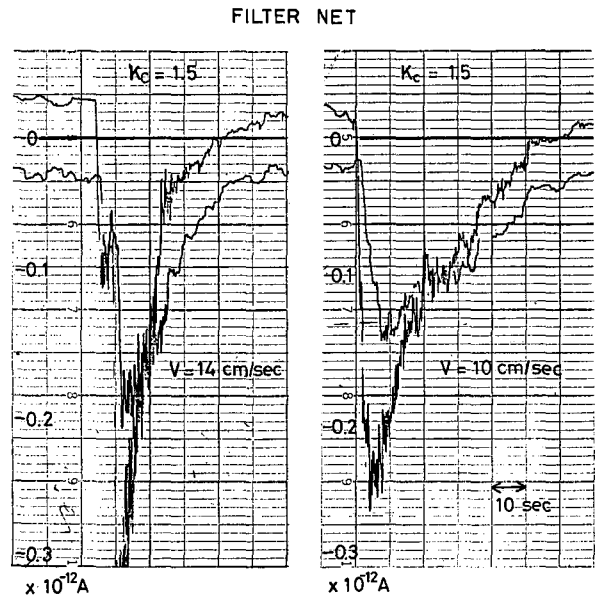

Fig. 2 Records of each polarity of ion current by the filter net method with filtration speed of 10∼14 cm/sec and Kc is the critical mobility in $cm^2/(sec \cdot V)$.

Three examples obtained by the spiral tube method are shown in Fig. 3. and similar changes to the previous figure are seen. The set critical mobilities were 0.35, 0.15, and 0.035 in the demension of $cm^2/(sec \cdot V)$. It is noted that the inflow of negative ion current into the positive side inner electrode was suppressed and stopped with the increase of the potential of the outer

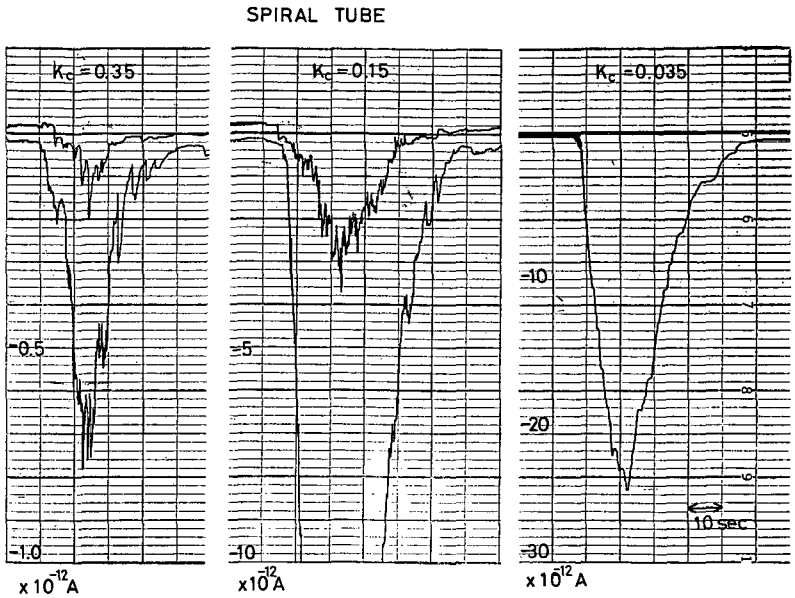

Fig. 3 Records of each polarity of ion current by spiral tube method and Kc is the critical mobility in $cm^2/(sec \cdot V)$.

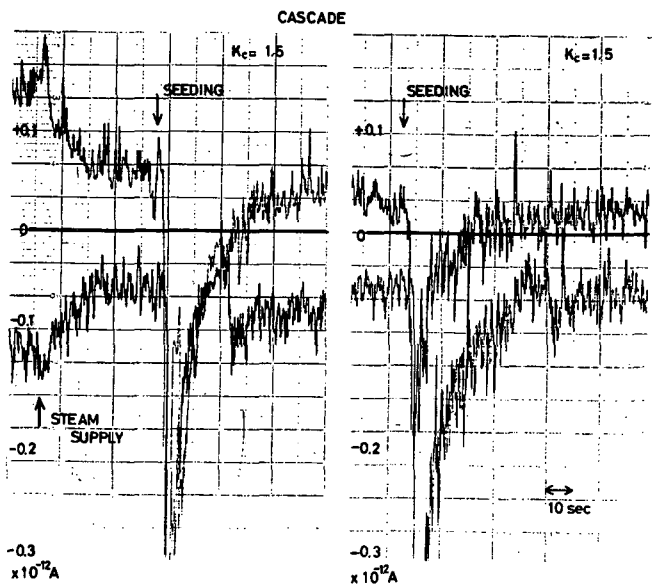

Fig. 4 Records of each polarity of ion current by the cascade method and Kc is the critical mobility in $cm^2/(sec \cdot V)$.

electrode. In the case of Fig. 4, it is also seen that a similar inflow of negative ion current occurred in both tube by the even cascade method.

4. Consideration

It was observed that the surrounding air except for ice crystals in their growing state caused considerably large ion currents with negative polarity. The sign of these ion currents are in good agreement to the results by Endoh (1981a).

Furthermore, this was seen in every three kinds of filtration methods. It is considered that such negative ion current may be proved valid because it is not changed depending on the differences of filtration methods.

In many cases, a negative ion current was also seen in the positive side of the inner electrode. It is considered to be caused by the effect of a small fraction of turbulence in the Gerdien tube apart from the complete laminar flow. It was revealed that such negative ion currents may be suppressed and stopped by means of increasing the potential of positive side outer electrode in spiral tube method of Fig. 3. The obtained results are summarized in Fig. 5. The axis of the abscissa is set at the critical mobility and equivalent radius of ion. The axis of the ordinate shows the ion current or number concentration of ions at a constant flow rate in the tubes. In the figure, open and solid circles indicate the value of ion current and number concentration of ions in the positive and negative side of the inner electrode respectively. A pair of positive and negative side values which were measured at the same time are shown to be connected with a straight line. It is seen that almost all open circles are distributed on the negative side of the ion current, however since the set critical mobility is decreased to $0.035\ \mathrm{cm^2/(sec \cdot V)}$, open circles are lean to the negative side and are suppressed around zero. This mobility is considered to be the minimum value to reject such a charge carrier and the corresponding size of the carrier is about 40 Å in radius. At the same time, the ion current and number concentration measured with negative side inner electrode were -7×10^{-12}A and 9.1×10^{4} particles per $\mathrm{cm^3}$ respectively.

When positively charged particles lose their charges by recombination with negative ions in ion concentration of N and their mobility of K, relaxation time τ is described as

$$\tau=\frac{2\pi}{eKN},$$

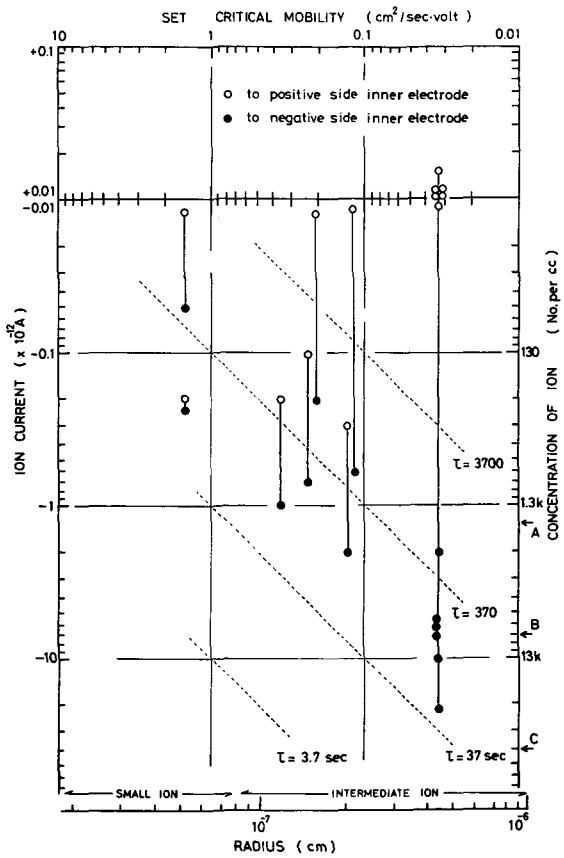

Fig. 5 Ion currents into the positive and negative side inner electrodes of the Gerdien tube versus critical mobility. Those may be translated into concentration of ions (ordinate) and equivalent critical radius of ions (abscissa). Broken lines are isopleth of relaxation time of electric charge in corresponding conductivity of the atmosphere. A and B-C are concentration of condensation nuclei in ordinal cold room air and in air of tower under experiment respectively.

where e is an elementary charge. In Fig. 5, thin broken lines show isopleths of relaxation time. In these experiment, since $K=0.035\ \mathrm{cm}^2/(\mathrm{sec}\cdot\mathrm{V})$, $N=9.1\times10^4/\mathrm{cm}^3$, relaxation time τ are seen in the range between 40 sec to 400 sec. Accordingly, the mean values of minimum relaxation time in these experiment are reduced about 100 sec. The values of carrier size and relaxation time obtained are considered to be the maximum and minimum of corresponding ions respectively, in the total atmosphere surrounding growing ice crystals.

5. Conclusion

The sign of the ion current obtained with Gerdien tube type ion counters was invariably negative in spite of changing the types of filtration method. With the increasing potential of the outer electrode, a set critical mobility which prevents unexpected flow to the inner electrode for opposite sign of ion due to some turbulences were decided and the value was 0.035 $cm^2/(sec \cdot V)$, where ion concentration was calculated 9×10^4 particles per cm^3 and mean values of deduced relaxation time was 100 sec.

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