

The Mechanism of Dissolution of the Atmospheric Chloride into Rain Water

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Abstract

The mechanism of the dissolution of the atmospheric chloride particles into rain drops by their mutual collision has been studied. The results obtained are as follows.

1. Relations among the chloride content per drop, the radius and the number of falling drops have been obtained, assuming that there is no supply of the chloride particles by an exchange or a flow of the air mass, and that the number of falling drops through the unit area per sec. and the radius of rain drops do not vary much.
2. A formula expressing the time variation in the amount of the chloride precipitation in a rain has been deduced.
3. The relation of the chlorinity, C , to the rainfall amount, P , can be expressed as follows:

$$C \cdot P = D(1 - e^{-P \cdot 3\sigma / 4r})$$

where, D is the total chloride content in the air column with the base of the unit area; σ , the rate of capture with which a rain drop captures salt particles; r , the mean radius of rain drops.

4. The order of magnitude of the radius of the atmospheric chloride particles can be obtained by estimating the value of σ in the above formula. The result agrees well with that of Wright.

Introduction

The process of dissolution of the atmospheric saline matter in water drops can be divided into two stages. The first is that in which drops exist as the cloud state.

In the second stage, leaving the cloud base, they fall to the ground as rain drops. The first stage consists of so many complicated processes as the coagulation and the sublimation of water vapour or the growing of cloud particles to rain drops. Therefore, it admits of no simple treatment. On the contrary, in the

second stage it would be sufficient to consider only the dissolution of the atmospheric salt particles into rain drops by collision.

In this paper the authors intend to report the result of a study on the latter stage.

1. The mechanism of dissolution of rain water by collision.

Now let us consider the mechanism of washing down the atmospheric salt particles by rain drops. For the sake of simplicity, it is assumed that the radii of rain drops, the intensity of rainfall and the rate of capture with which a rain drop captures salt particles by collision are nearly constant, and also that there is no supply of salt particles by an exchange or a flow of the air mass during a certain time interval in a rainfall. Then, the chlorinity δ_0 of air at the height h decreases with the lapse of time after the beginning of rainfall as follows;

$$(1) \quad \delta_0(1 - nS\sigma)^t = \delta_0 e^{-ns\sigma t}$$

Where n is the mean number of rain drops falling through the unit area per unit time, S is the mean area of cross sections of rain drops. Since the rain drop dissolves salt particles during its fall from the cloud base to the ground, the amount of chloride precipitation Cl , that is, the amount of chloride fallen on the unit area of the ground surface during τ sec., from t to $t+\tau$ sec. after the beginning of rainfall can be expressed by the following;

$$(2) \quad Cl = \int_0^h \int_t^{t+\tau} \delta_i n S \sigma dh dt.$$

Here, δ_i is assumed as a product of a simple function of h and $\exp(-ns\sigma t)$ and by putting $\alpha = nS\sigma$, the above formula becomes as follows.

$$(3) \quad Cl = D e^{-\alpha t} (1 - e^{-\alpha \tau}),$$

where, $D = \int_0^h \delta_i dh$, that is, the amount of total chloride contained in the air column with a height h standing on the base with the unit area. As the mean chloride content per one drop ρ is $Cl/n\tau$,

$$(4) \quad \rho = D e^{-\alpha t} (1 - e^{-\alpha \tau}) / n\tau,$$

Therefore, the variation of ρ due to the minute variation of n and r may be written in the following two equations.

$$(5) \quad \partial \rho / \partial n = -(D e^{-\alpha t} / \tau n^2) [\alpha \{t - (t + \tau) e^{-\alpha \tau}\} + 1 - e^{-\alpha \tau}]$$

$$(6) \quad \partial \rho / \partial r = -(D \pi r e^{-\alpha t} / \tau) (2\sigma + r \partial \sigma / \partial r) \{t - (t + \tau) e^{-\alpha \tau}\}$$

2. Results of observations

Rain water was collected in a large enamelled dish. The number of traces of rain drops fallen on a filter paper coated with the mixed powder of eosin and talc was measured. The exposure of the filter paper was done at every five minutes. The chlorinity of rain water was determined by the method of drop colorimetry contrived by one of the authors (Sugiura)¹⁾.

The mean radius of drops was calculated by the amount of precipitation and the mean number of falling drops per unit time. Thus, the relation among the

chloride content per drop, the number of falling drops and the radius were examined, using the observed data obtained on 4th Oct. 1949. As to the rate of capture σ , we used the formula which Albrecht²⁾ gave for a cylinder with a radius R capturing particles of radius a .

$$(7) \quad \sigma = \{1 + 1.06(KR/V)\}^{-1}$$

where, V is the speed of flow at the infinite distance, $K=9\mu/2da^2$, μ is the viscosity coefficient of the liquid; d , the density of particle.

In our observation, the mean radius r of rain drops was 0.46 mm., the mean number of falling drops n through the unit area per sec. was $0.047\text{cm}^{-2}\text{sec}^{-1}$, and the mean chloride content per drop ρ was 54.6×10^{-11} g. In Figs. 1 and 2 the relation of ρ to n and r are given. The full lines show inclinations which are mean

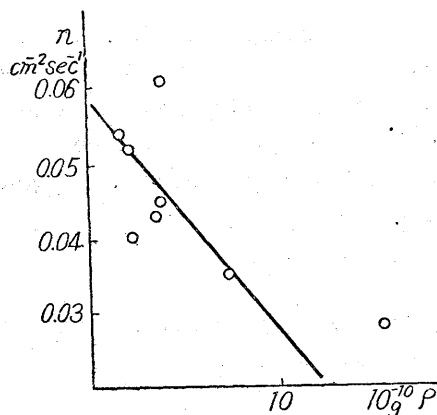


Fig. 1 The relation between the chloride content ρ per drop and the number n of falling drops.

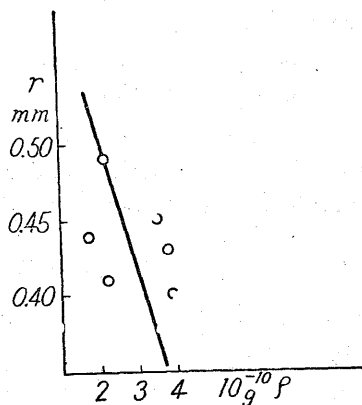


Fig. 2 The relation between the chloride content ρ per drop and the radius of rain drops.

values of $\partial\rho/\partial n$ and $\partial\rho/\partial r$ calculated by the formulae (5) and (6). These figures show an approximate agreement between calculated and observed values which prove the appropriateness of the above formulae for the dissolving process of the atmospheric chloride in rain water. In other words, the main part of the mechanism of dissolution seems to be the collision process between falling rain drops and salt particles suspending in the air.

3. The time variation of the amount of chloride precipitation

Next, we investigated the variation of the amount of chloride precipitation with the lapse of time from the beginning of a rainfall. In the case of actual rain the drop size has naturally a certain distribution and the number of falling drops and the rate of capture change with time. However, we can calculate approximately by the equation (3) the amount of chloride precipitation during a short time inter-

val using their mean values. When the time of the beginning of a rainfall is fixed as the time origin and the collection of water sample is done successively during $\tau_1, \tau_2, \dots, \tau_{i-1}, \tau_i, \dots$ sec., the amount of chloride precipitation Cl_i during τ_i is given by

$$(8) \quad Cl_i = D \cdot e^{-\sum_{i=1}^{i-1} \alpha_i \tau_i} (1 - e^{-\alpha_i \tau_i}),$$

where α_i is the product of mean values of n, S and σ during the i -th collection. As D was unknown here, it was selected so that the chlorinity in the first collection should satisfy the above formula. Fig. 3 gives a comparison between the calculated

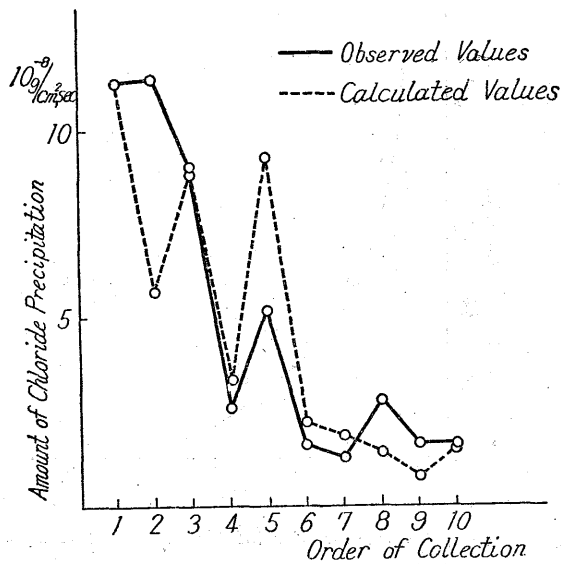


Fig. 3 The time variation of the amount of chloride precipitation.

change in time of the chlorinity by the equation (8) using observed values of α and the actual amount of chloride precipitation. In this figure also, we see an approximate agreement between them.

4. The relation between chlorinity and rainfall amount

Formerly one of the authors (Miyake)³⁾ found that the chlorinity of each rainfall quickly decreases with increasing total amount of the rainfall. According to Sugawara and his collaborators,⁴⁾ an approximate relation between the amount of precipitation P and the chlorinity C is nearly hyperbolic especially for rains caused by a similar meteorological condition at a certain place, that is,

$$C \cdot P = \text{const.}$$

The amount of chloride precipitation of each rain from the beginning to the end $t=T$ may be given by the equation (3).

$$(9) \quad Cl_{0-T} = D(1 - e^{-\alpha T})$$

where, α is the mean value from the beginning to the end. Then, the chlorinity of rain water C may be given in the form,

$$(10) \quad C = D \cdot (1 - e^{-\alpha r}) / P.$$

On the other hand, as the amount of precipitation P is

$$P = (4/3)\pi r^3 n T,$$

then, the above equation can be written as follows,

$$(11) \quad C \cdot P = D \cdot (1 - e^{-P \cdot 3\sigma/4r})$$

We determined the values of D and $3\sigma/4r$ in the above formula using two arbitrary chlorinity values observed by Sugawara and others in the rainy season of 1943 at Nagoya City and obtained the relation between C and P (Fig. 4).

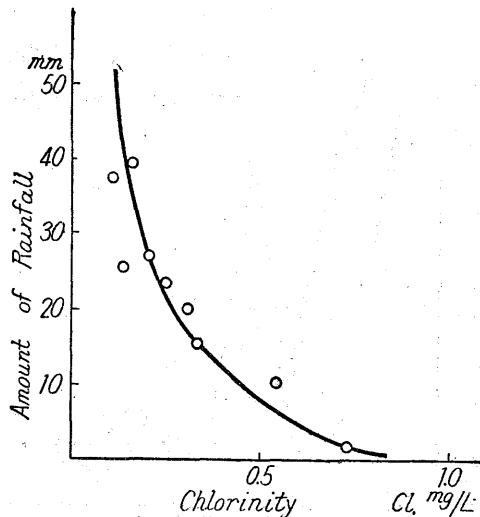


Fig. 4 The relation between the amount of rainfall and the chlorinity in rain water.

Curve : Calculated value.

Circle : Observed value by Sugawara.

It shows a good agreement between calculated and observed values. Therefore, it may be said that Sugawara's hyperbolic relation is an approximate expression of our formula. In this case, we obtained 1.97 as a value of $3\sigma/4r$, therefore, assuming that the radius of rain drops is 0.5mm., we could obtain 0.104 as the rate of capture σ . Using this value, the mean radius a of salt particles can be estimated by Albrecht's equation as follows,

$$a = 0.8 \times 10^{-4} \text{ cm.}$$

It is to be noted that this value is the same in the order of magnitude as that which Wright⁵⁾ gave for salt particles in the atmosphere by a different method.

References

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