Freezing characteristics of rain water drops with different solutes and their implication on anomalous ice crystal concentrations in clouds

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ABSTRACT

In an attempt to examine the probable cause for the reported anomaly between the ice crystal-and ice nucleus concentrations in clouds, the authors have carried out laboratory experiments on the freezing of rain water drops, under various conditions of temperature, with various solutes. Sulphates, when present in adequate concentration, have been found to accelerate remarkably the process of ice-formation in the drops. The contrast noticed has been greater at warmer temperatures. The ice-forming ability of silver iodide has also improved remarkably in the presence of sulphates. Chlorides, on the contrary, not only decelerated natural ice-formation in the drops but also deactivated silver iodide. Based on certain considerations, the features observed have been interpreted to account for at least part of the anomalous ice crystal concentrations reported in clouds.

1. Introduction

It was generally accepted until recently that each ice crystal in a cloud originates on an ice nucleus. But, field observations have pointed out that this is not always the case (Braham, 1964; Mossop, 1968; Auer et al., 1969). Upto about 4 orders of magnitude more of ice crystals than ice nuclei have been reported in some cumulus clouds depending upon how near was the cloud top temperature to 0°C. Many mechanisms have been suggested to explain this anomaly, but none of them has been conclusively proved (Mossop et al., 1970). Certain new mechanisms have been also recently suggested (Ramachandra Murty and Ramana Murty, 1971a and 1971b).

The present authors consider that at least part of the anomaly reported could have something to do with the effect of the soluble salts present in the cloud air on the ice-forming ability of the non-soluble nuclei contained therein, and the effect possibly not being reflected fully in the estimates made of the ice nucleus concentration in conventional manner. The following reasons prompted the authors to this consideration:

(1) the anomaly has been particularly noticed in maritime clouds (Mossop, 1968), (2) even as early as in 1949, definite evidence of freezing in relatively warm maritime clouds was pointed out (Coons et al., 1949), (3) though the results of experiments reported so far on the effects of soluble salts on the freezing temperatures of drops have not been definitive (Lafargue, 1950; Mason, 1954; Hosler & Hosler, 1955; Hoffer, 1961; DePena et al., 1962 & Pruppacher, 1963), the fact that soluble salts do influence freezing has not been ruled out, and (4) conditions simulated for ice nucleation in the conventional type of equipment used for measuring ice nucleus concentration could be different from those actually obtaining in natural clouds to take fully into account of the effect of the soluble salts present in the cloud air on the ice-forming ability of the non-soluble nuclei contained therein.

Study has, therefore, been undertaken to examine the effect of commonly present soluble salts in the air on the ice-forming ability in drops which contain natural non-soluble nuclei. The study has revealed that such drops do freeze more readily than normal in the presence

of sulphates and less readily than normal in the presence of chlorides. The experiments conducted and the results obtained are presented below. Based on certain considerations, the implication of the results on the reported anomaly between the ice crystal and ice nucleus concentrations in clouds has been discussed.

2. Soluble salts chosen for study

Chlorides and sulphates constitute the bulk of the soluble component in natural aerosols. The salts chosen for study are sodium chloride, magnesium chloride, sodium sulphate, ammonium sulphate and magnesium sulphate. The first three, which are present in concentrations in sea water in the order stated, constitute the bulk of the soluble component in the sea which is one of the main sources of hygroscopic aerosols (soluble salts) in the air. Ammonium sulphate has been suggested to be invariably present in natural aerosols (Mészáros, 1968). Magnesium sulphate also has been chosen because of the definite presence of magnesium in natural aerosols as revealed by the chemical composition of rain waters (Junge, 1963).

3. Experiments

As rain water contains natural non-soluble nuclei, study has been carried out with one of the several rain water samples which had been collected at the station. Drops of diameter 2.2 mm, which could be readily produced with a standard grade hypodermic needle, have been used all through. The procedure followed in the experiments is given below.

Pure rain water drops and solution drops (rain water drops containing salt in given concentration) have been taken in equal numbers (30 each) in two identical metal dishes coated with water repellant films using Dow Corning silicone lubricant. The dishes have then been sealed from the top with glass covers and subjected to identical rates of cooling by transferring them simultaneously on to a cold stage which has been kept precooled in a cold box to the desired temperature with the help of a suitable refrigerator system. The number of drops freezing in each dish at successive one-minute intervals of time has been noted with naked eye until all the drops taken in both the

dishes have frozen. The temperatures attained by the dishes at the successive intervals have been measured by thermocouples made from SWG-36 copper-constantan wires and given correct to the first decimal place. The mass of each metal dish being small (590 g) as compared to that of the cold stage (100 kg) and the insulation of the cold box used being good, the dishes, after attaining the equilibrium temperature, have retained that temperature, in every case, over an hour as revealed by actual measurements.

The experiment has been carried out with each of the five salts and with the cold stage, in each case, initially at temperatures $-20°C$, $-15°C$ and $-10°C$. Pure rain water drops in the one dish served as reference to solution drops in the other dish at these temperatures. The experiment has also been carried out with the cold stage initially at temperatures $-5°C$ and $-3°C$, but in the experiments at these warmer temperatures, the drops taken in both the dishes i.e. rain water drops as well as solution drops, contained powdered silver iodide (L–R grade of BDH) in concentration of 2 g per litre. Rain water drops containing silver iodide in the one dish served as reference to solution drops containing silver iodide in the other dish at these temperatures.

Experiment has been carried out, but in a qualitative manner, with smaller drops of non-uniform size, at two warmer temperatures, $-10°C$ and $-3°C$.

In one series of trials made, drops from samples of sea water have been examined with the cold stage initially at temperatures $-20°C$, $-15°C$ and $-10°C$.

4. Results

Except for sodium sulphate the effects of all the other salts have been examined only at 1 M concentration. The effect of sodium sulphate has been examined at 1 M and other smaller concentrations of 0.1 M, 0.01 M and 0.001 M.

(i) Cold stage at $-20°C$, $-15°C$ and $-10°C$

The fractions frozen of rain water drops and solution drops at successive 1-minute intervals of time have been shown in Figs. 1 to 3 with cold stage temperatures initially at $-20°C$, $-15°C$ and $-10°C$ respectively. The temperatures of the dishes at 5-minute intervals have been
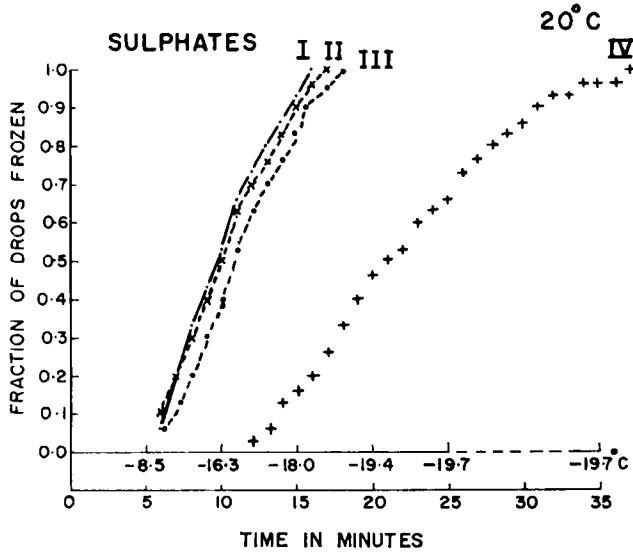
Fig. 1a. Fraction of solution (sulphate) drops frozen when the cold stage was initially at − 20°C. I, sodium sulphate; II, ammonium sulphate; III, magnesium sulphate; IV, pure rain water. Dish temperatures are given at 5-minute intervals.

indicated in the figures. Also, for better clarity, the temperature at which the first freezing event was noticed and the total time which was taken for all the 30 drops to freeze (time in minutes for the last freezing event) in each dish are listed in Table 1.

Cold stage initially at − 20°C: The dishes attained equilibrium temperature, which was − 19.7°C, in 23 min. Solution drops in the case of both sulphates and chlorides froze quicker than rain water drops (Figs. 1a and b). The presence of each sulphate elevated the
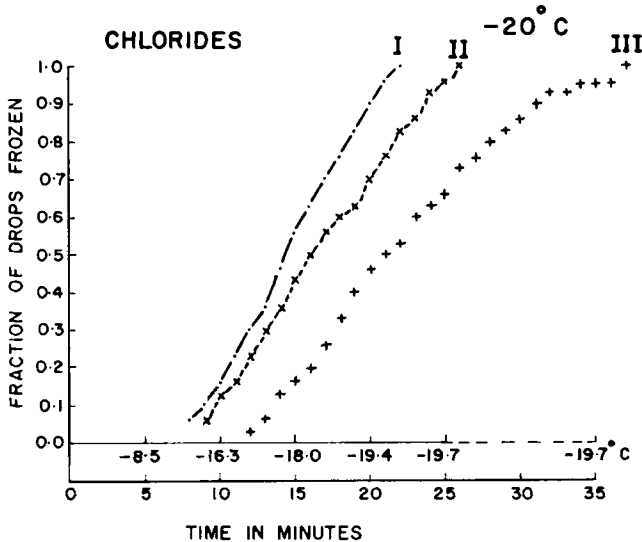

Fig. 1b. Fraction of solution (chloride) drops frozen when the cold stage was initially at − 20°C. I, sodium chloride; II, magnesium chloride; III, pure rain water. Dish temperatures are given at 5-minute intervals.
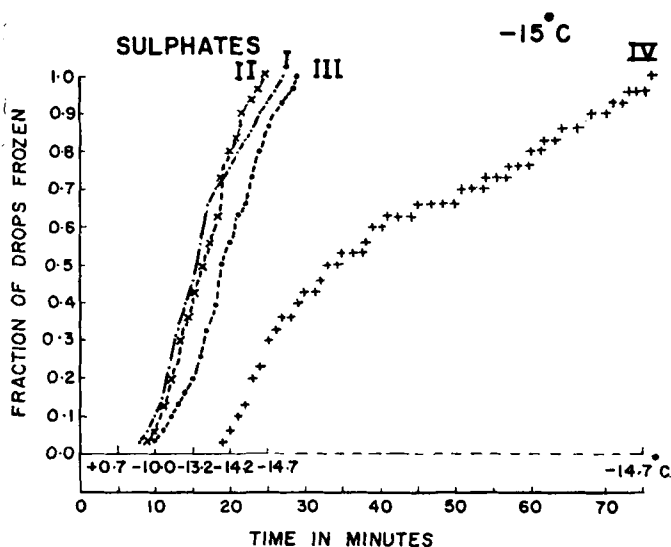
Fig. 2a. Fraction of solution (sulphate) drops frozen when the cold stage was initially at − 15°C. I, sodium sulphate; II, ammonium sulphate; III, magnesium sulphate; IV, pure rain water. Dish temperatures are given at 5-minute intervals.

temperature of the first freezing event (compared to rain water) by 4.3°C. The presence of sodium chloride elevated it by 2.7°C and the presence of magnesium chloride by 1.7°C (column 2 of Table 1).

Cold stage at − 15°C: The dishes attained

equilibrium temperature, which was − 14.7°C, in 25 min. Solution drops froze quicker than rain water drops (Figs. 2a and b). But, of the solution drops of the two kinds, drops containing sulphates froze quicker than those containing chlorides. The first freezing event
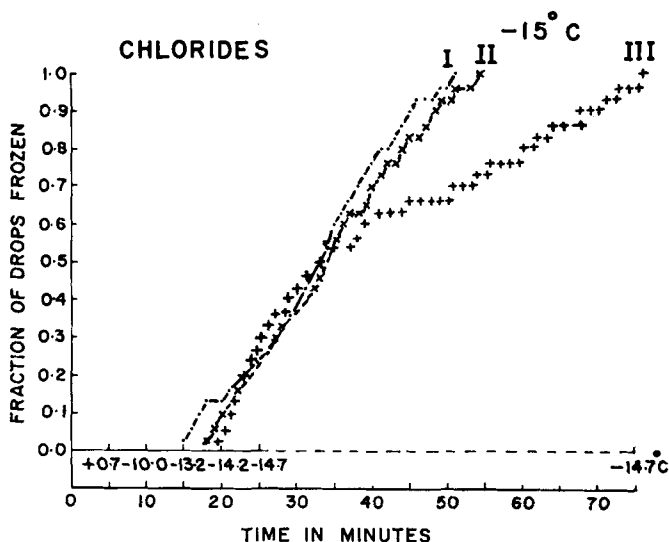

Fig. 2b. Fraction of solution (chloride) drops frozen when the cold stage was initially at − 15°C. I, sodium chloride; II, magnesium chloride; III, pure rain water. Dish temperatures are given at 5-minute intervals.
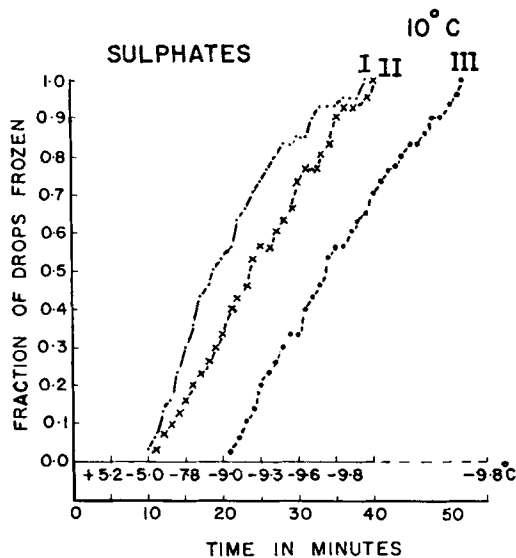
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Fig. 3. Fraction of solution (sulphate) drops frozen when the cold stage was initially at −10°C. I, sodium sulphate; II, ammonium sulphate; III, magnesium sulphate. No freezing event was ever observed in the dish which contained pure rain water drops. Dish temperatures are given at 5-minute intervals.

was elevated (compared to rain water) by 6.4°C, 5.1°C and 3.9°C by sodium sulphate, ammonium sulphate and magnesium sulphate respectively, and by only 0.7°C and 0.1°C by sodium chloride and magnesium chloride respectively (column 4 of Table 1).

Cold stage at −10°C: The contrast in temperatures of the first freezing event between solution drops containing sulphates and rain

water drops is best noted in this experiment as well as in the following ones.

The dishes attained equilibrium temperature, which was −9.8°C, in 33 min. Solution drops containing chlorides as well as the pure rain water drops never froze. Only solution drops containing the sulphates froze. Of the three sulphates (Fig. 3), sodium sulphate stands out, for, the first freezing event in this case occurred at as warm a temperature as −5.0°C (vide column 6 of Table 1). Ammonium sulphate closely followed sodium sulphate.

In order to establish by how much the temperature of the first freezing event in the drops was elevated by each salt under the conditions of this experiment, it is necessary to know the reference temperature, i.e., the temperature at which the first freezing event occurred in rain water drops under the same conditions. As the rain water drops never froze even well after the dish containing them attained the equilibrum temperature, a slightly different procedure had to be adopted in this case in order to arrive at a reasonable value for this temperature. For this purpose, the rain water drops in the dish after attaining the equilibrium temperature of −9.8°C on the cold stage were allowed to cool further on the same stage when the refrigerator system was again switched on to lower the temperature of the cold stage until the first freezing event was noticed in the dish. The dish could be cooled this way, as is also required, only at a very slow rate which was less than 5°C per hour. As the first freezing event was repeatedly found, by such operation, to occur at about −13.7°C this temperature was

Table 1. *Freezing characteristics of drops of various composition under different cold stage temperatures*

Cold stage temperatures ...	−20°C		−15°C		−10°C	
Composition of drops	First freezing event (°C)	Last freezing event (min)	First freezing event (°C)	Last freezing event (min)	First freezing event (°C)	Last freezing event (min)
Sodium sulphate 1 M	−12.9	20	− 7.5	27	−5.0	39
Ammonium sulphate 1 M	−12.9	20	− 8.8	25	−5.8	40
Magnesium sulphate 1 M	−12.9	24	−10.0	29	−9.0	52
Sodium chloride 1 M	−14.5	22	−13.2	51	—	—
Magnesium chloride 1 M	−15.5	26	−13.8	54	—	—
Sea water	−12.9	31	−13.3	46	−9.3	131
Rain water	−17.2	37	−13.9	76	a	—

[a] First freezing event occurred, after slow cooling, only at −13.7°C as explained in text.

Fig. 4. Fraction of solution (sulphate containing AgI) drops frozen when the cold stage was initially at −5°C. I, sodium sulphate plus AgI; II, ammonium sulphate plus AgI; III, magnesium sulphate plus AgI; IV, pure rain water containing AgI. Dish temperatures are given at 5-minute intervals.

accepted as the reference temperature. Considering that the temperatures noticed of the first freezing event in the case of solutions containing sodium, ammonium and magnesium sulphates are respectively −5.0°C, −5.8°C and −9.0°C, it would mean that the first

freezing event was elevated by 8.7°C, 7.9°C and 4.7°C respectively by these salts.

(ii) *Cold stage at −5°C and at −3°C*

Neither the rain water drops nor the solution drops of any of the salts tested ever froze in the
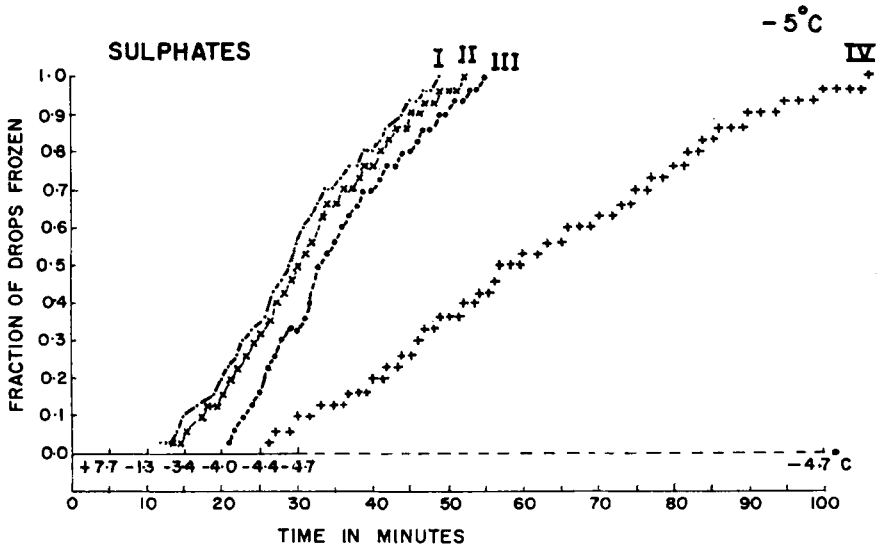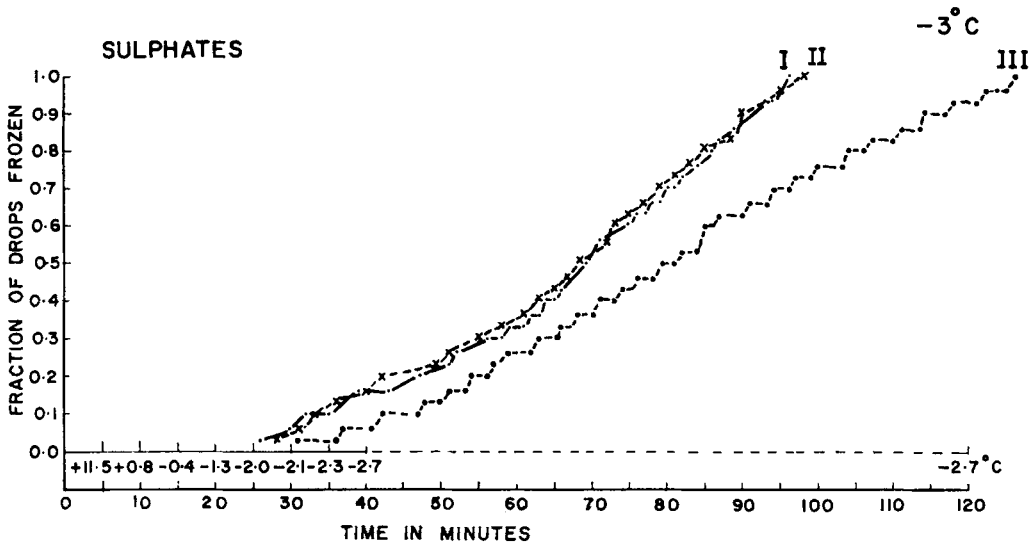

Fig. 5. Fraction of solution (sulphate containing AgI) drops frozen when the cold stage was initially at −3°C. I, sodium sulphate plus AgI; II, ammonium sulphate plus AgI; III, magnesium suphate plus AgI. No freezing event was ever observed in the dish with pure rain water drops containing AgI alone. Dish temperatures are given at 5-minutes intervals.

Table 2. *Freezing characteristics of drops of various composition under different cold stage temperatures*

Cold stage temperatures...	−5°C		−3°C	
Composition of drops	First freezing event (°C)	Last freezing event (min)	First freezing event (°C)	Last freezing event (min)
Sodium sulphate 1 M +Ag I (2 g/l)	−2.3	49	−2.0	97
Ammonium sulphate 1 M +Ag I (2 g/l)	−2.9	52	−2.1	98
Magnesium sulphate 1 M +Ag I (2 g/l)	−4.2	55	−2.1	126
Ag I (2 g/l)	−4.4	106	—	—

trials made at these temperatures. Silver iodide was used, threfore, as booster to promote freezing in the first instance. Rain water drops containing silver iodide in an arbitrary concentration of 2 g per litre and solution drops containing silver iodide in the same concentration have been examined accordingly. The characteristics of the freezing noticed have been shown in Figs. 4 and 5 and Table 2.

Cold stage at −5°C: The dishes attained equilibrium temperature, which was −4.7°C, in 29 min. The first freezing event in rain water drops containing silver iodide occurred only at −4.4°C. But, the drops froze more readily in the presence of all the sulphates. Sodium sulphate, which is found to be the most effective in facilitating ice-formation, raised the temperature of the first freezing event by 2.1°C, followed closely by ammonium sulphate which

raised it by 1.5°C (vide column 2 in Table 2).

None of the drops, inspite of the silver iodide within, ever froze in the presence of the chlorides.

Cold stage at −3°C: The dishes attained equilibrium temperature, which was −2.7°C, in 40 min. Drops with silver iodide froze only when the sulphates are present in them. The drop freezing was facilitated more by sodium and ammonium sulphates than by magnesium sulphate (Fig. 5). The first freezing event occurred in the case of sodium sulphate at as warm a temperature as −1.95°C (vide column 4 in Table 2).

(iii) Effect of solute concentration on drop-freezing

As the sulphates have been found positively to help activate ice-formation in drops, and of the sulphates tested, sodium sulphates has been found to be the most active, the effect of solute concentration on drop-freezing has been examined at 0.1 M, 0.01 M and 0.001 M concentrations for this particular salt only. The results have been presented in Table 3.

Freezing has been facilitated with higher solute concentrations in the concentration-range tested. The rise noticed in the temperature of the first freezing event was about 2°C (varied between 1.0°C and 3.6°C) when the solute concentration increased by one order of magnitude in the concentration range 0.01 M to 1.0 M.

(iv) Freezing of drops from samples of sea water

Sea water drops were found to freeze more readily than rain water drops, but compared to solution drops containing sulphates the sea water drops froze very slowly (vide Table 1).

Experiment has also been carried out with drops produced from a concentrated sea water

Table 3. *Freezing characteristics of solution drops at different solute concentrations under different cold stage temperatures*

Cold stage temperatures ...	−20°C		−15°C		−10°C	
Concentration of sodium sulphate in drops	First freezing event (°C)	Last freezing event (min)	First freezing event (°C)	Last freezing event (min)	First freezing event (°C)	Last freezing event (min)
1.0 M	−12.9	20	− 7.5	27	−5.0	39
0.1 M	−14.5	25	−11.1	41	−7.1	50
0.01 M	−15.5	29	−13.2	58	−9.0	95
0.001 M	−16.3	32	−13.3	67	—	—

sample. For this purpose, sea water from the sample taken has been allowed to reduce from its original volume by a factor of 7 (the factor chosen is only arbitrary) by slow evaporation at 50°C in a closed oven. Observations made with cold stage initially at −10°C have shown that none of the drops taken in the dish from the concentrated sea water sample ever froze.

(v) *Experiments with smaller drops of non-uniform size*

No attempt has been made to study systematically the freezing characteristics referred to above on drops of size smaller than 2.2 mm. However, the question whether the presence of salt in smaller but non-uniform sized drops has produced freezing under conditions when the drops without salt may not show freezing has been looked into. For this purpose, drops produced by a homespray atomizer, which were in the size range of few tens to few hundreds of microns, have been considered. The effect of only sodium sulphate has been examined at cold stage temperatures initially at −10°C and −3°C.

Observations made have revealed that with the cold stage at −10°C, only the solution drops froze but never the drops from the pure rain water sample. Further, with the cold stage at −3°C, solution drops (these contained silver iodide as before in the arbitrary concentration of 2 g per litre) only froze. Drops from rain water sample containing silver iodide alone never froze.

5. Discussion

All the sulphates tested have accelerated the process of ice-formation in drops at all the temperatures considered. The inference that sulphates serve as positive aids to freezing has been further corroborated by the fact that these solutes, by their presence, have improved the ice-forming ability of silver iodide by raising the temperature of the first freezing event by as much as 2.1°C and also, by activating freezing at as high a temperature as −1.95°C at which silver iodide is never known to be active. The results of the tests on non-uniform but smaller size droplets showed that the effect noticed of the sulphates is not dependent on the drop-size. Also, it is not dependent on the particular rain water sample selected, for, tests

carried out with other samples selected at random have revealed the same behaviour.

It is well known that sulphates are present in natural abundance in the atmosphere as has been revealed by the results of the chemical composition of atmospheric particulates as well as of rain water (Junge, 1963). Even in regions nearer coasts, this is the general feature which has been found. Also, it has been pointed out that the majority of the cloud condensation nuclei in both maritime and continental air are of composition similar to ammonium sulphate and certainly not sodium chloride or sea-salt (Twomey, 1971). As soluble and non-soluble nuclei will both be present in cloud air and as the majority of the soluble nuclei could be, for reasons as stated above, of sulphate composition, the simultaneous presence of sulphates in adequate concentration, at least for limited time periods, and non-soluble nuclei cannot be ruled out in a fraction of the cloud droplets in any cloud. Such droplets should freeze more readily than those containing non-soluble nuclei alone serving as ice nuclei. The feature suggests, therefore, that the number of ice crystals which will be actually produced in a cloud would always be more than what is anticipated on the basis of the number of ice present in the cloud.

The question to be considered next is whether the effect noticed of the sulphates could explain the trend of dependence on the cloud top temperature of the reported anomaly between the ice crystal- and ice nucleus concentrations. The results obtained at the various initial cold stage temperatures considered and also at the various solute concentrations tested help throw light in this regard. It was found that, with warmer initial temperatures of the cold stage, the rise in temperature noticed of the first freezing event in the drops was greater. For example, sodium sulphate, which is the most active of the solutes tested, elevated the temperature of the first freezing event by 4.3°C, 6.4°C and 8.7°C when the cold stage initially was at −20°C, −15°C and −10°C respectively. In terms of ice nucleus spectrum such elevations in temperature would mean progressively increasing concentrations upto about two orders of magnitude. If by the above initial cold stage temperatures considered it is nearly analogous to considering typical cloud situations having those cloud top temperatures, the feature as

above points out, in agreement with the re-
ported findings, that the suggested increase
in the ice crystal concentration over the ice
nucleus concentration, due to the presence of
the sulphate aerosol in cloud air, should become
more marked in situations of warmer cloud top
temperatures. As one extreme example, the
following may be considered. In a cloud situa-
tion when the cloud top temperature is $-10°C$,
none of the non-soluble nuclei present in the
cloud-air, serving as ice nuclei, may give rise
to ice crystals at any level (at cold stage
temperature of $-10°C$ none of the rain water
drops taken in the dish froze). However, if a
sulphate ion is also simultaneously present in
the required concentration, at last in a portion
of the cloud droplets, ice crystals may begin
appearing right from $-5°C$ level itself. Also, the
observation that freezing is facilitated more
at higher sulphate concentrations suggests
that, in the cloud air, solution cloud droplets
containing non-soluble nuclei freeze more
readily when these are in lesser dilution. Such
condition may become more possible in the
formative stages of the cloud droplets and
with droplets formed at lower levels in the cloud
(aerosol concentration would be more at lower
levels), in which case also the probability of ice
crystals forming in excess of ice nuclei could
increase at warmer temperatures.

The extent to which measurements made in
and inferences drawn from the present study
are representative of conditions in real clouds
is now required to be considered. Measurements
reported of the chemical composition of cloud
water (Petrenchuk & Drozdova, 1966) have
shown that in addition to a high content of
soluble constituents, there was a considerable
amount of insoluble constituents too, in most
samples. The concentration of sulphate ion in
the cloud water varied from a few milligrams
per litre to a few tens of milligrams and, some-
times, even more than 100 mg per litre depend-
ing upon how contaminated the cloud air under
question is. These features help support the
primary condition which is assumed, namely,
of the simultaneous presence of sulphates and
non-soluble nuclei in a fraction of the cloud
droplets. Also measurements reported on sul-
phate particle concentration in the air have
shown that sulphates are present in the atmos-
phere both in the large size (radius between 0.1
and 1 micron) and in the giant size (radius 1

micron and above) range, but being prepon-
derant in the former (Kapoor & Ramana Murty,
1966). Some recent measurements have also
pointed out that while 50 % of the sulphate mass
is in the Aitken size range, 40 % and 10 % of the
masses lie respectively in the large and giant
size range (Mészáros, 1970). Certain other meas-
urements reported have even shown that sul-
phates formed an ever-present particulate
constituent of the upper air, occurring in giant
sizes in about the same manner as the chlorides,
although less variable in geographic distribution
(Byers et al., 1957). These features help point
out that the presence, in cloud air, of sulphate
particles in the higher mass range of 10^{-13} to
10^{-10} gm is a reality. Recent measurements
reported of the hygroscopic nucleus masses of
individual cloud droplets have pointed out that
the nucleus masses are of the order of $8 \times 10^{-14} g$
to 10^{-10} g (Naruse & Maruyama, 1971). If,
therefore, sulphate particles in the mass range
10^{-13} to 10^{-10} g are considered to be present
in cloud droplets—an assumption which appears
to be reasonable in the light of the observa-
tional data as referred to above—the presence
of such particles would render the droplets in
their formative stages, say, before they attain
10 micron diameter (this value corresponds
roughly to the mode diameter which is generally
reported in clouds), to be concentrated in the
concentration range from about 0.001 M to 1 M.
When such condition is satsified in supercooled
regions of the cloud even with respect to a small
fraction of the cloud droplets present therein,
the freezing temperatures of those droplets,
according to the present findings, are likely
to be elevated by amounts ranging upto 8°C
or more. But, no such elevations in the freezing
temperature may be possible in the case of
cloud droplets which contain sulphate particles
of mass less than 10^{-13} g.

The chlorides examined accelerated the ice-
forming process in the drops only at the colder
cold stage temperatures considered, namely,
$-20°C$ and $-15°C$. At warmer temperatures
of the cold stage, chlorides not only failed to
show improvement but completely suppressed
the ice-forming ability of silver iodide. The
results obtained with chlorides in the present
study are in partial agreement with those re-
ported by other investigators according to
whom the chlorides tested showed depression
of freezing temperatures in drops (Mason, 1954;

Hoffer, 1961; Pruppacher, 1963) or deactivation of natural aerosols (Mossop & Thorndike, 1966).

The original ice-forming ability of the sea water drops was completely lost when the drops were concentrated. The feature, in view of what has been said above of the deactivating effect of chlorides and also in view of the fact that chlorides constitute the main bulk of the soluble component in sea water, suggests that the dominating influence in the concentrated sea water in suppressing ice-formation could be that of the chlorides in it.

The effects noticed of the soluble salts in help promoting ice-formation may not be fully reflected in the actual measurements made of ice nucleus concentration. The reasons could be as follows:

In the Millipore technique of measurement of ice nuclei, the possibility of missing particles in the size range in which sulphates preponderate chlorides in not ruled out. The present study has clearly shown that whereas sulphates aid ice-formation chlorides do the opposite. In the mixing and expansion types of technique of measurement, the thermal conditions simulated for activation of ice nuclei are not the same as those present in natural clouds. That the pattern of thermal conditions does exercise, sometimes, considerable influence on the activation temperatures of ice nuclei may be seen by reference to figures in the first row of Table 1. Under the situations of the cold stage temperatures initially at $-20°C$ and $-10°C$ the drops experimented have been subjected to two very different patterns of cooling. The temperatures at which the first freezing event occurred in the case of drops containing sodium sulphate in the two situations referred to above are respectively $-12.9°C$, and $-5.0°C$. In terms of ice-nuclei spectrum such variations in temperature could mean variations in ice nucleus concentration of about two orders of magnitude. Also, the conditions as in actual clouds, under which natural non-soluble nuclei in cloud-air sometimes get attached to the concentrated solution droplets, thereby facilitating their freezing, which otherwise may not take place, are absent in the conventional techniques of measurement.

Conclusion

The presence, in adequate concentration, of sulphates accelerated, in all the conditions tested, ice-formation in the drops which contained natural non-soluble nuclei. The presence of chlorides, while accelerating ice-formation in certain limited conditions, actually decelerated it under all other conditions. No explanation has been offered for the features noticed. Various views have been put forward by investigators in an attempt to explain the results obtained by them in similar contexts (Mason, 1954; Hosler & Hosler, 1955; DePena, et al., 1962). It does not appear possible to explain fully in that light the behaviour of sulphates and chlorides as observed in the present study. Further investigations are needed in this regard.

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ХАРАКТЕРИСТИКИ ЗАМЕРЗАНИЯ КАПЕЛЬ ВОДЫ С РАЗЛИЧНЫМИ РАСТВОРЕННЫМИ ВЕЩЕСТВАМИ И ИХ ОТНОШЕНИЕ К АНОМАЛЬНЫМ КОНЦЕНТРАЦИЯМ ЛЕДЯНЫХ КРИСТАЛЛОВ В ОБЛАКАХ

В попытке проверить вероятные причины описанной аномалии в отклонении величины концентраций ледяных кристаллов от концентрации ядер конденсации в облаках, авторы провели лабораторные эксперименты по замораживанию капель дождевой воды при разной температуре с добавлением различных растворимых веществ. Найдено, что сульфаты в соответствующих концентрациях заметно ускоряют процесс образования льда в каплях. Этот эффект усиливается при боль-

ших температурах. Свойство ускорять образование льда у иодистого серебра также заметно увеличивается в присутствии сульфатов. Наоборот, хлориды не только замедляют естественное образование льда в каплях, но и уменьшают активность иодистого серебра. Высказаны определенные соображения, что эти наблюдаемые особенности могут объяснить хотя бы часть аномалии концентрации ледяных кристаллов в облаках.