Alaskan Ice Fog* I

(A progress report of ice fog research)

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Abstract

This study began in the fall of 1964 in the Fairbanks area of Alaska. It involves an inquiry into the sources and role of water vapor in the ice fog, investigation of the relative concentrations of ice-fog particles, ice nuclei and condensation nuclei, and examination of the characteristics of nuclei and crystals by electron microscopy. With the electron microscope it was found that most nuclei of ice crystals which developed from sublimation of water vapor were located at the center of the ice crystals. In contrast, ice-fog particles result from freezing of supercooled water droplets which form by condensation of water vapor from man-made sources of air pollution such as exhaust gases, open water surfaces on cooling pond, etc. The nuclei in these particles are not located in the center. Dense ice fog covering small areas originated from open water where the condensation nuclei concentration was much lower than in the downtown area, while thin but widespread ice fog was observed in the downtown area and along the highway. Dense ice fog was associated with large sources of moisture regardless of whether or not nuclei were abundant. The role of ice-forming nuclei and a preliminary consideration of synoptic conditions which cause ice fog is also discussed.

I. Introduction

Fairbanks, Alaska is frequently covered with dense ice fog in winter. The ice fog forms in the very cold atmosphere of −35°C or below and causes many traffic and health problems to inhabitants, as well as hampering airport activities because of seriously reduced visibility. The ice fog problems, *i.e.*, the cause of its formation and various meteorological conditions associated with it, have been studied by many investigators. However, there are many aspects to the problem and much work remains to be done. Ice fog phenomena are similar to those involved in the formation of ice crystals in the upper air during warm seasons or in temperate regions. The continuing study of ice fog will therefore provide an excellent approach to the physics of cloud formation, as well as contributing to the practical problem of this type of air pollution during Alaskan winter conditions.

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The Stanford Research Institute carried on a detailed micro-meteorological study of ice fog in the lowest 30 m of air at Eielson Air Force Base 42 km southeast of Fairbanks. Their research included a study of the size, shape and frequency distribution of ice crystals from ice fog (*i. e.*, near surface) and upper air sources. Their report (Robinson *et al.*, 1955) has provided a valuable starting point for additional studies.

Kumai (1964) showed that ice fog consisted of spherical ice forms of 2μ to 15μ diameter together with hexagonal and columnar forms of 5μ to 30μ diameter. He also examined the nuclei under an electron microscope, and found them to be mainly combustion by-products from coal- or oil-burning sources such as power plants and furnaces, and from car exhausts.

Benson (1965) reported that the inversions formed in the first 50 m of air over Fairbanks are among the steepest in the world with values of 10° to 30°C per 100 m, and he discussed the relation between ice fog and human activities.

This investigation of ice fog in the Fairbanks area of Alaska began in 1964. It involves an inquiry into the sources and role of water vapor in ice fog, investigation of the relative concentrations of ice-fog particles, ice nuclei and condensation nuclei, and examination of the characteristics of nuclei and crystals by electron microscopy. This report includes descriptions of instruments, methods, and results; and further discusses a proposed mechanism of the ice fog.

The term "ice-fog particle" used here refers to the small (2μ to 15μ diameter) irregularly shaped, rounded, ice particles which are found in ice fog. Their abundance increases as temperature decreases. Robinson *et al.* (1955) referred to them as "droxtals" and showed that they constitute more than 90% of all ice-particle types in ice fogs at temperatures below −40°C. The term ice-fog particle is used here to include euhedral crystals, as well as the small irregular ice and/or water droplets. The term "particle" instead of "crystal" includes the possibility that some of the ice may not be in the crystalline state. This differs from Benson's (1965) assumption that all of the ice in the air is crystalline regardless of size or shape.

The term "ice crystal" is used here exclusively for well-formed ice crystals of the diamond dust or cirrus cloud types. This usage is primarily for convenience in the following discussion.

II. Electron Microscopic Study of Ice-Fog Particles

A) Smoke samples. Some smoke samples of possible sources were taken and examined electron microscopically. The specimens included car exhausts, smoke from oil- and coal-burning furnaces, exhaust smoke from a power plant, and smoke of burning dry grass or dead trees. The electron micrographs for them are shown in Figs. 1 to 4. Generally speaking, combustion for heating and power plants produced soot or carbon black only, while car exhausts showed various shapes. Gasoline for cars includes lead compounds and other additives to prevent knocking. Also the characteristics of the exhaust varied from car to car, and as a function of motor adjustment, age of the car, etc. Sometimes car exhausts showed a granular structure as shown in Fig. 4. Smoke of dead plants showed very thin and semi-transparent structure.

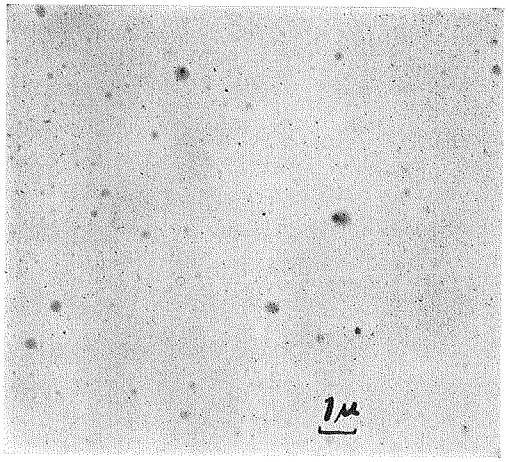

Fig. 1. Smoke from burning dry wood

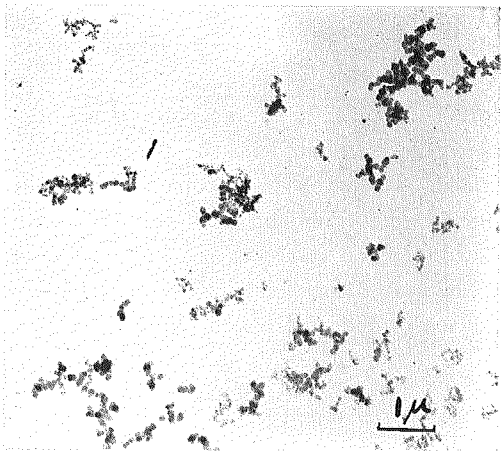

Fig. 2. Smoke from heating plant

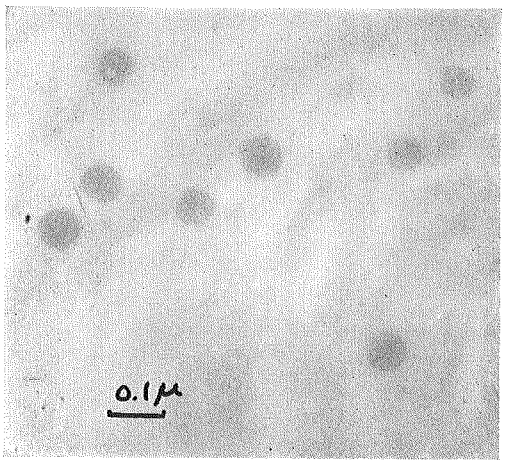

Fig. 3. Auto exhaust (MG)

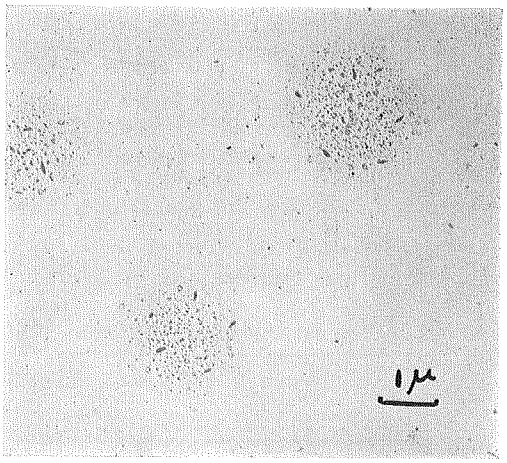

Fig. 4. Auto exhaust (Ford Falcon)

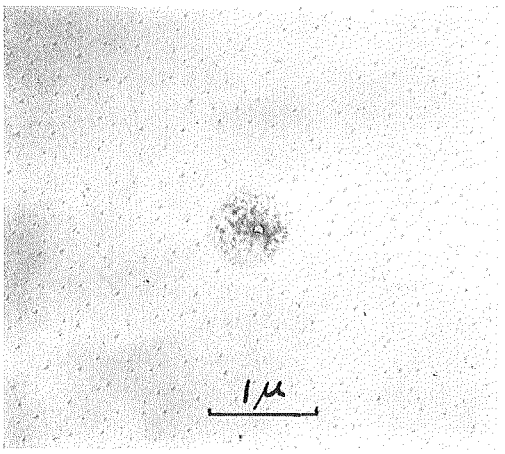

Fig. 5. Radiation fog nuclei (presumed to be combustion product)

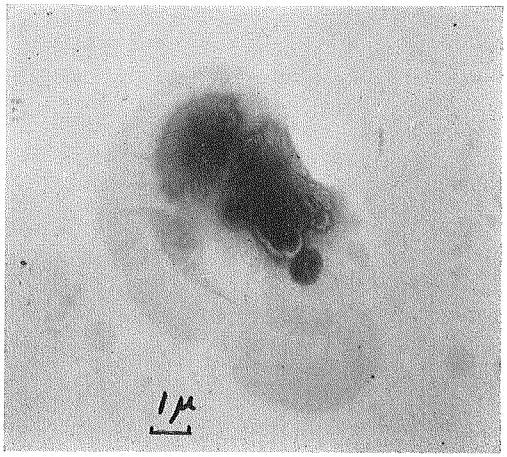

Fig. 6. Radiation fog nuclei (presumed to be sea-salt particle)

B) Radiation fog nuclei. On clear nights during the warmer season, radiation fog usually developed due to radiation cooling of air near the ground, especially near lakes. The mechanism of formation of radiation fogs seems to be similar to that of ice fog formation, except for absolute temperature. Under such conditions, fog can be seen above and around lakes or damp ground even in unpopulated areas or areas far from traffic. Radiation fog droplets were collected on electron microscope grids and their nuclei were examined with the electron microscope. Most of the nuclei was identified as combustion products (see Fig. 5 as an example). In addition to the combustion nuclei, a few sea-salt particles have been detected as shown in Fig. 6. These nuclei were identified as in Yamamoto and Ohtake (1953).

C) Ice-fog particles and their nuclei

(1) Method for making specimens: To prepare the ice-fog samples for electron microscopic examination, the vapor replication method was used instead of the liquid method. The liquid method has two main disadvantages: (i) the ice-fog particles will be displaced and concentrated into a small portion of the slide glass because of the surface tension of the liquid, and (ii) the film is thicker than desired for use with the electron microscope. The vapor method, which was developed by Schaefer (1962) prevented any displacement of ice particles and produced good replicas for the electron beam. The exposure times for slide glass coated with 1% formvar solution to be in contact with chloroform vapor were figured out by means of saturation vapor pressure over chloroform for various temperatures. In this matter, the only exposure time Schaefer (1962) gives is 20 seconds for −20°C. The exposure times for chloroform vapor at various temperatures are shown in Table 1.

Table 1. Exposure time for vapor method of replication

Temperature	°C	0	−10	−20	−30	−40	−45	−50
Exposure time	sec	8	13	20	40	80	120	160

To prepare the specimen, first the cleaned slide glasses were coated with 1∼0.5% formvar solution at room temperature. Warm temperatures cause the solvent to evaporate rapidly. The slide glasses were then cooled to ambient temperature and exposed to the ice fog. After the ice-fog particles were allowed to deposit on the slide glass for several minutes, the slide glass was exposed to chloroform vapor in a closed petri dish for the time shown in Table 1. The slide glass should be kept cold and dry during the sublimation of the ice-fog particles after the replica is formed. The slide glass is dipped into distilled water so that the replica film may be removed from the slide glass and examined by regular electron microscope techniques including chromium shadow casting. Laboratory tests for permanency of replicas and for displacement of nuclei were made prior to the ice fog season. Under an optical microscope the real ice-fog particles and their replicas deposited on a slide glass in a specially made glass container were observed during evacuation of the container. The results of the test were quite satisfactory.

Direct collections of ice-fog particles were also made on specimen grids coated with formvar film during the 1965–1966 winter. An ice-fog particle or any kind of hydro-

particle, such as radiation fog, will evaporate in an electron microscope because of the high vacuum inside. So we cannot see the outlines of the original ice-fog particles and fog droplets on a specimen grid. Up to the present time, the original positions of particles on the grids had been deduced from pictures taken with an optical microscope. Using these pictures, the exact positions of the ice-fog particles or radiation-fog droplets, even to the exact outline of ice particles, could be determined with accuracy as great as 1 to 2 μ by means of the "Specimen Position Indicator" built in the JEM-electron microscope. This method has also been used for checking the displacement of nuclei or other effects during the replication of ice-fog particles.

Many specimens of ice-fog particles and ice crystals for electron microscopic examinations were collected at different places and times. It was expected that the ice-fog particles would have different kinds of nuclei according to their conditions of formation.

(2) The size and shape of ice-fog particles and ice crystals: Most ice-fog particles were hexagonal columns and the rest of them were spherical or irregular. Though the detailed examination is still in progress, a rough idea of the shape of size distribution of ice-fog particles is as follows: When the temperature was lowering through $-30°C$, and the visibility was slightly decreased with the appearance of an ice crystal display, the sizes of ice crystals were normally large-averaging about 20 μ in diameter with no ice particles smaller than 10 μ. The number of such large ice crystals decreased with further decrease in temperature. Smaller sized ice-fog particles, about 8 μ average diameter, appeared at about $-37°C$. These were composed from spherical or slightly irregular forms with decreasing numbers of the large ice crystals. The visibility sometimes decreased to 100 m. When the temperature was lower than -41 to $-42°C$, the fog was composed of a few medium-sized ice crystals, 8 μ in diameter, and a lot of smaller ice-fog particles 1 to 2 μ in diameter with spherical or irregular hexagonal shape (Figs. 7 and 8).

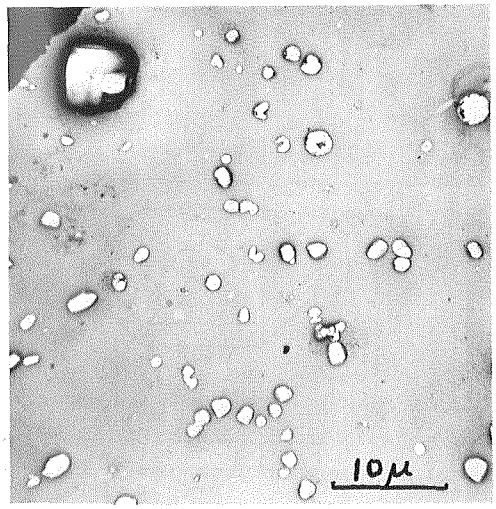

Fig. 7. One big and many smaller ice fog particles. Bigger one has nucleus at the center

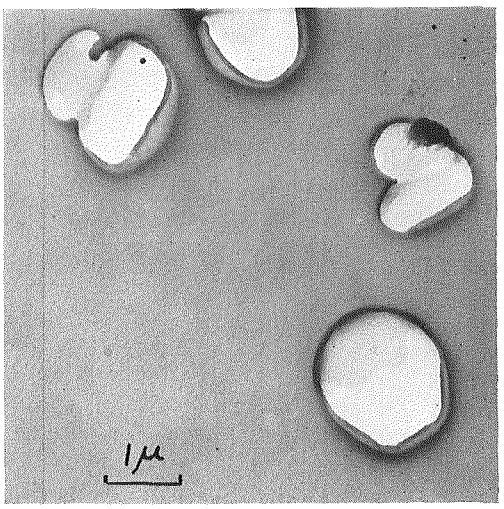

Fig. 8. Smaller ice fog particles and their nuclei

The shape of ice-fog particles also differs from station to station. At sites near open water, most of the particles were spherical rather than hexagonal, with a scarcity of big crystals. The observations taken 3 m from the water surface showed many supercooled water droplets in the ice fog even at air temperature of −35°C. This was confirmed by direct observation with an optical microscope of ice-fog particles collected on an electron microscope grid. Under such conditions, water droplets evaporated much more quickly than ice particles deposited at the same time, due to the different saturation vapor pressures for water and ice surfaces.

The spherical shapes of some ice-fog particles were confirmed by electron micrographs with the use of the shadow casting technique (see Fig. 9). In line with this, we have noticed frequently a circular crystal structure in the center of plane hexagonal ice crystals or snow crystals. We observed that the three dimensional structure of the

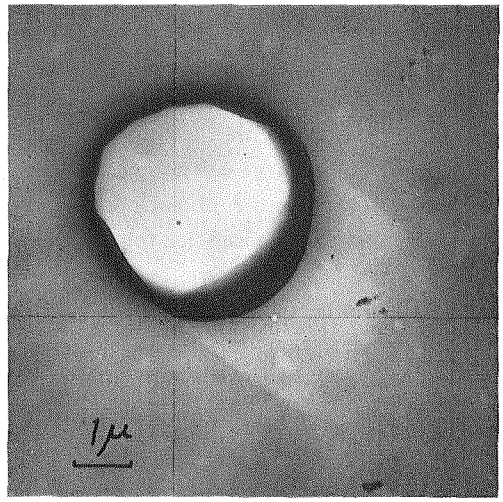

Fig. 9. Ice fog particle, spherical

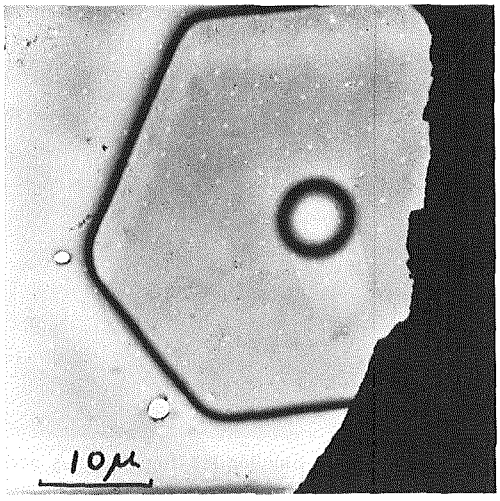

Fig. 10 a. Ice fog particle, hexagonal

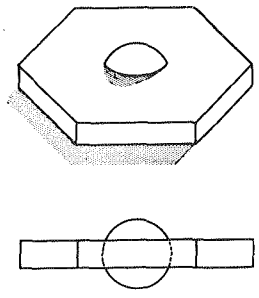

Fig. 10 b. Sketch of three dimensional structure of hexagonal ice fog particle

circular feature appeared to be hemispherical by the use of the electron microscope and shadow casting as shown in Fig. 10 a. By consideration of the spherical ice-fog particles mentioned above and the hemispheric structure at the center of hexagonals, it can be said that the hexagonal plate was probably oriented and developed from the spherical ice crystal as sketched in Fig. 10b. Note the replica of those particles can show only one side of the surfaces of ice crystals.

(3) Composition of nuclei of ice-fog particles: Most of the nuclei were identified as combustion products: either carbon black (or soot) or thin blurred particles which come from car exhaust or the burning of heating oil (Figs. 11 to 14 b). About 80 good micrographs for radiation-fog nuclei and 300 good micrographs for nuclei of ice-fog particles have been taken to date, but there are not enough yet for statistical conclusions. Details will be published in the near future.

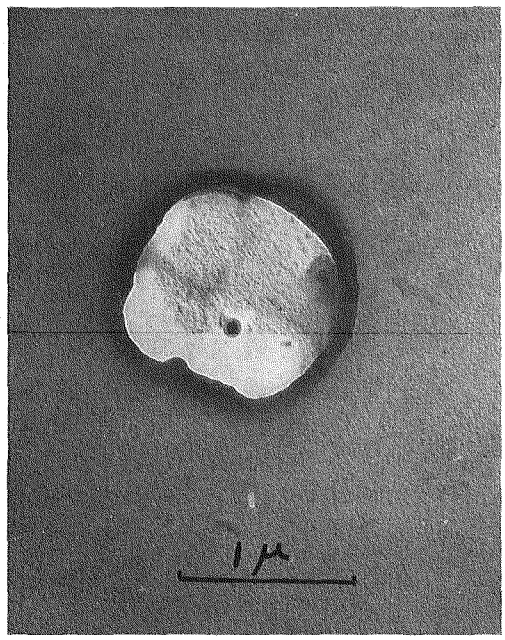

Fig. 11. Ice fog particle and its nucleus. The nucleus was presumed to be a combustion product, off center

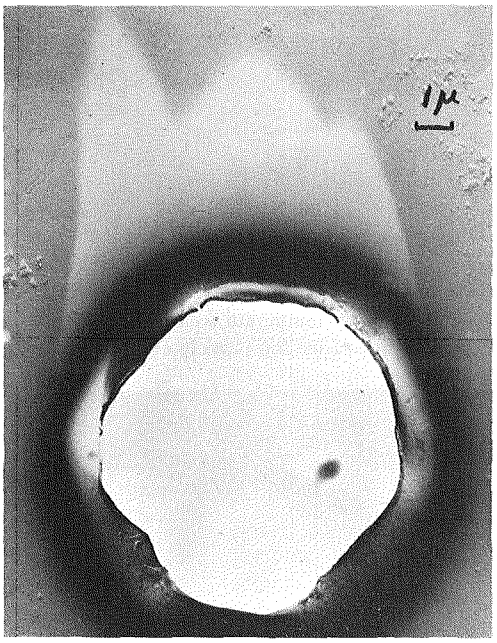

Fig. 12. Hexagonal ice fog particle and its nucleus. The nucleus was presumed to be a combustion product, off center

Some specimens of ice-fog particles were collected directly on electron microscope grids coated with formvar film. Some nuclei consisted of one mother nucleus surrounded by several small daughter nuclei (Figs. 13 a and 13 b). The thickness of both mother and daughters was quite thin. These compound nuclei are interpreted to be the residue of what was originally a liquid nucleus at temperatures of −35°C or below. In a warmer climate such nuclei may not occur because their components would exist in the vapor phase. This is important because it means that for a given amount of exhaust products more condensation nuclei are available at the lower temperatures. During the drying process the volatile part of the liquid nuclei is driven off leaving a residue which we see as a compound nuclei in the electron micrographs. If the compound nuclei were caused

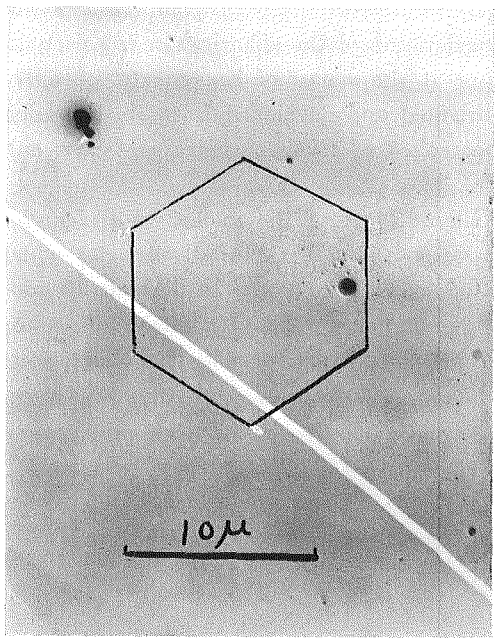

Fig. 13 a. Nuclei of ice fog particle. The nuclei were presumed to be combustion products, which may have been gas phase in temperate weather. Original outline of ice fog particle also illustrated

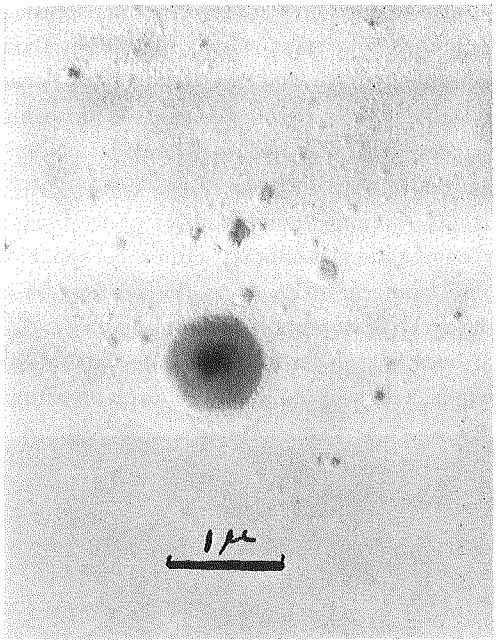

Fig. 13 b. Enlargement of the nuclei

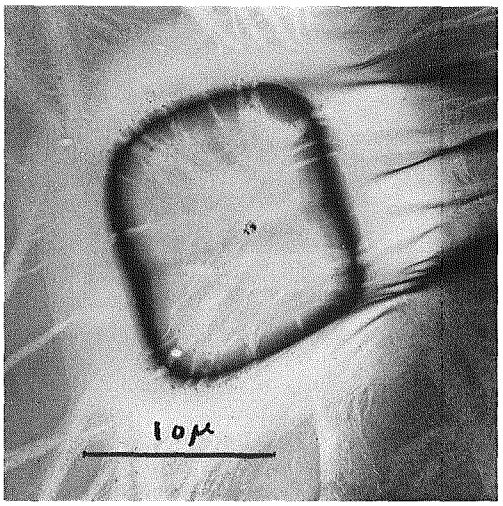

Fig. 14 a. Ice crystal, the nucleus at the center, the nucleus was presumed to be soot

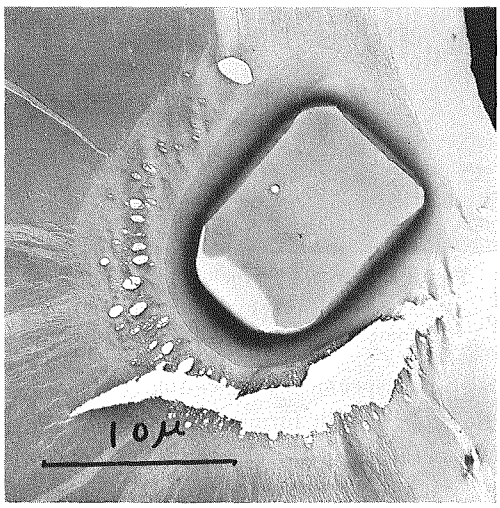

Fig. 14 b. Ice crystal, the nucleus at the center, the nucleus was presumed to be soot

by a parent nucleus breaking into several smaller ones, this breakup must have occurred during the drying process. Though the nuclei did not show any micro-diffraction pattern, they were presumed to be some kind of hydrocarbon from car exhaust.

(4) Position of nuclei of ice-fog particles and ice crystals: The positions of the nuclei of ice-fog particles and ice crystals were examined by means of the replica technique and the specimen position indicator as previously described. Most nuclei of ice-fog particles were found not in the center but rather at the edge of the particles, especially in ice particles which had been collected when air temperature was lower than −35°C. In contrast the nuclei of ice crystals, which are defined as ice particles larger than 10μ diameter, were normally at the exact center of the ice particle. A good example is Fig. 7. This specimen was taken at Fairbanks International Airport on January 1, 1966, at a temperature of −43°C. It consists of many of the smallest size of ice-fog particles and some medium sized ice-fog particles, mixed together on the same slide. Most of the nuclei of the bigger ice-fog particles are located at the center and those of the smaller ones are away from the center or missing. The possible explanation for these positions of the nuclei follows: Ice crystals are formed on some kinds of nuclei, possibly soil particles, through the sublimation process, which means these nuclei must act as sublimation nuclei. These grow into big ice crystals through the sublimation of water vapor. The small ice-fog particles on the other hand result from the spontaneous freezing of supercooled water droplets. Supercooled droplets are formed on condensation nuclei through water vapor condensing onto the nuclei. If the condensation nucleus grows into a water droplet, the nucleus can move anywhere inside of the water droplet, because the water droplet is in the liquid phase. The nucleus will probably not be at the center of the droplet. Under low temperature, a supercooled droplet will be frozen into an ice particle while the nucleus is not at the center. This may be an explanation for most of the small ice-fog particles which had nuclei off the centers of the particles.

(5) Inactivated nuclei for ice fog: As will be seen later in this paper, we have about 50 000 particles per cm^3 of total condensation nuclei in the atmosphere in the Fairbanks city. However, the concentration of ice-fog particles during ice fog was about 200 particles per cm^3. The role of the inactive nuclei is of interest. For this reason, the inactive nuclei during ice fog in the air filtered by a Millipore filter, pore size 14μ, have

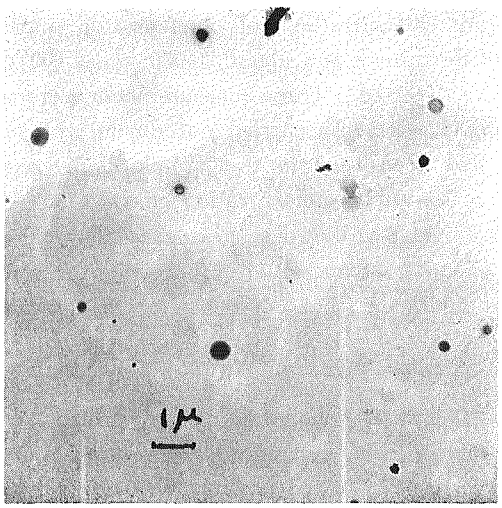

Fig. 15. Inactive nuclei

been taken on specimen grids for examination by electron microscope. Up to the present time, although we have only three electron micrographs for them, the nuclei were presumed from their shape to be combustion products from car exhausts (see Fig. 15 as an example).

III. Measurement of Condensation Nuclei and Ice-Forming Nuclei Concentration

In order to determine the critical parameters in the formation of ice fog, measurements of condensation nuclei have been conducted by means of a "Small Particle Detector" made by Gardner Assoc., Inc. The counter was adjusted to count the particles down to 1.3×10^{-5} cm in diameter. The counter had to be kept warm because of its construction. A vinyl tube connected with the inlet of the detector was used. The end of the tube was also connected with an open type millipore-filter holder which can filter the air for different size ranges of particles. The air was taken into the counter with use of 0.45 μ, 5 μ, 8 μ, and 14 μ pore-size filters, and without filtration.

It should be pointed out that many particles smaller than the nominal pore size were also trapped. Measurements retained on the filter have been conducted at several places and under different conditions. The result may be seen in Table 2. From the

Table 2. Condensation nuclei counts ($\times10^3$/cm^3)

	Downtown area			Riverside		U. of A. Campus	Manley
Without filter	50	180	500	100	26	60	0.5–1
With 14 μ pore size	20	55	130	3	15	15	—
With 8 μ pore size	0.3	0.55	1.2	0.15	0.15	0.18	—

table, it can be seen that most of the nuclei were filtered out by the 8 μ pore-size filter, and that nuclei downtown were smaller than those of the site near the Chena River. The figure indicates relative number for the air without filter to 14 μ and 8 μ pore size filtered. For the absolute concentrations of condensation nuclei, about 50 000 (max. 500 000) particles per cm^3 downtown and about 26 000 (max. 100 000) particles per cm^3 at the Chena River site were detected. These measurements were made during ice fog.

Ice-nuclei measurements were also carried out during the summer using the same ice-nuclei counter that had been used in the Tohoku University, Japan (Ohtake and Isaka, 1964). The average ice-nuclei concentration effective at -15°C observed in Fairbanks was essentially the same as observed in Japan, *i.e.* 1–3 nuclei per liter of air. This number of ice nuclei is an order of magnitude higher than the average number reported by Kline (1963), Soulage (1961), etc., but not measured in Fairbanks.

IV. Measurement of Water Vapor Amount

In order to measure the water vapor amount at various places and under different ice fog conditions, an easily operable and portable instrument has been developed which withstands extreme cold weather. A rough sketch is shown in Fig. 16. Air is taken into a drying tube containing magnesium perchlorate, through a 8 μ pore size millipore

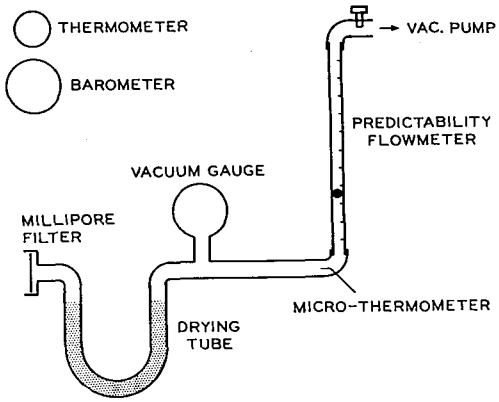

Fig. 16. Diagram of humidity measuring instrument

filter, by a vacuum pump with controllable flow rate.

Flow rate of air is measured by a "Predictability Flowmeter" made by Monostat Corp. and calculated by reading of temperatures and vacuum gauges. The calculation includes correction for vacuum pressure and temperature in the flow rate readings of the flow meter, and barometric and temperature corrections for the incoming air. The difference of weight of the drying tube before and after air is passed through it and the volume of air passed through gives the absolute humidity. In the downtown area with ice fog, the moisture was around ice-saturation, and at the site near the Chena River, much higher moisture contents sometimes close to water-saturation have been detected.

At both stations with increasing cold the moisture gradually increased and approached a maximum value. With the appearance of ice fog no sudden change in moisture was noticed. However, at the site near the Chena River there was always much more ice fog than in the downtown area. It was noticed that the poor visibility due to dense ice fog seemed to be associated with high moisture content. Further observations will be needed on this point.

For continuous measurements a thermo-hygrometer has also been used, although it has too much lag to allow accurate values. The records showed the same tendencies as did the drying tube method. From appearance to increase of ice fog, the record did not show much change in relative humidity.

V. Concentration of Ice-Fog Particles

Kumai (1964) reported that the average numbers of ice-fog particles per unit volume of air were about 200 particles per cm^3 of air in the Fairbanks area. He exposed slide glasses in ice fog expecting the ice-fog particles would be freely falling onto the slides. From the horizontal distribution of ice-fog particle size, he derived the spatial distribution by dividing by their Stokes' Law fall speed. However, ice-fog particles are drifting almost horizontally due to slight winds and tend to evaporate on a slide glass. Also it has been shown that in Fairbanks some of the small ice particles have a net upward motion (Benson, 1965). We tried to use a collector similar to a konimeter.

The size of the nozzle used is about 1 mm and a small piece of slide glass covered with silicone oil was set 5 mm below the nozzle. Normally, 5 cm^3 to 10 cm^3 of air was taken in. Considering the collection efficiency of the slide, bigger particles should be collected on the center of the glass and smaller particles around the bigger ones. Sometimes smaller particles may escape from a slide, but with the use of appropriate air speeds at the nozzle, all particles included in the air could be collected near the center of the glass. This means the collection efficiency must be 100 %. Evaporation also could be prevented because of the covering oil, and, after collecting the sample, optical micrographs were taken. As the result, to date average concentration of ice-fog particles have been 200 (max. 400) particles per cm^3 of air or more, depending on the density of ice fog. Additional observations are still needed.

VI. Temperature of Car Exhaust

To determine the degree of supersaturation for car exhaust, air temperatures were measured from the inside of car exhaust pipe to the surrounding air along the exhaust plume as can be seen in Table 3. The degree of supersaturation of the exhaust was

Table 3. Temperature distribution of car exhaust

Distance from exhaust pipe, cm	0	50	100	200	500
Temperature of exhaust gas, °C	50	−15	−24	−27	−28

calculated to be roughly 400 %, assuming −40°C for ambient air temperature. This supersaturation degree may allow droplets to form from water surrounding combustion products from the exhaust. In other words, the car exhaust may produce water droplets with and sometimes without inclusion of combustion products. The remaining combustion products may supply available condensation nuclei to the atmosphere, and combustion gases may also be puffed out then condensed into liquid-phase condensation nuclei. These droplets will be frozen into ice particles prior to their evaporation in the cold and almost ice saturated air. Thus car exhausts may make ice-fog particles directly without any vapor phase.

VII. Discussion of Ice-Fog Mechanism

From careful ground and air observations of ice fog, most dense ice fog originates from open water such as cooling water dump areas for power and heating plants, while relatively thin ice fog comes from car exhausts and heating exhausts from the houses. Exhaust from power plants does not seem to be a major source of ice fog, because it is discharged at a higher altitude—generally above the steepest part of the inversion. This smoke diffused into the higher atmosphere or drifted far from the ice fog area.

Observations from the beginning of ice fog also showed that at first the fog developed from the open water and then slight ice fog appeared along the roads. Although ice fog from open water is dense, it generally does not spread out into wide areas, while that which came from car exhausts was thin but widespread. These observations may be explained as follows: The ice fog over open water at temperatures

above −35 to −40°C includes unfrozen water droplets as well as ice particles. As the fog spreads into area with lower water vapor pressure, the droplets evaporate preferentially. In contrast, car exhausts make ice particles directly, and cars scatter ice-fog particles and their nuclei over a wide area while running.

Many condensation nuclei and considerable water vapor exist in the lowest layer of the atmosphere in the Fairbanks area during ice fog, because these are products of human activity which are concentrated by the remarkable surface temperature inversion. High concentrations of condensation nuclei are not essential to formation of ice fog, it will form wherever excess moisture is available. Very high relative humidities which in rare cases were close to saturation with respect to water were observed during ice-fog formation. It is probable that most ice-fog particles originate from freezing of supercooled water droplets due to condensation of water vapor from the open waters, and due to direct condensation of water vapor from car exhausts. This does not mean the water vapor condensed onto dry nuclei from car exhausts or other sources.

Now we should consider the role of ice nuclei. In normal conditions, the lowest air layers in Fairbanks contain about 50 000 condensation nuclei per cm^3, this number is not expected to vary significantly with temperature. In contrast, the number of ice-forming nuclei effective at −15°C are of the order of 10^{-3} particles per cm^3. Generally speaking, the ice-forming nuclei increase one order of magnitude in their number with a decrease of 3°C in temperature of air, according to the author's previous experiments. Therefore, if the air temperature goes down to −39°C, the concentration of effective ice-forming nuclei must be about the same order (10^5 particles/cm^3) as that of condensation nuclei assuming a constantly increasing rate with decreasing temperature. If so, we can expect some ice-fog particles will spontaneously originate (through sublimation) in the atmosphere, while others will be frozen from supercooled water droplets. Most of the nuclei of ice crystals which were formed in air saturated with respect to ice, but not with respect to water, were at the center of the ice crystals. Also some ice-fog particles had nuclei at their centers. Those nuclei must have acted as ice-forming nuclei. At Manley Hot Springs, where is located 140 km west of Fairbanks, the number of condensation nuclei was 500 to 1 000 particles per cm^3. This is about 1% of the number measured in the Fairbanks area. Ice fog at Manley Hot Springs normally occurs only at −40°C or below. A possible reason is that the natural ice-forming nuclei will be activated as ice-fog nuclei even at extremely low concentrations of condensation nuclei. Therefore, it is possible that any nuclei observed in ice fog at Manley will be at the center of the ice-fog particles. Another possibility is that the abundant moisture would make a lot of droplets and they will be frozen spontaneously into ice-fog particles. If so, we can expect ice-fog particles without any nuclei. To date, no observations of ice-forming nuclei effective in −40°C have been published. Laboratory experiments will be made this summer.

The most important effect for ice-fog formation in the Fairbanks area is water vapor and low temperature rather than nuclei. Narrow and dense ice fog comes preferentially from open water, and thin and widespread ice fog comes directly from car exhaust. Many water droplets come from auto exhaust and a part of them will be rapidly frozen into ice-fog particles, the remaining droplets will evaporate. This evapo-

ration increases both the amount of inactive condensation nuclei and water vapor. Measurements of the amounts of water vapor and total condensation nuclei (both those which did, and did not, form ice-fog particles as determined with the electron microscope) together with synoptic considerations support these views.

The electron microscopic studies have been described above and a preliminary account of our study of synoptic maps shows that ice fog is generally associated with high pressure and clear skies. Most of these highs originate in Siberia, but they may follow more than one path from Siberia to Alaska. The amount of moisture contained in the air mass varies according to the path followed. Highs which move directly east have less precipitable water than those which loop northward and traverse part of the Arctic Ocean before entering Alaska. The temperature at onset of an ice fog event is higher when the high has traversed part of the Arctic Ocean. This agrees well with the above-mentioned role of water vapor in producing ice fog.

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