It will be realized from the foregoing summary that icing in ships, particularly small ships, can still be a serious matter. Counter-measures on a much more ambitious scale than are at present attempted are entirely feasible, but would hardly be justifiable unless the ship concerned was being designed exclusively for Arctic or Antarctic work.

## DISCUSSION

The CHAIRMAN opened the meeting for discussion.

Dr. VINCENT SCHAEFER (General Electric Company, U.S.A.) said that a few years ago a very interesting method of changing a super-cooled cloud to one of ice crystals was found. Mr. Hardy had referred to that briefly and he would therefore like to describe some of the things that had been learned about supercooling.

Basically, water could be cooled, as far as was known, to a temperature of about $-38\frac{1}{2}°$ C. The only thing which prevented this degree of supercooling was the presence of foreign particles and frost crystal nuclei.

In the atmosphere there were natural nuclei of foreign particles which served to form snow. As far as he was aware this normally occurred at a temperature of about $-12°$ C. threshold temperature, and perhaps as low as $-36°$ C., depending on the particular particle. A certain spore had served as an ice nucleus and had been known to form a snow crystal at a temperature of $-36°$ C. So far as was known, bacteria did not form nuclei within a temperature of $-39°$ C. A small piece of clay had served as a nucleus at a temperature of $-15°$ C. A smoke cloud did not form nuclei but graphite had been known to do so under certain conditions.

A still different type of ice nucleus effect was that produced by freezing nuclei, called frazil ice, which formed thin, rounded discs in supercooled streams. These often developed when the air temperature was only a few degrees below 0° C. and often created a serious problem where hydro-electric plants utilized such water. A complete shut-down of a 30,000 kW. power plant had been observed less than an hour after such ice began forming.

Since January 1948 at the summit of Mt. Washington in New Hampshire, U.S.A., more than 8000 observations had been made of the concentration of ice nuclei in air samples. It had been found that the values varied by a factor of at least a million-fold. For example, about 50 per cent of the observations had shown a concentration of ice nuclei of less than 500 per cubic meter of air. All observations had been made with the air sample cooled to about $-18°$ C. About 42 per cent of the observations had shown the concentration to be in the range of $5 \times 10^2$ to $5 \times 10^5$ per cubic meter of air. The remaining 8 per cent had shown values between $5 \times 10^5$ and $1 \times 10^7$ per cubic meter. It was believed that about 10,000 ice nuclei per cubic meter were necessary if effective modification of a supercooled cloud was to occur within about thirty minutes. This variability of ice nuclei concentration was believed, to be one of the most important factors related to the difficulty of predicting the occurrence and persistence of supercooled clouds.

The result of being able to change a supercooled cloud to ice crystals was that it was also possible to modify its path in the atmosphere. One gram of dry ice could be used to produce $10^{16}$ ice crystals. Large areas of super-cooled cloud had been cleared over North America and it was technically very easy within a few minutes to clear two or three hundred square miles if the clouds were suitable for modification.

It was now thought that it would be reasonably easy to modify destructive storms, and one day it might be possible to tackle the hurricane because, as far as could be seen, destructive storms were bound up with super-cooling and if super-cooling could be prevented in the early stages, it should be possible to prevent the storms.

Mention had been made by Mr. Hardy of frost on refrigerator surfaces. The speaker believed that one direction which would pay dividends in the future would be the development of surfaces which produced frost in a controllable way. It was quite possible to modify the formation of frost by surface treatment. Whether it would be practicable was another matter. It was quite a problem, in the case of the domestic refrigerator, to get the housewife to do certain things and, as a rule, such things were not practicable. However, with the accumulation of more and more information there was always a chance of discovering the right kind of surface which would produce an entirely different kind of frost and which would result in a better solid ice. One of the things which he believed would have a profound influence in that connection was the silicones, but there was a great deal of work yet to be done and there must be research relating to these matters.

The remainder of the very considerable discussion was mainly focused on two topics, conductor rail icing and the problem of frost formation on cooling pipes. The following deals with the main points:

Dr. L. L. Levy (Institute of Refrigeration) suggested that the icing difficulty on the conductor rail could be largely overcome if the current were picked up from the underside of the rail. Mr. A. J. Whitten (British Glaciological Society) considered that modifications to the pick-up, to enable it to ride on top of the rail beneath a fixed hood over the rail, would reduce the incidence of icing because the outward night radiation would be less. Mr. Coombs in reply said that side pick-up had so far proved the most successful, but once any particular method was established there was always a vested power to continue in the same way.

Dr. Levy, Mr. M. Hickman (National Physical Laboratory) and Mr. Anderson (Institute of Refrigeration) indicated some of the difficulties which arose in estimating the variable heat transfer from pipes on which frost was forming. The boundary conditions, the density, the dimensions and the thermal properties of the frost varied during its formation. Mr. B. L. Rathmell (Ministry of Supply) referred to the more difficult problem of estimating the heat flow from a bundle of refrigerating pipes on which frost was forming. The Chairman cited a paper on this problem published by the National Physical Laboratory, which partly answered some of the questions.

Mr. Hardy, the Chairman and Dr. Schaefer gave additional information about electrical resistance glass used for windscreens at low temperatures. The glass contained an oxide of tin which was transparent and had a conductance down to 50 ohms per $cm.^2$. It was used in some of the most recent American transport aircraft. Some samples had been shown at the Physical Society's Exhibition in 1948.

Mr. A. O. Brandon (Institute of Refrigeration) suggested that instead of cooling the air lock of a cold store by means of cooling pipes to remove the moisture as suggested by Mr. Lilley it might be possible to use a silica gel plant. The quantity of water to be dealt with was quite small.

Mr. W. S. Douglas, speaking for the Institute of Refrigeration, said that the deposition of frost on cold surfaces certainly had an important bearing on the science and practice of refrigeration and a great deal of work had been done on heat transfer through the frost on a pipe, from the air to the fluid in the pipe.

This coating on refrigerated surfaces was undoubtedly a major nuisance. In this connection it was necessary to cope with the users of small refrigerators who very often thought that the refrigerator could not be good unless it displayed frost at every point! But provision had to be made for either preventing the frost from forming or spraying the pipes with brine. A great deal was wanted to be known about the deposition of ice on cold surfaces. At one time ice was always made in large blocks but it was now made in film form or thin sheets and the more we knew about this the better we should proceed.

The formation of ice was also a desired objective in some types of refrigerating plant for special purposes for high pressure refrigeration and it was customary in many cases to arrange for some means of ice formation. Ice cooling was a very convenient way of doing it although it had been discouraged in many cases. It had also been discovered in the modern dairy plant which was now using controlled water. The load in a dairy plant was of an intermittent character, however, and it called for the peak milk cooling in 4 or 5 hours. There seemed an opportunity here of having ice in the coils of the evaporators, if it could be arranged to provide for this peak load.

Therefore, the subject of this Symposium was of the greatest interest to refrigeration engineers, partly because sometimes the formation of ice was a nuisance and, at other times, a desired objective. Members of the Institute of Refrigeration were very grateful to the British Glaciological Society for the invitation to take part in this joint meeting.

On the motion of the Chairman, the authors of the papers and the contributors to the discussion were cordially thanked. The meeting was then closed.

# SNOW CRYSTAL GROWTH

## Electron Microscope Study of Snow Crystal Nuclei

(Advance communication)

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This study was made by Mr. Motoi Kumai, of the Physical Laboratory of Hokkaido University. The experiments were carried out on Mt. Taisetsu in Hokkaido, at an altitude of 1050 m. The snow crystal is received on a collodion film on the sample holder of the electron microscope, and is left in a desiccator kept at temperatures between $-4°$ and $-8°$ C. The crystal evaporates by sublimation and the supposed nucleus is left on the collodion film. The specimen is then brought to Sapporo and investigated under the electron microscope. One solid nucleus is always observed at the central portion of every snow crystal. It is proposed to call this the centre nucleus. The centre nuclei are between $0{\cdot}5$ to $8{\cdot}0\mu$ in the largest extension.

In the remainder of the snow crystal numerous small nuclei are to be seen. These are nearly of the same size as the condensation nuclei in the free atmosphere, that is to say, between $0{\cdot}01$ and $0{\cdot}2\mu$ in diameter. Forty-three successful photographs of centre nuclei have been obtained. Most of the nuclei are believed to be soil particles, but some are composed of carbon; others are micro-organisms or hygroscopic particles of certain chemical compounds. Sixty photographs of condensation nuclei have been taken and the frequency curve of the size has been drawn from 1200 data. Condensation nuclei are found to be composed of two kinds, the most frequent diameter of the larger ones being about $0{\cdot}15\mu$ and of the smaller $0{\cdot}05\mu$.

These preliminary observations provide data for consideration of the mechanism of snow crystal growth. The aerosol theory of snow crystal formation is proposed. According to this new theory the excess of water vapour in the free atmosphere is condensed on to the condensation nuclei and numerous minute water droplets in a super-cooled state are formed. There super-cooled droplets then collect on the ice germ and give rise to the snow crystal proper.