In accordance with the rules the following three co-opted members resigned, but were eligible for re-election:

Professor S. E. Hollingworth
Dr. M. F. Perutz
The Reverend W. L. S. Fleming.

Dr. A. J. Bull proposed that the existing Committee and the three co-opted members be re-elected. The proposal was seconded by Mr. D. L. Champion and carried unanimously.

5. *Appointment of Auditors.* The President said that he had approached Mr. V. Lavington Evans and Major W. M. Roberts, who were willing to act as auditors. Professor Hollingworth proposed that Mr. Evans and Major Roberts be appointed auditors. The proposal was seconded by Dr. N. E. Odell and carried unanimously.

6. *Future meetings and papers.* The President announced that a joint meeting with the Royal Meteorological Society had been arranged for 19th March, 1947, at which there were to be papers and a general discussion on a climatological subject. There was also a joint meeting to be arranged between the Society and the mountaineering and ski clubs in May. There would be two more meetings for which suggestions for papers would be welcomed.

7. There was no further business and the meeting was adjourned until 5 p.m.

8. The President then asked Professor Hollingworth to take the Chair.

Professor Hollingworth said that he felt sure he was expressing the wishes of members in saying how grateful they were to the President for bearing so much of the burden of the Society's activities. He then introduced the lecturers:

Dr. B. M. Cwilong—"Observations on the incidence of super-cooled water in expansion chambers and on cooled solid surfaces."

Dr. M. F. Perutz—"Description of the Iceberg Aircraft Carrier and experiments on the bearing of the mechanical properties of frozen wood pulp upon some problems of Glacier Flow."

Dr. Cwilong's paper and the discussion on it are given below. The paper and discussion on the Iceberg Aircraft Carrier will be published in the next issue.

OBSERVATIONS ON THE INCIDENCE OF SUPERCOOLED WATER IN EXPANSION CHAMBERS AND ON COOLED SOLID SURFACES*

By B. M. Cwilong (Oxford)

Introduction

The main object of this work was the design of a reliable dew point (or hoar frost point) hygrometer for use in the upper troposphere and lower stratosphere. The design was developed under the direction of Professor G. M. B. Dobson, F.R.S., for the Meteorological Office, Air Ministry, London.

* A short summary of the first part of this paper has already been published and a more detailed account is in course of publication (*Proc. Roy. Soc.* A). The following account is devoted to those results which have not been published and is concerned only with sublimation on cooled solid surfaces.

Condensation of water vapour on cooled surfaces from the air

Experiments on the deposition of water vapour from the air upon various easily reproducible surfaces were carried out. The water content of the air used during the experiments corresponded to saturation at various temperatures from room temperature down to —80° C. Arrangements were made in the apparatus to allow photomicrographs to be taken during the observations.[1, 2]

(*a*) Surfaces of zinc and of cadmium deposited by evaporation *in vacuo* were found to possess the power of causing sublimation of water vapour at temperatures very slightly below the sublimation curve (within 0·1° C.), i.e. below the theoretical frost point, at all temperatures which were investigated.

(*b*) Freshly split mica has just the opposite effect. It has no power whatever to cause sublimation. When the temperature of a mica surface falls only 0.1° C. below the condensation curve, that is to say below the dew point in respect to supercooled water, a layer of supercooled water is found to cover the mica. When this layer thickens it usually freezes very suddenly, sometimes revealing peculiar patterns.

(*c*) Certain other surfaces have properties intermediate between those of freshly deposited zinc and freshly split mica; e.g., surfaces formed by evaporation *in vacuo* of aluminium, silver, gold, copper and silica, as well as certain other polished metallic and plastic surfaces. On all these ice is deposited at temperatures further below the sublimation curve than on zinc, and large numbers of ice crystals do not readily form upon them. This accounts for the fact that if these surfaces are cooled below the condensation curve, supercooled water is deposited, although condensation does not begin immediately below the dew point. It is significant that this condensation differs from that which occurs on mica in that the supercooled water forms droplets, indicating that on these surfaces too condensation does not readily take place.

With the exception of aluminium and silica these surfaces when polished are somewhat more reluctant to cause sublimation than when they are newly deposited by evaporation.

(*d*) After several days of exposure to the air all surfaces, whether polished or evaporated become alike in their properties.

Sublimation on old surfaces usually takes place below —40° C. Above this temperature it is produced with difficulty. Crystals tend to grow at few (if any) points on the surface and always at the same points with successive depositions. They appear at temperatures far below the frost point, sometimes even below the dew point (Figs. 1 and 2, Pl. I).

(*e*) If a deposit of metal formed by evaporation *in vacuo* is so thin that light is easily transmitted through it, water vapour does not easily condense upon it. In order to obtain a deposit it is usually necessary to cool it well below the dew point, in fact as far below the dew point as the frost point is above it (Fig. 3, Pl. I).

Condensation of water vapour on cooled surfaces in the absence of air

Apparatus was arranged so that evaporation of the required metal and later deposition of pure water vapour thereon could be carried out wholly *in vacuo* without ever exposing the surface to air.

The general conclusion reached with this apparatus was that the results obtained *in vacuo* are more or less similar to those obtained on freshly formed surfaces in the first set of experiments described above, but in general the points which are active in promoting sublimation are more numerous. No ageing effect on surfaces was detected.

Deeply supercooled water. Vitreous ice

When the surface is cooled below −100° C. a glassy layer is deposited which in monochromatic light shows the optical phenomena of uniform films. This transparent film becomes translucent when heated to between −85° C. and −80° C. When it is again cooled below −100° C. the translucency remains. A similiar type of ice was observed at somewhat lower temperatures by Burton and Oliver.[3]

The experimental difficulties of research with such small amounts of water vapour at these low temperatures are well illustrated by the fact that even X-ray evidence regarding the structure of the resulting ice is at present contradictory. Burton and Oliver found it to be amorphous,[3] whereas König observed cubic symmetry.[4]

Deeply supercooled water. An attempt to repeat Rau's observations

A brief account of experiments carried out at Professor Regener's laboratory by Rau [5] was published in *Nature* shortly after the war.[6] Rau summarizes his observations as follows:

1. Freezing in super-cooled water starts on special "freezing nuclei."
2. Each nucleus has a characteristic temperature.
3. By analogy with the spectrum of condensation nuclei when their activity corresponds with varying degrees of supersaturation, the activity of "freezing nuclei" corresponds with varying degrees of supercooling.
4. A "freezing nucleus" can be rendered inactive by successive coolings. This takes place gradually while it remains in water or wet air.
5. Such a nucleus can be made active again by drying.
6. By rendering all "freezing nuclei" inactive, water can be supercooled down to —72° C.
7. At —72° C. a homogeneous formation of nuclei takes place and the ice so formed belongs to the cubic system of crystallographic symmetry.
8. Heating to —70° C. melts the cubic ice.
9. A further phenomenon is the great decrease of surface tension of water mainly noticeable below —55° C. This indicates a change in the structure of the binding conditions similiar to those which take place when the various types of high-pressure ice are formed.
10. Below —72° C. "primary sublimation" takes place. Ice nuclei originate direct from the vapour without the help of any other particles. The products of such sublimation are cubic crystals of ice.

Rau's experiments were conducted in dust-free air contained in a 5-litre chamber thermostatically cooled. A chromium-plated thick-walled tube, through which cooling liquid could circulate, was placed across the chamber. Microscopic examination of the deposit could be made by means of three polished mirrors (3 × 5 cm.) on the tube.

Our own experiments were carried out in an all-glass chamber connected to a vacuum system. Vapour was supplied from connecting test-tubes by turning a tap.

In spite of exceptional care and several repetitions of the experiments with as many as 100 consecutive meltings of ice crystals, *not one of Rau's phenomena was observed.*

In the presence of air as well as in an atmosphere of pure vapour, supercooled water drops froze on the test plate at various temperatures, which were constant for each drop. Successive melting and freezing did not lower the freezing points. Water vapour deposited on the test plate by sublimation between −72° C. and liquid air temperature invariably melted at 0° C.

It was only when some contamination was introduced into the chamber in the form of small amounts of ether or acetone vapour that *all* Rau's phenomena appeared. The only difference was a shift downwards of some 20° C. in the "homogeneous" freezing point and incidentally in the point of viscosity decrease. In his paper Rau unfortunately does not specify his cooling liquids. An extremely small amount of contamination is sufficient to change the picture entirely. Rau had also placed a powerful fan (*eine kräftige Ventilator*) inside his chamber to equalize the temperature. This fan when working was certainly above thermostatic equilibrium temperature, so that some of its lubricant could have evaporated.

As to the crystal structure, we found crystals of a shape identical with Rau's, on many occasions, in pure water and at various temperatures far above −72° C. (see Fig. 4, Pl. I). On other occasions hexagonal crystals were formed by sublimation at temperatures approaching −100° C.

REFERENCES

1. Cwilong. *Nature*, Vol. 155, March 24, 1945, p. 361.
2. Dobson, Brewer, Cwilong. Bakerian Lecture 1945, *Proc. Roy. Soc.*, *A*, Vol. 185, 1946, p. 144.
3. Burton and Oliver. *Proc. Roy. Soc.* A, Vol. 153, 1936, p. 166.
4. König. *Z. Krist.* Vol. 105, 1944, p. 279.
5. Rau. *Schriften Deut. Akad. Luftfahrtforsch.*, Vol. 8 (II), 1944, p. 65.
6. Frank. *Nature*, Vol. 157, March 2, 1946, p. 267.

DISCUSSION

Professor S. E. Hollingworth: It is clear that this Air Ministry research has produced results of very great interest to this Society. There are many questions members will wish to put to Dr. Cwilong.

Dr. L. Hawkes welcomed Dr. Cwilong's paper and proceeded: It is strange that the properties at low temperatures of so common a substance as water have so long remained unknown. Many years ago Sir George Beilby on testing water drops at −12° C. had the impression that they were hard and glassy. I had the same experience with drops at −20° C. Yet many facts told against this interpretation, and now Dr. Cwilong has shown that water can remain fluid down to much lower temperatures. I am at a loss to explain Sir George Beilby's observations and my own. I would like to ask the author how he determined that his greatly supercooled water was fluid and not glass?

Dr. B. M. Cwilong: It is quite easy to see if the drops on the test plates are supercooled, as at the moment of freezing they turn opaque. As long as they are transparent they are liquid. I tested them by touching each drop with a thin wire; when touched they all froze. Down to at least −60° C. these water drops show viscosity of the same order of magnitude as water at room temperature.

Dr. M. F. Perutz: I wish to say how extraordinarily interesting I have found Dr. Cwilong's account of this problem of nucleus formation and supercooling. It raises a host of new problems concerning the mechanism of crystal formation. A full discussion is hardly possible in view of the short time at our disposal, but I should like to ask a few questions. The first point that strikes me is that Dr. Cwilong mentioned that ice crystals grow on certain metals more easily than on others. I wonder whether there is any connection between the crystal structure of ice and of metals in such cases? Were the metal surfaces clean and free from oxide formations?

Dr. CWILONG: In the case of freshly evaporated zinc and cadmium surfaces (hexagonal) this was the case; but neither the evaporated silica surface nor other surfaces covered with fine crystalline silica dust showed any power to induce sublimation, although it was expected that the dust would "seed" the surface. Surfaces were coated by evaporation *in vacuo* in order to ensure their being clean. Mica was cleaned when placed in the observation chamber just before observation. During experiments on evaporated surfaces in the absence of air the surfaces were certainly free from oxide.

Dr. PERUTZ: What were the sizes of the nuclei?

Dr. CWILONG: They were very small; so small in fact that those parts of the surface on which sublimation was taking place did not appear different from other parts of the surface even under a magnification of 500 times. On all surfaces except those of evaporated zinc and cadmium the nuclei were sufficiently few in number to enable me to observe that they kept their ability to induce sublimation during consecutive depositions. It was only after the test plates had been heated to about 100° C. below their melting points for several hours that the loci of crystal formation shifted to other points on the plate.

Dr. PERUTZ: You are speaking of extraneous nuclei and not of nuclei in supercooled water?

Dr. CWILONG: Yes. In supercooled water the original point from which the solid phase spreads is difficult to locate owing to the high velocity of spreading. In supercooled water in a test-tube the addition of dust usually raises the semi-permanent freezing point of a sample, but a crystalline dust (silica) is not more effective in this respect than an amorphous one (glass powder).

Dr. PERUTZ: Do you consider that the crystals obtained in the German experiments were carbon dioxide or ice?

Dr. CWILONG: Rau's crystals, melting at −72° C. were, I think, a solution of water and some organic contamination. In König's experiments temperatures were very much lower and in spite of precautions contamination by carbon dioxide cannot be excluded.

The discussion was then closed by the Chairman with a tribute to the brilliant work of the lecturer.

THE FORMATION OF *Roches Moutonnées*

By HANS CAROL (Zürich)

(This paper in addition to its main theme gives observational evidence of plasticity and faster flow in the lower strata of a glacier under pressure. The conditions it describes provide additional support for the Extrusion Flow hypothesis. Ed.)

Roches moutonnées, the rounded rock hummocks found in glaciated regions, vary somewhat in shape according to the nature of the rock, its stratification or cleavage planes and the action of the ice. Usually they have a smooth, rounded back pointing uphill, while their downhill face is rough and often steep.

There are many theories to account for their development. Some authorities attribute them to highly resistant rock masses which have persisted after the erosion of the rest of the glacier bed; others believe them to have been rugged protuberances of pre-glacial times which the glacier has not been able to remove entirely.

I believed that controversy could perhaps be stilled by direct observations in the bed of a living glacier. In the years 1940, 1941 and 1942 I several times found it possible to make my