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Abstract

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CRYSTALLOGRAPHY

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CONTROL OF THE STRUCTURE OF CRYSTALS GROWING IN A FLOW OF SUPERCOOLED AEROSOL

(Presented by Academician A. V. Shubnikov on 12 VI 1962)

It is known that the structure of a crystal depends on the method by which it is grown (see ([1], [2]), etc.). In particular, when objects are iced in supercooled clouds, two principal types of ice are observed: structurally transparent ice and matte, nonuniform ice ([3], [4]).

From the theory ([5]) it follows that the structure of the crystallizing layer of water during icing of objects in a supercooled aqueous aerosol should be determined by the ratio between the radius of the aerosol droplets and the so-called equilibrium thickness h of the water film under viscous flow. If one adopts ([6]) the linear crystallization rate of water at small supercoolings at temperature T as

$$I = 0.16(T_0 - T)^{1.69} \text{ cm/sec}, \tag{1}$$

where T_0 is the temperature of equilibrium crystallization of water, then ([5])

$$h = \frac{\rho\lambda(T_0 - T)}{\rho_l LVqE}\left[1 - \frac{2.96}{T_0 - T}\left(\frac{VqE}{\rho}\right)^{0.592}\right], \tag{2}$$

where ρ and ρ_l are, respectively, the density of water and the density of ice; λ is the coefficient of thermal conductivity of water; V is the velocity of the aerosol flow relative to the object; q is the water content of the aerosol; E is the coefficient of capture of aerosol particles by the object; L is the specific heat of fusion of ice.

To verify and refine the theory ([5]), observations were made of the icing of templates in a flow of supercooled aqueous aerosol in an aerodynamic tube. Sprayed water was injected into the flow at the tube inlet at such a distance from the template that the droplets had time to assume the air temperature

Fig. 1. Structure of ice during icing at various values of the equilibrium film thickness h and the mean aerosol droplet radius $\bar{r}$.

Figure 1: Fig. 1. Structure of ice during icing at various values of the equilibrium film thickness h and the mean aerosol droplet radius $\bar{r}$.

before colliding with the template. In the experiments the temperature was varied from -4.2 to $-8.5°$, the flow velocity from 10 to 36 m/sec, the mean droplet sizes from 4 to 17 μ, and the water content of the aerosol from 0.02 to 1.2 g/m^3.

The results of the experiments are shown in Fig. 1. The same figure also gives the results of observations of aircraft icing in clouds, obtained by I. P. Mazin. The figure shows that at the critical value $h_k = 0.1$ cm there is a fairly distinct boundary separating the two types of icing. The boundary is drawn with greater confidence the larger the value of r/h. It may be assumed that the use of monodisperse aerosols will lead to an even clearer separation of the two types of structure.

In order finally to verify the possibility of controlling the structure of ice by changing any of the parameters entering into equation (2), the aerosol parameters were varied in such a way that several ice layers differing in structure were successively formed on the template (as on a hailstone (^{7}, ^{8})). The result is shown in Fig. 2. Layers 1 and 3 were obtained at $h = 0.07$ cm $< h_k$ ($t = -6°$; $V = 33$ m/sec; $qE = 0.5$ g/m^3; $r = 5.2\mu$), layer 2 at $h = 0.22$ cm $> h_k$ ($V = 11$ m/sec, the remaining parameters being the same).

Fig. 2. Ice layers. 1 and 3—at $h < h_k$; 2—at $h > h_k$

Fig. 4. Microphotograph of the boundary between two layers of crystalline salol differing in structure

Fig. 3. Microphotograph of the boundary between two layers of ice of different structure: 1—at $h > h_k$; 2—at $h < h_k$

Figure 3 gives a micrograph showing the boundary between two layers of ice. The homogeneous layer was obtained at $h = 0.08$ cm, the inhomogeneous one at $h = 0.14$ cm.

The results of the observations, among other things, indicate that the generally accepted explanation (7) of the causes of the formation of a layered hail structure is incorrect. Contrary to (7), layers can form if the hailstone remains all the time in the supercooled part of the cloud. It is only necessary that, during its motion in the cloud, the value of h pass several times through the critical value 0.1 cm.

Fig. 1. Structure of ice during icing at various values of the equilibrium thickness of the film h and the mean radius of aerosol droplets $\bar{r}$.
a and b —laboratory experiments (points $h > 0.6$ cm are plotted on the ordinate

$h = 0.6$ cm); v and g —observations in clouds; a and v —homogeneous transparent ice; b and g —inhomogeneous opaque ice.

From the theory (5) it follows that, not only for water but also for other substances, the structure of a crystal can be varied in a regular manner if the sprayed liquid is forced to crystallize in a flow at different aerosol parameters. This was confirmed by experiments with salol.

Figure 4 shows a microphotograph of crystallized salol. Layer 1 was formed at $t = 28^\circ$, $V = 26$ m/sec, $qE = 8$ g/m^3, $\bar{r} = 30\,\mu$. Observation with a microscope clearly shows how the crystals grow against the flow; moreover, when h decreases, the size of the crystals increases. Layer 2 was obtained at $V = 11$ m/sec, $\bar{r} = 15\,\mu$; the remaining parameters were the same.

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