11th IYPT '98
solution to the problem no. 17
presented by the team of Finland
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Icicles

Investigate and explain the formation of icicles.

Abstract

We have studied the formation of icicles experimentally and theoretically. We have studied also icicles which have grown naturally outdoors. When an icicle is growing there is on its tip a thin shell of ice inside which there is liquid water. The length of the tube of not frozen water is $1-3\,\mathrm{cm}$. The pressure due to surface tension prevents the water on the surface of an icicle from freezing when temperature is above $-13^{\circ}\mathrm{C}$. The thickness of this water layer is only a few molecular layers and is not easily detectable but it has a crucial effect on the physics of icicle growing. The water flows readily down the surface of an icicle and the freezing rate on its surface does not depend on temperature.

Thanks

We wish to thank Lasse Makkonen (Ph. D.) from the Technical Research Center of Finland for providing us his wide and deep knowledge of the freezing phenomen. He is the chairman of the Finnish Society of Ice Research and have long been involved in scientific study of snow and ice. We thank him for the excellent material he has given our disposal.

Overview

- Some properties of ice
- Waterlayer on the surface
- Tube of ice
- Growing of icicles in nature

1 Some properties of ice

There is a thin layer of water on the surface of a piece of ice. The water surface exists if the temperature of the ice is higher than $-13°C$. The pressure due to cohesion is changing the melting point of water (ice) on the surface of ice. When the pressure increases, the melting point gets lower. (The melting point becomes lower when the pressure increases, because the density of water is higher than the density of ice. So on the contrary to other substances, the pressure due to cohesion is lowering the melting point of water.)

2 Waterlayer on the surface

So, if the temperature is between $-13°C$ and $0°C$, there is a thin layer of water on the surface of the ice. Even if some freezing happens, the layer always exists. When the first drop of water freezes, it forms a substrate for an icicle. The water is flowing to the very tip of the icicle because of the water layer on the surface of the icicle. The water freezes just below the surface (the pressure due to cohesion is preventing the surface from freezing, if the temperature is higher than $-13°C$ at the tip of the icicles, where the length of the icicle is increasing because of freezing.)

3 Tube of ice

The thin tube of ice is getting thicker higher up the icicle, where the flowing water is freezing on the former ice. The typical length of the hollow core of the icicle is a couple of centimetres. The icicles which we have produced had a hollow core of $1-2\,\mathrm{cm}$. The temperature was $-4°C$. The water was flowing at speed of a couple of drops in a minute.

4 Growing of icicles in nature

We have found also icicles in nature with a hollow core of $3-4\,\mathrm{cm}$. The increase in the length and the thickness of the icicle is only proportional to the amount of the water flowing in a certain amount of time. The icicle always grows in the same manner despite of change in temperature, because the freezing temperature and the thickness of the layer of water are in balance. (No matter how cold it is, the rate of freezing is always the same.)
When no more water is flowing down the icicle, to keep the temperature steady, the hollow icicle freezes thoroughly. Small bubbles of air may be seen in the middle of an old icicles. The water contains gases, which form bubbles, when the water freezes. If the temperature is below $-13°C$ the water layer doesn't exist and it's impossible for icicles to form.

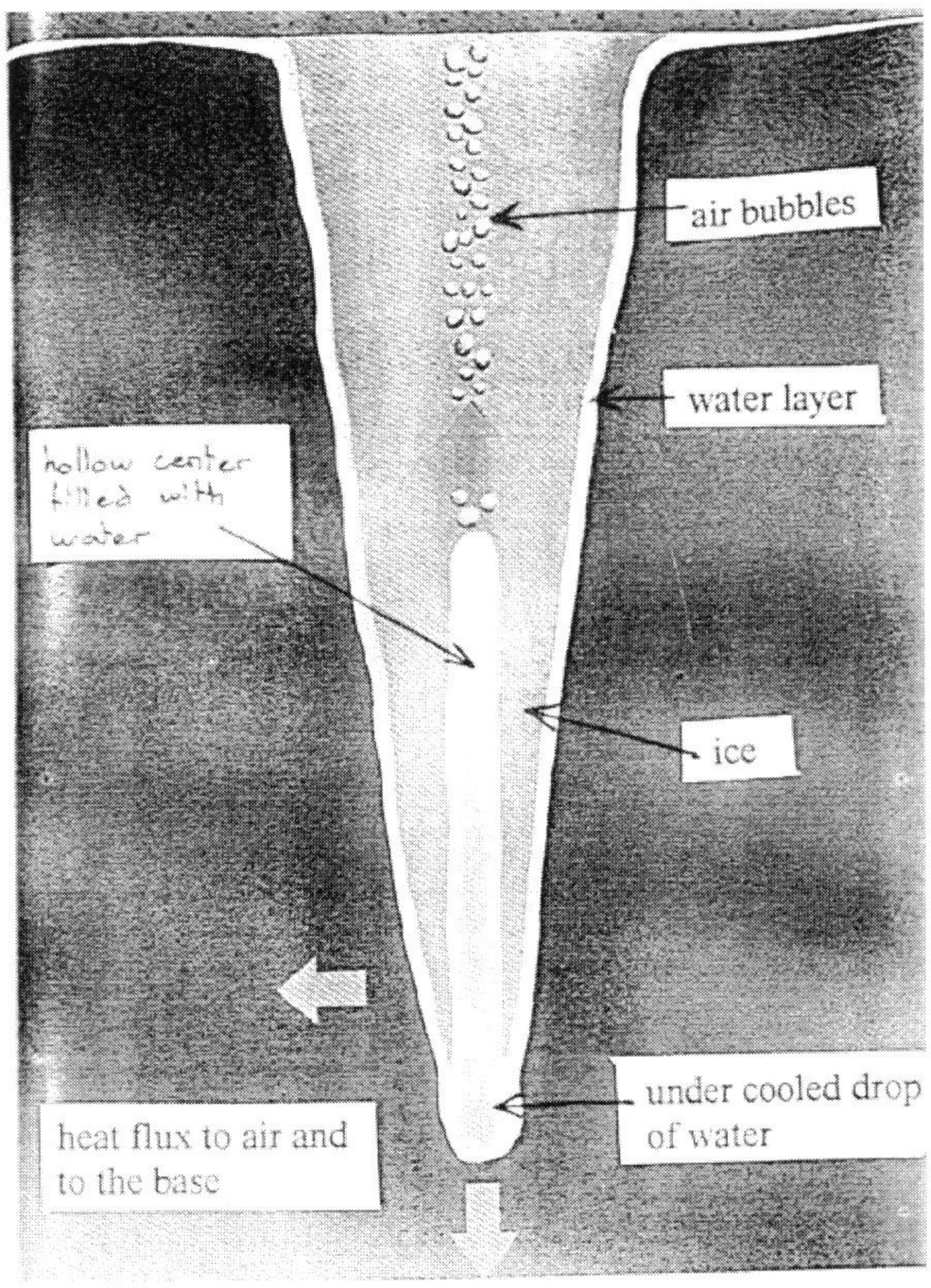
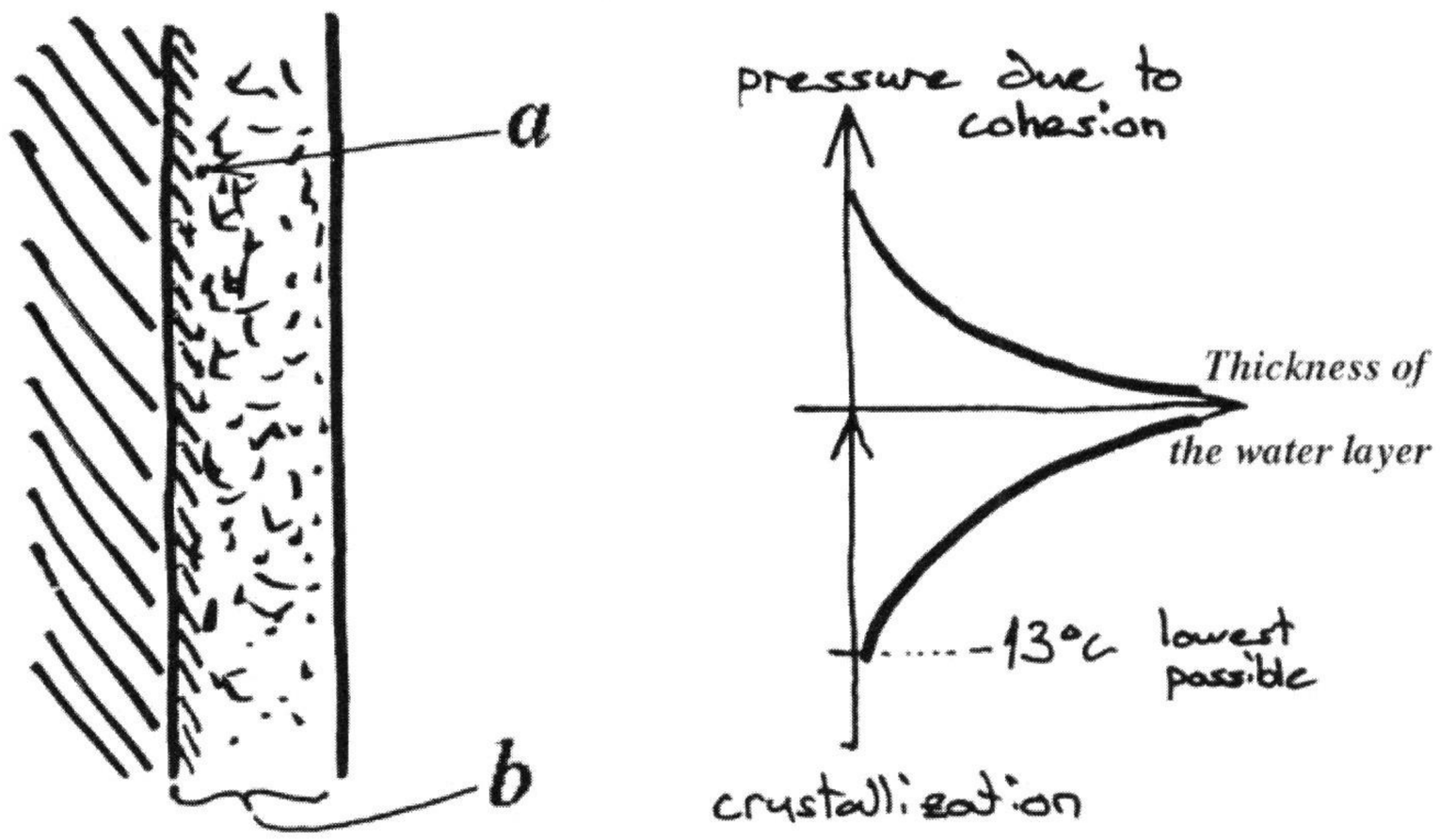


Figure 1: Cross-Section of an icicle



a: Crystallization takes place here. (On the surface of the ice)
b: The thickness of the water layer is only a few molecular layers.

Figure 2: Thin Layer of water