L.J.F. (Jo) Hermans
Leiden University, The Netherlands - Hermans@Physics.LeidenUniv.nl - DOI: 10.1051/epn/2013101

Heavy ice

Water is a vital substance for life on planet Earth. This is obvious for *liquid* water with its crucial role for any species living on the globe. But also *solid* water plays a more important role than one might expect. For one thing, in the old days before people managed to build bridges across rivers, the formation of ice in winter time increased the mobility of mankind substantially. And – for the sporty among us – ice is great fun to skate on. This pleasant aspect of ice was touched upon in an earlier column (EPN 41/6; *Physics in Daily Life* p. 29). The freezing process itself has some remarkable aspects. For example, in most of Europe, the ice layer on lakes and ponds never reaches the bottom, which is good news for fish and other creatures living in the water. As physicists, we realise that the basic reason behind this is that the ice layer grows more slowly as it gets thicker. Remember that the ice layer grows at its bottom, where the temperature is constant at 0 °C by definition, and that the heat of solidification must be transported through the ice layer to the cold air above. Let us assume for simplicity that the temperature at the top of the ice layer is constant, so that the heat flow though the ice layer of thickness h is proportional to $1/h$. Since the growth rate dh/dt is proportional to the heat flow, we have $dh/dt \sim 1/h$, yielding $h \sim \sqrt{t}$.

In other words, if air temperature and wind speed are constant, the ice layer thickness is proportional to the square root of time.

All this relies on a rather unique property of water: the fact that it expands when it goes solid. For most substances this is not the case. For example, if we look at the elements, only gallium, germanium, silicon and bismuth have that property.

It is interesting to speculate on what would happen if water would behave like most substances, *i.e.*, if it would *shrink* upon freezing. The freezing process would be entirely different. To begin with, the very first pieces of ice that are formed at the surface would sink to the bottom, exposing a fresh layer of water ready to be frozen at the top. The freezing top layer would now remain directly in contact with the cold air above, and the slowing down of the freezing process described above would not occur. Instead, the pond would freeze rapidly from the bottom up. The poor fish would have no choice but to swim higher and higher until the whole pond had frozen solid. Poor fish!

It's even worse. In cold winters, many lakes outside the tropics would behave precisely the same, and most of the marine life would be ruined. And that's not even the end of the story. Just think of the glaciers in Greenland or Antarctica, sliding into the ocean. Instead of forming floating icebergs as they do today, they would sink to the bottom, out of reach of the sunrays that would melt them. Sooner or later the deep sea would be filled with ice, instead of with water at 4 °C as it is today. That would completely upset life in the deep ocean.

Fortunately there is a bright side to the story, and things might not be as bad as sketched above. The density of sea water is about 1.027 kg/l, and it would go up even higher if the above scenario were to materialize. So, if freezing water would shrink only a little bit, the oceans would remain safe: only our ponds and lakes would freeze solid. And our favourite fish restaurant would no longer serve pike-perch with champagne sauce, but just herring, salmon and cod. ■