The point of icicles

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Contemplating some of nature's cool creations is always fun. Now a team of scientists from The University of Arizona in Tucson has figured out the physics of how drips of icy water can swell into the skinny spikes known as icicles.

Deciphering patterns in nature is a specialty of UA researchers Martin B. Short, James C. Baygents and Raymond E. Goldstein. In 2005, the team figured out that stalactites, the formations that hang from the ceilings of caves, have a unique underlying shape described by a strikingly simple mathematical equation.

However, stalactites aren't the only natural formations that look like elongated carrots. Once the researchers had found a mathematical representation of the stalactite's shape, they began to wonder if the solution applied to other similarly shaped natural formations caused by dripping water.

So the team decided to investigate icicles. Although other scientists have studied how icicles grow, they had not found a formula to describe their shape.

Surprisingly, the team found that the same mathematical formula that describes the shape of stalactites also describes the shape of icicles.

"Everyone knows what an icicle is and what it looks like, so this research is very accessible. I think it is amazing that science and math can explain something like this so well. It really highlights the beauty of nature," Short said.

The finding is surprising because the physical processes that form icicles are very different from those that form stalactites. Whereas heat diffusion and a rising air column are keys to an icicle's growth, the diffusion of carbon dioxide gas fuels a stalactite's growth.

Short, a doctoral candidate in UA's physics department, Baygents, a UA associate professor of chemical and environmental engineering, and Goldstein, a UA professor of physics and the Schlumberger Professor of Complex Physical Systems at the University of Cambridge in England, published their article, "A Free-Boundary Theory for the Shape of the Ideal Dripping Icicle," in the August 2006 issue of *Physics of Fluids*. The National Science Foundation funded the research.

As residents of cold climates know, icicles form when melting snow begins dripping down from a surface such as the edge of a roof. For an icicle to grow, there must be a constant layer of water flowing over it.

The growth of an icicle is caused by the diffusion of heat away from the icicle by a thin fluid layer of water and the resulting updraft of air traveling over the surface. The updraft of air occurs because the icicle is generally warmer than its surrounding environment, and thus convective heating causes the air surrounding the icicle to rise. As the rising air removes heat from the liquid layer, some of the water freezes, and the icicle grows thicker and elongates.

"At first, we focused only on the thin water layer covering the icicle, just like we did with stalactites," said Short. "It was only later that we examined the layer of rising air, which is technically more correct. Strangely though, both methods lead to the same mathematical shape for icicles."

The resulting shape turns out to be described by the same mathematical equation that describes stalactites. One could call it the Platonic form.

The team wanted to compare the predicted shape to real icicles. Because icicles are scarce in Tucson, the scientists naturally turned to the Internet. They were able to compare pictures of actual icicles with their predicted shape.

The team found that it doesn't matter how big or small the actual icicles were, they could all fit to the shape generated by the mathematical equation.

"Fundamentally, just like in the early stalactite work, it's a result that implies that the shape of an icicle, at least in its ideal, pristine form, ought to be described by this mathematical equation. And we found, examining images of icicles, that it is a very good fit," senior author Goldstein said.

The team's next step will be to solve the problem of how ripples are formed on the surfaces of both stalactites and icicles.

Source: University of Arizona

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