Physicists crack science of ice formation

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(Phys.org)—Salt—and just about anything else that dissolves in water, which is called a solute—lowers water's melting point, which is why it's useful for de-icing roads. And the higher the solute concentration, the slower ice forms. That's why solutes, or "cryoprotectants," are added to proteins, cells, tissues and even dead bodies to slow down ice formation during cryopreservation.

Intrigued by this rather poorly understood process, Cornell physicists have discovered that, for a variety of common cryoprotectants, the time for ice to form has a simple exponential variation with concentration. It's the first molecular-level understanding of exactly how solutes slow down ice formation, and it has implications in fields ranging from climate physics to cryopreservation and artificial insemination.

Matthew Warkentin, a physics postdoctoral associate, together with professors of physics Robert Thorne and James Sethna, published these findings online in Physical Review Letters in January.

Ice forms in supercooled pure water in about 1 microsecond (one-millionth of one second). That time gets multiplied by 10 for every incremental increase in solute concentration. In a 50 percent glycerol -water solution, for example, ice formation can take almost a minute.

The simple exponential behavior suggested that there might be a correspondingly simple explanation, Warkentin said.

In order for ice to form, a small cluster of about 50 water molecules must form a crystalline "nucleus"; a smaller cluster will tend to shrink and disappear, but larger clusters will keep growing as long as liquid water is available. The researchers postulated that the solute molecules "get in the way" of water molecules trying to form a nucleus.

By calculating the probability of finding a nucleus-size volume free of the solute molecules that were preventing nucleation, they derived the exponential dependence on solute concentration and were able to quantitatively replicate data for eight different solutes, ranging from salt to sugar to alcohol. The resulting simple theory used statistical mechanics to extend classical nucleation theory.

In looking at the implications of the work for climate change, for example, Thorne said that modern climate models must take into account a measure of the Earth's reflectiveness, which is influenced by cloud cover. This in turn requires understanding of when and why cloud particles crystallize or remain liquid.

Furthermore, cryopreservation is widely used in medicine and biotechnology, where ice formation can be lethal to cells and tissues. Fertility clinics routinely freeze sperm, eggs and fertilized embryos, and nearly all domestic cattle and swine are propagated using cryopreserved semen, Thorne said.

Aside from its simplicity, an exciting feature of the new theory is that it is generalizable to other liquids and to any system undergoing nucleation, the researchers added.

Provided by Cornell University

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