How can freezing make something warmer?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

We normally think of water as freezing at 0° C (32 °F). But this is an oversimplification. Water can be cooled to a much lower temperature that this. Water, or any other liquid, that is still liquid at a temperature below its freezing point is *supercooled*.

Water can be cooled to a temperature as low as -40 °C (-40 °F). When such supercooled liquid is induced to freeze, it actually *warms up* until it reaches its freezing point. And, as it freezes, it gives off heat.

This experiment uses a heat pack as the central element. And that's the key. The supercooled liquid in the packs freezes when you start the process going. And this freezing makes the heat packs warmer! *A freezing liquid keeps your hands warm.*

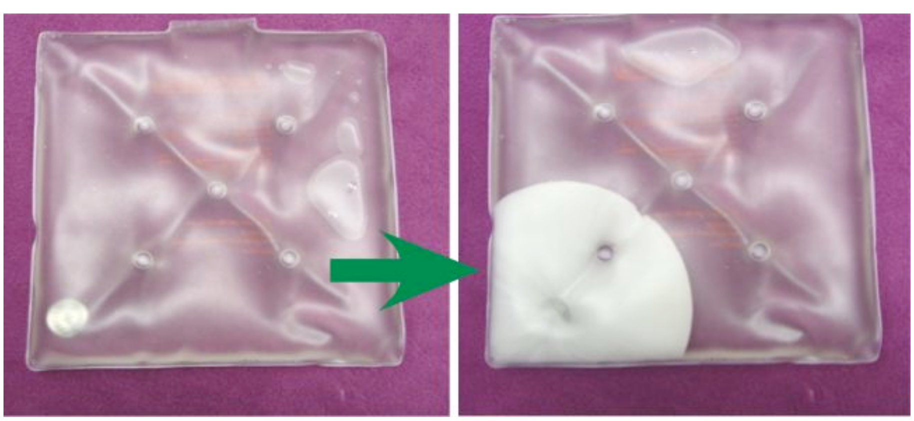
Necessary materials:

- Sodium acetate reusable heat pack
- Thermometer

The heat pack is the key element. These are pretty easy to find; look for "reusable heat pack." The pack is filled with a solution of sodium acetate. When you pop the disk in the pack, the solution freezes, releasing heat. But you can melt the resulting solid by adding heat. This is a simple matter of placing the pack in a pan on the stove and boiling it for 20 minutes.

Theory

You know that an ice cube will cool your drink. When the ice cube melts, it absorbs heat energy from its surroundings.Water molecules frozen in the form of ice are tightly bound. Water molecules in the form of liquid aren't. So to turn a liquid into a solid means breaking bonds, and that takes energy. As the ice melts, it cools off its surroundings.



Once the disk is popped, the heat pack freezes.

Now, think about freezing. When you make ice cubes, you put liquid water in the freezer. The freezer cools the water, taking energy out. When water melts, it takes in energy; when it freezes, it must give off energy.

This taking in and giving off of energy is a very important process for the earth. Ice can melt in one place (taking in heat) flow to another place and freeze there (giving off heat). Not only has water moved from one place to another, so has the heat energy.

The heat packs contain a sodium acetate solution that freezes at 60 °C, but that easily supercools. At room temperature, the sodium acetate is well below its freezing point, but it is still liquid. When you "pop" the metal disk, you create a small region of rapid expansion and cooling. This forms a single crystal of frozen sodium acetate which "seeds" the rest of the pack; you can watch the crystals grow outward from the single crystal. But the key thing to watch is this: As the pack freezes, it gives off heat, as it must. Some of the liquid freezes, warming the pack to 60 °C. Now the freezing continues; the pack will stay at 60 °C, the freezing point, as this happens, giving up heat as the freezing proceeds. The pack will stay at 60 °C until it is all frozen.

Of course, you can melt the solid sodium acetate again by boiling the packs on the stove. When you do this, you put heat in. And this heat is released when the pack freezes again. You can use the packs to move heat from one place to another. You put heat in using the stove in your kitchen; the liquid stores this heat which is then released when the pack freezes. The heat that warms your hand ultimately came from someone's stove!

Doing the Experiment

This can be done as a very short activity, in which students simply induce freezing and then watch the process, or you could do a more involved experiment involving detailed measurements.

We'll start with the simple version. First, the usual safety note:

> **SAFETY NOTE: The contents of the packet aren't toxic; this is food-grade sodium acetate. But when the packet freezes, it gets quite hot. (It is a heat pack, after all!) It can be hot enough to be uncomfortable, and may cause minor burns if you aren't careful.**

The short version of the experiment goes like this:

- Pass out the heat packs. Ask your students to tell you what phase of matter is in the packs. Have them note the temperature.
- Now have them watch the packs closely and pop the disk. Let them observe for a few minutes.
- Have your students explain what they see.

Here's the crucial piece:

> **The packs are freezing, but they warm up and give off heat energy as they do so.**

This can be the basis for a good discussion of supercooling, phase transitions and energy.

If you want to do more, measure the temperature as a function of time. And then try this with an insulate pack. As the packs freeze, they stay at the freezing point. If you insulate a pack, it will stay warm for a longer time. To freeze the pack, all of the heat released in the freezing must be released. If there is insulation, this takes longer!

Summing Up

This is a quick and dramatic experiment that you can use as a springboard from some great discussions of the physics behind the transport of energy in the atmosphere.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu