

Salt and the Freezing Point of Water

Under normal conditions, ordinary water freezes at 0°C , or 32°F . However, if you add salt to water, its freezing point becomes lower. Let's look at why a salt water solution has a freezing point below zero, and how you can use this fact to make ice cream!

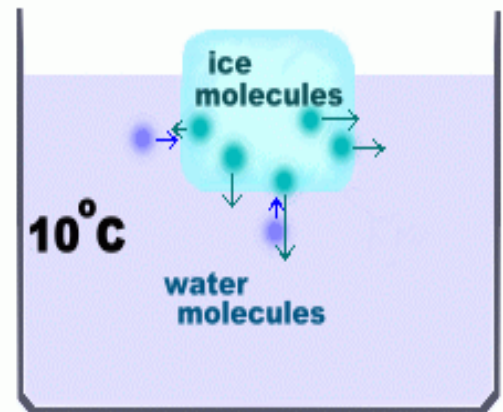
At the right is a container of water with several ice cubes in it (we'll just show one ice cube for simplicity). We've started with cold tap water at 10°C (about 50°F) and ice at 0°C , and we've placed the mixture in a nice, insulated cup that prevents the flow of heat into the cup from the outside world.

Water molecules are constantly escaping from the solid ice into the liquid water (melting). At the same time, water molecules are being captured on the surface of the ice (freezing). But because the water molecules in the liquid are moving quickly (they are at elevated temperature compared to the ice), they can't easily be captured by the surface of the ice, so not very many of them freeze.

Freezing occurs at a slower rate than melting.

Because there are fewer water molecules being captured by the ice (being frozen) than there are ice molecules turning to water, the net result is that the amount of water increases, and the amount of ice decreases. Now as the ice melts, what happens to the temperature of the water? Of course, the water temperature falls because we've put a "cold thing" into the "warm water". But much more importantly, the water temperature falls *because energy is removed from the water to melt some of the ice*. In fact, if we start with enough ice in the container, eventually the water in the container will reach 0°C , along with the remaining ice.

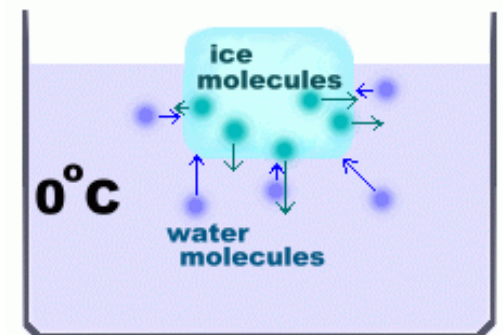
The "phase transition" from a solid to a liquid extracts energy from the liquid.



In the picture at the right, the water in the container has finally reached 0°C along with the remaining ice. Molecules of water are still escaping from the solid ice into the liquid water (melting), and molecules of water in the liquid are still being captured on the surface of the ice (freezing). But now, the *rate of freezing is the same as the rate of melting*, and the amount of ice and the amount of water won't change. The ice and water are said to be in *dynamic equilibrium* with each other. The ice is melting, and the water is freezing, but both are occurring at the same rate, so there is no net change in either quantity.

Freezing occurs at the same rate as melting.

This balance will be maintained as long as the container stays insulated or unless something else happens to favor one of the processes over the other.

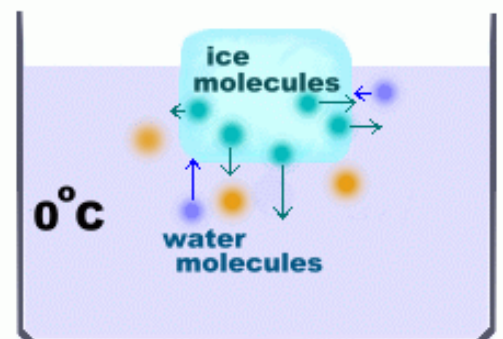


What we've learned so far is that when an ice cube is immersed in water, some of the ice is always melting, and some of the water is always freezing. If these are both happening at the same rate, the contents of the container are at the freezing/melting point. For pure water, this happens at 0°C .

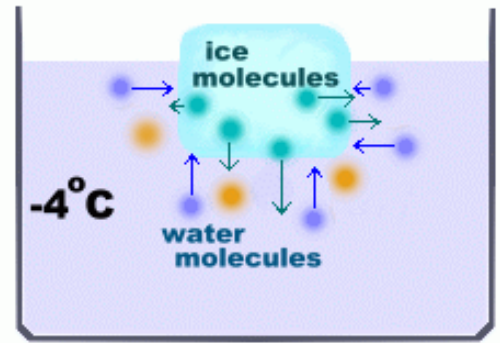
So how does adding salt to the water affect the result? Let's look.

Here's the same container with the water at 0°C , only this time the water contains salt molecules. Adding salt, or anything other than water, *disrupts the equilibrium*.

The salt molecules dissolve in the water, but do not attach easily to the solid ice. There are fewer water molecules in the liquid because some of the water has been replaced by salt. This means that the *number of water molecules able to be captured by the ice (frozen) goes down*, so the rate of freezing goes down. The rate of melting of the ice is unchanged by the presence of the salt, so *melting is now occurring faster than freezing*



But just as in the first picture, as ice melts, energy is extracted from the surrounding liquid, and the liquid cools. And it continues to cool until the system returns to equilibrium, where the number of molecules of water that are freezing is equal to the number of ice molecules that are melting. Eventually, the temperature falls sufficiently to make the water molecules *slow down* enough so that more can attach themselves to the ice. When the number of water molecules that are freezing equals the number of ice molecules that are melting, equilibrium will be reached again. In our example, this point is reached at -4°C , which would be the new freezing/melting point. The higher the concentration of salt, the lower the temperature of the new freezing/melting point.



Summary:

1. *The mixture gets colder because energy, extracted from the liquid water, goes into melting the ice.*
2. *The cooling process stops when the ice-water mixture reaches dynamic equilibrium (water freezes at the same rate ice melts). The temperature at which this happens depends on the concentration of salt (or other impurity) dissolved in the water.*

As ice begins to freeze out of the salt water, the fraction of water in the solution becomes even lower, and the freezing point drops further! However, this doesn't continue indefinitely. At some point the solution will become *saturated* with salt. This happens for salt in water at -21.1°C , which therefore is the coldest a saturated solution of salt and water can get. At that temperature, the salt begins to crystallize out of solution, along with the ice, until the solution completely freezes. The frozen solution is a mixture of separate salt ($\text{NaCl}\cdot 2\text{H}_2\text{O}$) crystals and ice crystals. This heterogeneous mixture is called a *eutectic* mixture.

Any foreign substance added to the water will cause a freezing point drop. For every mole of foreign particles dissolved in a kilogram of water, the freezing point goes down by roughly 1.8°C . Sugar, alcohol, or any chemical salt will also lower the freezing point and melt ice. Salt is used on roads and walkways because it is inexpensive and readily available.

You might suppose that larger molecules might inhibit the freezing of water molecules even more, and have a more dramatic effect on the freezing point. However, that isn't the case. Actual molecules are so tiny compared to the distance they move through the liquid that size is hardly a factor at all.



Now for the fun part! In order to make proper ice cream, which is smooth and creamy, you have to freeze it uniformly and quickly.

This is most easily done by using a mixture of ice, water, and salt, which will be at a temperature many degrees colder than 0°C .

Since you are using the salt/ice solution just for rapid cooling, and not eating it, you can use any kind of salt. Rock salt works well.

For your enjoyment, here are two recipes for home-made ice cream which use the principle of lowered freezing point.

1. ICE CREAM IN A BAGGIE:

Put in a sandwich-size Zip-Loc bag and 'zip' closed:

- 1 tablespoon sugar
- 1/2 cup milk
- 1/4 teaspoon vanilla

Put in a gallon-size Zip-Loc bag and 'zip' closed:

- the filled and zipped sandwich bag from above
- 2 tablespoons rock salt
- enough ice cubes to almost fill the bag

Shake and roll the big bag over and over, until the inner mixture is frozen (about 20 min.)

2. COFFEE CAN AND DUCT TAPE ICE CREAM:

You will need a regular size coffee can, a jumbo size coffee can, duct tape, ice, and ordinary salt.

Vanilla Ice Cream Ingredients:

- 1 cup heavy cream
- 1 cup light cream
- 1 beaten egg
- 1/2 cup sugar
- 1 tsp. vanilla extract

Chocolate Ice Cream Ingredients:

- 1 cup heavy cream
- 1 cup light cream
- 1/2 cup sugar
- 4 tablespoons cocoa
- 1/2 tsp. vanilla extract
- 1/8 tsp. salt

Coffee Ice Cream Ingredients:

- 1 cup heavy cream
- 1 cup light cream
- 2 tablespoons instant coffee granules
- 1/2 cup sugar
- 1/8 tsp. salt

Method for all varieties:

In a regular coffee can mix all the ingredients. Seal the can lid well with duct tape.

Put this smaller, sealed can inside a jumbo size coffee can.

Pack ice and 1 cup of salt around the sealed small can. Put the lid on the large can, and duct tape it closed.

Roll back and forth for 15 minutes.

Open the containers and stir the mixture, scraping the sides of the can. At this point, you can add any additional ingredients you wish (eg: chopped nuts, raisins, chocolate chips).

Reseal the small can and place back in the larger can. Repack it with salt and ice, and reseal it.

Continue rolling for 10 more minutes.