Chemistry of Ice-Cream Making: Lowering the Freezing Point of Water

Kit Contents

QTY	ITEM DESCRIPTION
7	Test tubes
1	Test tube rack
6	Tripour beakers, 250 mL
1	Graduated cylinder, 100 mL
1	Gram balance, accurate to 0.1 gram
1	Thermometer, 6"
2	Stir rods
1	Salt, 26 oz
1	Sugar, 1 lb
1	Foam cup
1	Teaspoon, metal
1	Lab notebook

You will also need from home:
- Water
- Ice

Summary

Prerequisites	Understanding the concepts of molecular weight and moles. Access to a gram balance accurate to 0.1 gram.
Safety	No issues
Frequently Asked Questions	http://www.sciencebuddies.org/science-fair-projects/project_ideas/FoodSci_p013.shtml#help

Abstract

Have you ever made your own ice cream? If you have, you probably surrounded the ice cream container with ice and rock salt to get the mixture cold enough to freeze. But why does that work? How does adding salt (or other substances) affect the freezing point of water? Find out with this ice-cold science project.

Objective

In this science project, you will investigate how dissolving chemicals in water changes the freezing point of a solution.

Introduction

If you have ever made ice cream with an old-fashioned hand-crank machine, you probably packed a mixture of ice and rock salt around the container holding the cream. The salt allows the ice/salt mixture to get colder than pure water ice. This extra-cold ice/salt mixture freezes the cream in the ice cream machine.

If you live in a cold climate, you may also have seen trucks spreading salt and sand on the streets to prevent roads from getting icy after a snowfall. The salt lowers the temperature at which water freezes, so ice can melt even when the temperature is below the normal freezing point of water.

In both cases, salt is used to lower the temperature at which water freezes, a temperature called the **freezing point**. The decrease in freezing point that happens when salt is added to water is called **freezing point depression**. Pure water freezes at 0° Celsius (C), but water mixed with salt will freeze at *less* than 0° C.

Freezing point depression is not unique to water and salt; it happens with all solutions. To make a **solution**, we dissolve a solute in a solvent. The **solvent** does the dissolving, and the **solute** is the thing that is dissolved. In this science project, you will use water as the solvent and sodium chloride (table salt) and sucrose (granulated sugar) as the solutes.

Adding a solute, like salt, to a solvent, like water, lowers the freezing point of the solvent. But, by how much? One degree? Ten degrees? The answer to that question depends on three things: the molality of the solution, the van't Hoff factor of the solute, and the molal freezing-point-depression constant of the solvent. We will take a look at each of these factors.

Molality, *m*, is defined as **moles** (mol) solute per kilograms (kg) solvent, as shown in Equation 1, below:

Equation 1:
$$\text{Molality (moles/kg)} = \text{Moles (mol) of Solute/Kilograms (kg) of Solvent}$$

We care about molality because freezing point depression is a **colligative property**, a property that depend on how *many* solute particles are in the solvent, not the *kind* of solute particles. Molality, *m*, is one piece of this "how many solute particles are present?" question. The van't Hoff factor is the second part of the "how many solute particles are present?" question.

The **van't Hoff factor**, *i*, deals with how a molecule of solute **dissociates**, or breaks apart, in the solvent. Covalent compounds, like sucrose ($C_{12}H_{22}O_{11}$), do not dissociate in solution. These compounds have van't Hoff factors *i* = 1. Ionic compounds, like table salt (NaCl), dissociate when in solution. Table salt (NaCl) has a van't Hoff factor *i* = 2 because it dissociates into two ions in solution, Na^+ and Cl^-.

The third factor, the **molal freezing-point-depression constant**, K_f, is different for every solvent. It has units of (° C/*m*), and it tells us how much 1 mol of solute added to 1 kg of solvent will lower the solvent's freezing point. For pure water, K_f = 1.86° C/*m*.

We can combine these three factors—molality, *m*, van't Hoff factor, *i*, and molal freezing-point-depression constant, K_f—into an equation that predicts how much the freezing point of a solvent will decrease, *ΔT*, when a certain amount of solute is added. Equation 2, below, is the freezing point depression equation:

Equation 2:
$$\text{Degrees Freezing Point is Depressed (° C)} = \text{Molal Freezing-Point-Depression Constant (° C/}m\text{)}$$
$$\times \text{ molality of solution (mol solute/kg solvent)} \times \text{van't Hoff Factor (unitless)}$$
$$\Delta T = K_f\, m\, i$$

- *ΔT* is the freezing point depression in degrees Celsius (° C)
- K_f is the molal feezing-point-depression constant in degrees Celsius per molal (° C/*m*)
- *m* is the molality of the solution in moles per kilogram (mol/kg)
- *i* is the van't Hoff factor of the solute, which does not have units

If you want to know the new freezing point of a solution, T_n, you subtract the change in temperature, *ΔT*, from the original freezing point, T_f, as shown in Equation 3, the solution freezing point equation:

Equation 3:

Solution Freezing Point (° C) = Solvent Freezing Point (° C) - Degrees Freezing Point is Depressed (° C)

$$T_n = T_f - \Delta T$$

- T_n is the freezing point of the solution in degrees Celsius (° C)
- T_f is the freezing point of the solvent in degrees Celsius (° C)
- ΔT is the freezing point depression in degrees Celsius (° C)

In this science project, you will investigate how the freezing point of a solution changes with the concentration and kind of solute in the solution. You will also compare the results from your experiments with the results predicted by Equation 3, the new freezing point equation.

Terms and Concepts

To do this project, you should do research that enables you to understand the following terms and concepts:

- Freezing point
- Freezing point depression
- Solution
- Solvent
- Solute
- Molality
- Mole (chemistry)
- Colligative properties
- van't Hoff factor
- Dissociate
- Molal Freezing-Point-Depression Constant
- Molecular weight

Questions

- When sodium chloride dissolves in water, how many solute molecules result from each molecule of solid dissolved?
- When sucrose dissolves in water, how many solute molecules result from each molecule of solid dissolved?

Bibliography

For more information on colligative properties, see:

- Eli, Todd & Keith. (n.d.). "Colligative Properties," *Chemworld*, ThinkQuest Library, Oracle Education Foundation. Retrieved August 13, 2012, from http://library.thinkquest.org/C006669/data/Chem/colligative/colligative.html?tqskip1=1 (http://library.thinkquest.org/C006669/data/Chem/colligative/colligative.html?tqskip1=1).

For information on Avogadro's number and molecular weight, see:

- Lachish, U. (2000). Avogadro's Number, Atomic and Molecular Weight. Retrieved August 13, 2012, from http://urila.tripod.com/mole.htm (http://urila.tripod.com/mole.htm).

To try a simulated experiment on freezing point depression or boiling point elevation, see (Flash animation, requires browser plug-in):

- Greenbowe, T.J. (2005). Boiling-Point Elevation and Freezing-Point Depression. Department of Chemistry, Iowa State University. Retrieved August 13, 2012, from http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/propOfSoln/colligative.html (http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/propOfSoln/colligative.html).

This idea for this Project Idea came from this source.

- MacQuade, J., et al. (1986). It's Getting Colder (Freezing Point Depression). Retrieved August 13, 2012, from http://www.woodrow.org/teachers/chemistry/institutes/1986/exp9.html (http://www.woodrow.org/teachers/chemistry/institutes/1986/exp9.html).

Experimental Procedure

Preparation of Ice Bath

1. Fill the Styrofoam cup (or 400 mL beaker) 3/4 full with ice.
2. Cover the ice with 1/4 to 1/2 inches of table salt.
3. Stir this ice-salt mixture with a spoon or stirring rod.
4. Use the thermometer to check the temperature of the ice-salt mixture. It should be at least −10° C.
5. You will use this ice bath to freeze many samples of test liquids. During the course of your experiments, you may need to pour melted water out of the ice bath and replenish the ice and salt. When you do this, wait until the temperature of the ice bath drops to at least −10°C before continuing your experiment.
   a. *Tip:* Check the temperature of the ice bath before freezing each of your test liquids.
6. Always carefully rinse and dry the thermometer before using it to measure the freezing point of your test liquids. You do not want the thermometer to carry salt water into your test liquids!

Determination of Freezing Points of Test Liquids

1. You will measure the freezing point of seven different test liquids: three salt solutions, three sucrose solutions, and a pure water control. The pure water control is important for determining the freezing point of the water in your experiment, which may or may not be exactly 0° C.
2. Use a permanent marker to label one of the test tubes and one of the 250 mL beakers (or 8 oz. disposable cups, if you are using those instead) as "#1".
3. Prepare your first test liquid in the beaker labeled #1.
   a. Put beaker "#1" on the gram scale.
      i. *Tip:* Some scales, like the one in the Science Buddies kit, have a cover over the weighing surface. This should be removed before using the scale.
   b. Zero the gram scale. This is usually done by pressing a button that says "Zero/Tare".
   c. Put 2.9 g of table salt (NaCl) into the beaker.
   d. Take the beaker off the scale and place the beaker on a stable surface.
   e. Measure 100 mL of water in a graduated cylinder, and pour it into the beaker with the salt. Stir with a spoon or stirring rod until all of the crystals are dissolved.
   f. Rinse the spoon or stirring rod with water. You do not want to contaminate the other test liquids.
4. Fill test tube #1 half-way full with test liquid #1. Place the test tube in the Styrofoam cup with the ice and salt.
   a. The liquid in the test tube should be below the level of the ice and salt in the cup.
   b. Do not allow any ice or salt from the cup to get into the test tube.
5. Stir the test liquid in the test tube gently with a thermometer while keeping track of the temperature.
6. When the first ice crystals appear on the inside wall of the test tube, record the temperature in your lab notebook. This is the freezing point of the test liquid. Figure 1, below, shows what ice crystals look like.

Figure 1. The opaque, white regions of this liquid are frozen. You know that you have reached the freezing point when the transparent liquid develops opaque, crystalline regions.

7. Empty the test tube (you can pour the liquid down a drain in your house), and then refill the same test tube with fresh test liquid #1. Repeat steps 6 through 8 with a fresh sample. Then empty and refill the test tube again, repeating steps 6 through 8 for a third time. You should have a total of three replicates for test solution #1, all carried out in the same test tube.
   a. If you need to make more of the test liquid, simply repeat step 3.
8. Repeat steps 2 through 7 for each of the remaining test liquids, making sure to use a different beaker and test tube for each of the test liquids. You do not want the residue from one test liquid to contaminate the other test liquids. Make sure to label the beakers so that you know which test liquid is in which beaker.
   a. Test liquid #2 = 5.8 g NaCl in 100 mL water
   b. Test liquid #3 = 11.7 g NaCl in 100 mL water
   c. Test liquid #4 = 17.1 g sucrose in 100 mL water
   d. Test liquid #5 = 34.2 g sucrose in 100 mL water
   e. Test liquid #6 = 68.5 g sucrose in 100 mL water
   f. Test liquid #7 = 100 mL water (simply measure 100 mL of water in the graduated cylinder and store the water in the graduated cylinder)
9. Calculate the freezing point depression, ΔT, for all three replicates of each of the NaCl and sucrose solutions. Record these values for ΔT in your lab notebook.
   a. First, average the freezing point temperatures you observed for plain water, test liquid #7. This averaged temperature will be the solvent freezing temperature.
   b. Re-arrange the terms in Equation 3 of the Introduction to figure out how to calculate ΔT.
10. Average the freezing point depression, ΔT, for each of the NaCl and sucrose solutions. Record these averages in your lab notebook.

Calculation of Expected Freezing Point Depression

1. Calculate the molalities of the NaCl and sucrose solutions.
   a. Molality is defined as the number of moles of a substance, divided by the weight (in kg) of the solvent, as shown in Equation 1 in the Introduction.
   b. The number of moles of a substance is defined as the weight of the substance (in g) divided by the gram molecular weight of the substance.
   c. The gram molecular weight of NaCl is 58.443 g.
   d. The gram molecular weight of sucrose is 342.3 g.
   e. 100 mL of water weighs 0.1 kg.
2. Make a table of your results, like the example shown in Table 1, below.

Solution	g Substance	Molecular Weight Substance (g)	Amount Water (kg)	Molality (mol/kg)
Test liquid #1	2.9 g NaCl	58.443	0.1	0.50
Test liquid #2	5.8 g NaCl	58.443	0.1	0.99

Table 1. Table for calculating the molality of NaCl and sucrose solutions.

3. How do the molalities of the NaCl and sucrose solutions compare?
4. For each of your NaCl and sucrose solutions, graph the molality of the solution (x-axis) versus the average amount of freezing point depression, ΔT (y-axis). What trend do you notice?
5. Use Equation 2 in the Introduction to calculate the expected freezing point depression for each of the NaCl and sucrose solutions. Make a second table to help you calculate with these calculations. Table 2, below, shows what that table might look like.

Solution	Substance	van't Hoff Factor	Molality	K_f for water (° C/m)	Expected Freezing Point Depression (° C)
Test liquid #1	NaCl	2	0.50	1.86	
Test liquid #1	NaCl	2	0.99	1.86	
Test liquid #1	NaCl	2		1.86	
Test liquid #2	Sucrose	1		1.86	
Test liquid #2	Sucrose	1		1.86	
Test liquid #2	Sucrose	1		1.86	

Table 2. Table for calculating expected freezing point depression using Equation 2.

6. Compare the experimentally-measured freezing point depression to the calculated freezing point depression for each of the NaCl and sucrose solutions. How close are the experimental and calculated values? What do you think causes any differences between the measured and calculated values?
   a. *Hint:* The real van't Hoff factors for solutes in solution are often less than their ideal values due to interactions between the ions in solution.

Variations

- Try doing the experiment with calcium chloride (CaCl2) or magnesium chloride (MgCl2), seasonally available at hardware stores, often sold as ice melt. How do the results from these chemicals compare with those from sucrose and NaCl?
- Try doing the experiment with both higher and lower concentrations of NaCl or sucrose. Does the difference between the experimental and calculated values for freezing point depression change with the concentration of NaCl or sucrose?
- For some other chilly experiments, see the Science Buddies projects:
  - Supercooling Water and Snap Freezing (http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_p033.shtml)
  - Investigating the 'Mpemba Effect': Can Hot Water Freeze Faster than Cold Water? (http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_p032.shtml)

Related Links

- Science Fair Project Guide (http://www.sciencebuddies.org/science-fair-projects/project_guide_index.shtml)
- Other Ideas Like This (http://www.sciencebuddies.org/science-fair-projects/recommender_solt.php?solt=FoodSci_p013)
- Cooking & Food Science Project Ideas (http://www.sciencebuddies.org/science-fair-projects/recommender_interest_area.php?ia=FoodSci)
- Chemistry Project Ideas (http://www.sciencebuddies.org/science-fair-projects/recommender_interest_area.php?ia=Chem)
- My Favorites (http://www.sciencebuddies.org/science-fair-projects/recommender_show_favorites.php)
- Chemistry Safety Guide (http://www.sciencebuddies.org/science-fair-projects/project_ideas/Chem_Safety.shtml)

If you like this project, you might enjoy exploring these related careers:

Chemist

Everything in the environment, whether naturally occurring or of human design, is composed of chemicals. Chemists search for and use new knowledge about chemicals to develop new processes or products. Read more (http://www.sciencebuddies.org/science-fair-projects/science-engineering-careers/Chem_chemist_c001.shtml)

Food Scientist or Technologist

There is a fraction of the world's population that doesn't have enough to eat or doesn't have access to food that is nutritionally rich. Food scientists or technologists work to find new sources of food that have the right nutrition levels and that are safe for human consumption. In fact, our nation's food supply depends on food scientists and technologists that test and develop foods that meet and exceed government food safety standards. If you are interested in combining biology, chemistry, and the knowledge that you are helping people, then a career as a food scientist or technologist could be a great choice for you! Read more (http://www.sciencebuddies.org/science-fair-projects/science-engineering-careers/FoodSci_foodscientistortechnologist_c001.shtml)

Food Science Technician

Good taste, texture, quality, and safety are all very important in the food industry. Food science technicians test and catalog the physical and chemical properties of food to help ensure these aspects. Read more (http://www.sciencebuddies.org/science-fair-projects/science-engineering-careers/FoodSci_foodsciencetechnician_c001.shtml)

Chemical Technician

The role that the chemical technician plays is the backbone of every chemical, semiconductor, and pharmaceutical manufacturing operation. Chemical technicians conduct experiments, record data, and help to implement new processes and procedures in the laboratory. If you enjoy hands-on work, then you might be interested in the career of a chemical technician. Read more (http://www.sciencebuddies.org/science-fair-projects/science-engineering-careers/Chem_chemicaltechnician_c001.shtml)

Credits

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Contact Us

If you have purchased a kit for this project from Science Buddies, we are pleased to answer any question not addressed by the FAQs on our site. Please email us at help@sciencebuddies.org (mailto:help@sciencebuddies.org?subject=Chemistry%20of%20Ice-Cream%20Making:%20Lowering%20the%20Freezing%20Point%20of%20Water) after you have checked the Frequently Asked Questions for this PI at http://www.sciencebuddies.org/science-fair-projects/project_ideas/FoodSci_p013.shtml#help

In your email, please follow these instructions:

1. What is your Science Buddies kit order number?
2. Please describe how you need help as thoroughly as possible:

   Examples

   Good Question *I'm trying to do Experimental Procedure step #5, "Scrape the insulation from the wire. . ." How do I know when I've scraped enough?*
   Good Question *I'm at Experimental Procedure step #7, "Move the magnet back and forth . . ." and the LED is not lighting up.*
   Bad Question *I don't understand the instructions. Help!*