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

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## Experimental Procedure

### Preparing the Ice Bath

Follow these step-by-step instructions and click through the slideshow (#slideshow-prepare) to see how the ice bath should be prepared.


Slideshow with step-by-step instructions viewable online.

1. Fill the Styrofoam cup ¾ full with ice and cover the ice with ¼–½ inches of table or sea salt.
2. Stir this ice-salt mixture with a spoon or stirring rod.

3. Use the thermometer to check the temperature of the ice-salt mixture. It should be close to −10°C.
4. You will use this ice bath to freeze several 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 again to about −10°C before continuing your experiment.
    a. *Tip:* Check the temperature of the ice bath before freezing each of your test liquids.
5. 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!

## Determining the Freezing Points of Test Liquids

The following instructions and the slideshow (#slideshow-sample) will guide you through each individual step for preparing and testing your samples.


Slideshow with step-by-step instructions viewable online.

1. You will measure the freezing point of seven different test liquids: three salt solutions, three sucrose (sugar) 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 as "#1".
3. Prepare your first test liquid in the beaker labeled #1.

a. Use the digital scale to weigh 2.9 g of table or sea salt (NaCl) into the beaker.
    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. Measure 100 mL of water in a graduated cylinder, and pour it into the beaker with the salt. Stir with a stirring rod until all of the crystals are dissolved.
c. Rinse the stirring rod with water. You do not want to contaminate the other test liquids.

4. Fill test tube #1 one-third 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. Check the test tube frequently during the first 5 minutes for appearing crystals, then go on to check every minute after that for at least 45 minutes. Figure 1 shows what ice crystals look like. *Note:* The exact amount of time before crystals form will depend on the particular circumstances of your test. You should, however, see crystals form quickly in the majority of your tests, but may notice that test liquid 6 takes substantially longer to form crystals.

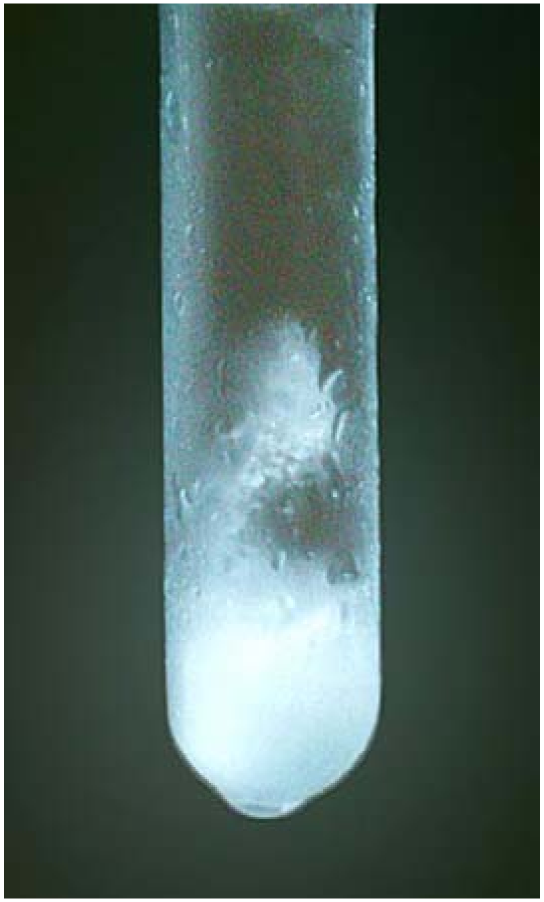

**Figure 1.** The opaque, white regions of this liquid are frozen. You know that you have reached the freezing point when the transparent liquid develops opaque, crystalline regions.

7. 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.
8. Melt the ice again by rolling the test tube in your hand and empty the contents of the test tube down the drain. (**Important:** Be especially careful when handling

the very cold glass test tubes, as they are very brittle. Exposing them to rapid temperature changes makes them more prone to breakage.) Next, refill the same test tube with fresh test liquid #1. Repeat steps 4–7 with a fresh sample. Then empty and refill the test tube again, repeating steps 4–7 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.

9. Repeat steps 2–8 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)

## Analyzing your Data

1. 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. Then calculate *ΔT*. Use the equation below, which was derived from rearranging the terms in Equation 3 of the Introduction (#background).

$$\Delta T = T_f - T_n$$

2. Average the freezing point depression, *ΔT*, for each of the NaCl and sucrose solutions. Record these averages in your lab notebook.
3. 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 kilograms) of the solvent, as shown in Equation 1 in the Introduction (#background).
   b. The number of moles of a substance is defined as the weight of the substance (in grams) 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.
4. Make a data table of your results, like the example shown in Table 1.

| Solution | Grams of the Substance | Molecular Weight of the Substance (g) | Amount of 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 (#background) to calculate the expected freezing point depression for each of the NaCl and sucrose solutions. Make a second

data table to help you with these calculations. Table 2 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? *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 a solution.

## Optional: Applying Your Results to Make Your Own Ice Cream

One of the keys to creamy ice cream is making sure that your ice cream freezing process is really fast. A fast freezing process means that smaller ice crystals are formed and the smaller the ice crystals, the creamier your ice cream will be. The easiest way to freeze ice cream quickly is to put it in an environment that is as cold as possible. The following procedure describes how you can make your own ice cream using the same principles that you have applied during the experiment for lowering the freezing temperature of different solutions. For this add-on experiment you will need all the optional materials that are listed in the Materials and Equipment (#materials) section. Follow these steps and click through the slideshow (#slideshow-making) to see how to make your own ice cream.

Slideshow with step-by-step instructions viewable online.

1. Prepare your ice cream mix by adding 1 tablespoon of sugar, ½ cup of half-and-half (or milk or heavy whipping cream), and ¼ teaspoon of vanilla extract to a small sealable baggie.
2. Add 4 cups of ice cubes or crushed ice to a large, gallon-sized baggie. The ice in this baggie is used to freeze your prepared ice cream mix as fast as possible. Depending on your previous results, decide if you want to add ½ cup of sugar or salt to the ice cubes for the best freezing results. *Note:* Remember, that you want this ice-salt or ice-sugar mixture to be as cold as possible for the best and creamiest ice cream results. In your previous experiment, which mixture (water-salt or water-sugar) got coldest and resulted in the lowest freezing point?
3. Once you have added the salt or sugar to the large baggie, put the small baggie with the prepared ice cream mixture into the large baggie with the ice cubes. Be sure both baggies are sealed shut.
4. Put on oven mitts or wrap the baggie in a small towel and then shake the bag for 5 minutes. Every couple of minutes, feel the smaller baggie and take a quick peek at it.
5. When you are done shaking, carefully open the large baggie and remove the small baggie with the ice cream mix. Did the mixture turn into delicious, creamy ice cream? If so, enjoy it now as a tasty reward for your chemistry challenge! If not, revisit your previous results and repeat this procedure, but this time modify the substance that you add to the large baggie with the ice cubes. *Note:* You can also try to modify this procedure to make even creamier ice cream or to create different ice cream flavors.

## Frequently Asked Questions (FAQ)

FAQ for this Project Idea available online at https://www.sciencebuddies.org/science-fair-projects/project-ideas/FoodSci_p013/cooking-food-science/chemistry-of-ice-cream-making#help (http://www.sciencebuddies.org/science-fair-projects/project-ideas/FoodSci_p013/cooking-food-science/chemistry-of-ice-cream-making#help).