Freezing Point Depression and Making Ice Cream

Introduction:

When it comes to food preparation, humans have developed many techniques to alter the temperature of foods and beverages to optimize the eating and drinking experience. This sometimes comes in simply heating or cooling foods directly and other times comes in using temperature changes to alter the properties of the food or beverage. When doing so, we frequently take advantage of the physical properties of particles in solution, colligative properties, to facilitate temperature changes.

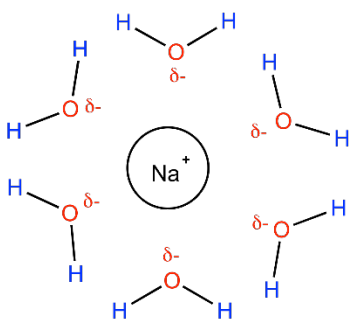
If you live in a cold weather climate your daily life is enhanced by an understanding of colligative properties. During icy road conditions, highway crews treat the roads with salts (NaCl or $CaCl_2$) or brine solutions made of these salt to reduce ice build-up. Adding NaCl brine to highways helps to melt the existing ice and prevents the formation of new ice. In a similar fashion, to keep the engine coolant in vehicles from freezing during severe cold, people use antifreeze. Most common antifreeze solutions contain ethylene glycol which when mixed with water lowers the freezing point. Having an understanding of the colligative properties of solutions enhances our lives in many practical ways, and also in less practical and more enjoyable ways, like making ice cream.

sodium chloride (i.e. table salt) is an ionic compound. It is made of 2 different types of atoms that are held together by a positive-to-negative attraction called an *ionic bond*

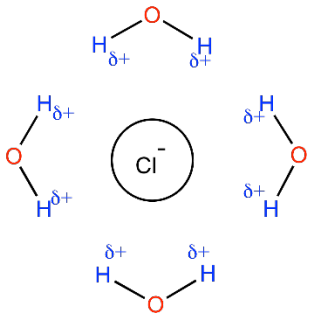
$Na^+ Cl^-$

\+

H_2O



The sodium cation (Na+) is surrounded by a cloud of water molecules that are oriented to present their *slightly* negative oxygens toward the positively charged sodium



The chloride anion (Cl-)is surrounded by a cloud of water molecules that are oriented to present their *slightly* positive hydrogens toward the negatively charged chloride.

Solutions are homogenous mixtures of two or more substances. The solvent is the major component of the solution and the majority of the physical properties of the solution are due to the solvent. The minor component or components of a solution are called solutes. Some of the physical properties of a solution are independent of the type of solute present and are only dependent upon the concentration of dissolved particles. These properties are referred to colligative properties. Colligative properties include boiling point elevation and freezing point depression. Properties that we take advantage of in preparation of foods such as homemade ice cream.

In this exercise we will look at one of the colligative properties of solutions, freezing point depression and then how we take advantage of this property to make homemade ice cream. Then we will evaluate another property of ice cream, taste, to evaluate how changes to the ingredients used to make ice cream impact flavor.

Background:

Colligative Properties

As you have learned several times, pure water freezes at 0 °C (32 °F) and boils at 100 °C (212 °F). We also know that these values can be altered by the addition of different solutes to the water. Using two examples from the introduction, we know that NaCl brines can be prepared to decrease the freezing point of water. A 23.3% solution of NaCl freezes at -51°C or -60°F, dramatically colder than the freezing point of pure water. The use of antifreeze in vehicles provides a similar impact. A 50/50 (v/v) mixture of antifreeze and water has a freezing point of -34°C or -29°F. Using a 70/30 mixture of antifreeze to water extends the freezing point to -84°C or -119°F.

How does understanding colligative properties help us with making ice cream? When you make ice cream whether in an old-fashioned, hand-cranked, ice cream maker or in a sealable plastic bag the temperature of the cream mixture needs to be maintained at temperatures below 0°C (32°F). Since ice water only reaches a minimum temperature of 0°C, we take advantage of colligative properties to reduce the temperature of the ice bath around the ice cream maker to accelerate the freezing.

Ice Cream Making and Tasting

As we have learned throughout this course, the perception of taste and flavor is a personal characteristic. Your preferences for spicy or salty food is a personal characteristic similar to your choice of chocolate, vanilla, or cookies and cream ice cream. The challenge with doing a taste test is endeavoring to place on objective measurement on a very subjective topic. To help in this process, we will need to define a series of terms that will be used to address flavor, body, and texture characteristics of ice cream. In this experiment we will taste test a series of vanilla ice cream products that vary both in price and the nature of the ingredients.

Flavor Characteristics

- Flavoring or Sweetness: Is the flavor or sweetness lacking or too strong. We will evaluate both flavor and sweetness. For the vanilla ice cream we will be tasting we will ask is the vanilla too weak, too strong, exactly what you like. We will also ask whether the ice cream is too sweet, not sweet enough or exactly what you like.
- Syrup Flavor: The syrup flavor is a measure of the presence of corn syrup sweetener present in the ice cream. Liquid corn syrup is the common reference point for this characteristic. Most people prefer their ice cream to be sweet without being syrupy.
- Whey Flavor and Texture: Whey is the common form of non-fat milk solids (NMS) added to ice cream that contribute to both flavor and texture. High levels of whey protein or the use of low quality whey protein lead to a flavor described as earthy, grassy or alfalfa-like in the ice cream that most people do not like.
- Bloom / Bouquet: These terms are used (often interchangeably) to describe the emergence of flavors as odorants are volatilized as the ice cream melts in your mouth and enter rear of the nasal cavity (retronasal). The bloom of ice cream is describe using terms such as insufficient, delicate, light, full, rich, overpowering.

Pre-Laboratory Questions and Concepts:

Calculations and Questions:

1. NaCl has a molecular weight of 58.44 g / mol. Calculate the concentration of NaCl in both a 10% and 20% NaCl solution.

2. When NaCl is dissolved in water, how many solute molecules result for each molecule of solid dissolved?

3. What is the concentration of dissolved particles in the 10% NaCl solution and the 20% NaCl solution?

4. Sucrose has a molecular weight of 342.30 g / mol. Calculate the concentration of sucrose in both a 10% and 20% NaCl solution.

5. When sucrose is dissolved in water, how many solute molecules result for each molecule of solid dissolved?

6. What is the concentration of dissolved particles in the 10% sucrose solution and the 20% sucrose solution?

Process of Sciences:

You will be evaluating the freezing points of different solutions and the freezing point depression of water based upon the addition of different solutes and solute concentrations to water. The questions you have just answered should help you think about the different experiments you will be doing in this laboratory exercise. At this time, just as you have seen in the previous laboratory exercises for Laboratory Exercises 6.1 and 6.2 you should create:

1. A key question being investigated in each of the exercises below.

2. A hypothesis or proposed answer to the question asked.

3. A prediction for the outcome of the experiment based upon your hypotheses you developed.

   The prediction should written as an if/then statement and be specific to the measurements being made.

4. An explanation of your reasoning for each of your hypotheses and predictions.

Procedures:

Exercise 6.1: Ice Bath Experiment

A. Ice Bath Preparation
   1. Label the three containers
      a. Ice
      b. Ice + NaCl
      c. Ice + Sucrose
   2. Add crushed ice only to the first container until approximately half full.
   3. Add approximately ¼ inch of NaCl to the bottom of the Ice + NaCl container and then add crushed ice until approximately half full.
   4. Add approximately ¼ inch of sucrose to the bottom of the Ice + Sucrose container and then add crushed ice until approximately half full.
   5. Mix the contents of each container thoroughly.

B. Temperature Measurement
   1. Insert a thermometer into each of the three containers.
   2. Observe the temperature for each solution until the temperature stabilizes.
   3. Record the equilibrium temperature in Data Table 6.1.1.
   4. Repeat the observations a total of three times.
   5. Calculate the mean and standard deviation for each condition.

Exercise 6.2: Freezing Point Depression Experiment

A. Solution Preparation
   Prepare solutions by combining and mixing the solutes as describe in Table 5.1.
   1. Label five volumetric flasks with the solutions names.
   2. Add approximately 50 mL of distilled water to each volumetric flasks.
   3. Add the appropriate amount of solute to each of the flasks.
   4. Mix to dissolve the solute.
   5. Add water to the final volume of 100 mL.
   6. Mix thoroughly.

Table 6.1: Solution Preparation for Freezing Point Depression

Solution	Sodium Chloride (g)	Sucrose (g)	Water (Final Volume, mL)
Pure Water	0	0	100
10% NaCl	10	0	100
20% NaCl	20	0	100
10% Sucrose	0	10	100
20% Sucrose	0	20	100

B. Cooling Bath Preparation
   1. Obtain 500 mL of the 80/20 solution of ethylene glycol and denatured ethanol from your instructor.
   2. Place this solution into the cooling bath container.
   3. Add approximately 100 grams of dry ice to the container
   4. Stir slowly
   5. Measure the temperature of the cooling bath and record that temperature in Data Table 5.2.1.

C. Freezing Point Measurements
   1. Label 5 large test tubes, one for each solution.
   2. Place 25 mL of each solution into the appropriate test tube.
   3. Place a stopper containing a thermometer into each test tube.
   4. One at a time, place each test tube into the cooling bath.
   5. Measure the temperature of the solution every 30 seconds for 5 minutes.
   6. Record the results in Data Table 6.2.2.
   7. Repeat the experiment 3 times.

Exercise 6.3: Making Vanilla Ice Cream

In this exercise we will be making vanilla ice cream. The recipe makes about 1 cup of ice cream. Each person in your group that want to eat some ice cream should prepare a batch of ice cream.

A. Ingredient Preparation
   1. Obtain a 1 quart zip seal plastic freezer bag.
   2. To this bag add:
      a. ½ cup whole milk
      b. ½ cup heavy whipping cream
      c. ¼ cup table sugar (sucrose)
      d. ¼ teaspoon vanilla or vanilla flavoring
   3. Seal the bag.
   4. Mix the contents gently by squeezing and rocking the bag.
   5. Place this bag in the freezer or on ice while preparing for C.

B. Ice Bath Preparation
   1. Obtain a 1 gallon zip seal plastic freezer bag.
   2. To this bag add:
      a. 3 cups crushed ice.
      b. ½ cup cold water.
      c. ¾ cup table salt (NaCl)
   3. Seal the bag.
   4. Mix the contents gently by squeezing and rocking the bag.

C. Ice Cream Making
   1. Open the 1 gallon zip seal plastic freezer bag.
   2. Carefully place the 1 quart zip seal plastic freezer bag with the ice cream ingredients into the 1 gallon bag.
   3. Seal the 1 gallon bag.
   4. You may want to wear a pair of winter gloves since the bag will get quite cold.
   5. Gently rock the 1 gallon bag from side to side gently squeezing the contents occasionally.
   6. Continue to rock and squeeze the bag for 10 to 20 minutes until the contents of the quart bag harden to form ice cream.
   7. Remove the quart back from the gallon bag and dry the outside of the quart bag.
   8. Taste your ice cream!

Exercise 6.4: Ice Cream Taste Test

In this exercise you will be taste testing different brands and qualities of ice creams. In you group you should decide which flavor of ice cream you are tasting and who is responsible for obtaining the ice cream

A. Preparation
   1. Determine which flavor of ice cream you are tasting, vanilla, chocolate, cookies and cream etc.
   2. Determine who is purchasing five different ice cream samples. The samples should range in quality from inexpensive store brand to top quality.

B. Tasting
   1. Take a small amount of each ice cream and rate it on a scale of 1 (poor) to 5 (exceptional) for each of the following:
      a. Sweetness
         Self-explanatory and very much a personal preference
      b. Flavor
         Self-explanatory and very much a personal preference
      c. Syrup
         Syrupiness is associated with the addition of corn syrup as a sweetener.
      d. Bloom
         Describes the emergence of the flavor as the ice cream melts in your mouth. Typically described as delicate, full, rich, or powerful.
      e. Body
         The substance or structure of the ice cream. Typically described as weak, gummy, fluffy or chewy.
      f. Texture
         Refers to the relative smoothness of the ice cream. Can be describes as coarse, thin, or greasy.
   2. Record the results of the taste test in Data Table 6.4.1.

Results:

Exercise 6.1: Ice Bath Experiment

Data Table 6.1.1: Equilibrium Ice Bath Temperature.

Equilibrium Temperature	Ice	Ice + NaCl	Ice + Sucrose
Trial 1			
Trial 2			
Trial 3			
Mean			
Standard Deviation			

Exercise 6.2: Freezing Point Depression Experiment

Data Table 6.2.1: Temperature Data Changes Over Time for Pure Water.

	Cooling Bath Temperature:				
	Sample Temperature				
Time (s)	**Pure Water Trial 1**	**Pure Water Trial 2**	**Pure Water Trial 3**	**Mean**	**Standard Deviation**
30					
60					
90					
120					
150					
180					
210					
240					
270					
300					

Data Table 6.2.2: Temperature Data Changes Over Time for 10% NaCl.

	Cooling Bath Temperature:				
	Temperature				
Time (s)	10% NaCl Trial 1	10% NaCl Trial 2	10% NaCl Trial 3	Mean	Standard Deviation
30					
60					
90					
120					
150					
180					
210					
240					
270					
300					

Data Table 6.2.3: Temperature Data Changes Over Time for 20% NaCl.

	Cooling Bath Temperature:				
	Temperature				
Time (s)	20% NaCl Trial 1	20% NaCl Trial 2	20% NaCl Trial 3	Mean	Standard Deviation
30					
60					
90					
120					
150					
180					
210					
240					
270					
300					

Data Table 6.2.4: Temperature Data Changes Over Time for 10% Sucrose.

	Cooling Bath Temperature:				
	Temperature				
Time (s)	10% Sucrose Trial 1	10% Sucrose Trial 2	10% Sucrose Trial 3	Mean	Standard Deviation
30					
60					
90					
120					
150					
180					
210					
240					
270					
300					

Data Table 6.2.5: Temperature Data Changes Over Time for 20% Sucrose.

	Cooling Bath Temperature:				
	Temperature				
Time (s)	20% Sucrose Trial 1	20% Sucrose Trial 2	20% Sucrose Trial 3	Mean	Standard Deviation
30					
60					
90					
120					
150					
180					
210					
240					
270					
300					

Data Table 6.2.6. Mean Freezing Point Temperatures

Solution	Freezing Point Temperature
Pure Water	
10% NaCl	
20% NaCl	
10% Sucrose	
20% Sucrose	

Data Table 6.2.7. Freezing Point Depression

Solution	Freezing Point Depression
10% NaCl	
20% NaCl	
10% Sucrose	
20% Sucrose	

Exercise 6.4: Ice Cream Taste Test

Data Table 6.4.1. Ice Cream Taste Comparison. Ice cream 1 to 5 for each category with average.

	Ice Cream Brand				
	1.	**2.**	**3.**	**4.**	**5.**
Sweetness					
Flavor					
Syrup					
Bloom					
Body					
Texture					
Average					

Conclusions and Discussion:

Exercise 6.1: Ice Bath Experiment

Graphing 6.1.

1. Calculate mean and standard deviation for the equilibrium temperature for each of the solutions in Data Table 6.1.1.
2. Prepare a bar graph of the solution type versus equilibrium temperature.
3. Include error bars in the graph.

Questions 6.1.

1. What was the temperature sequence, highest to lowest, for the three different ice baths?

2. Describe colligative properties and how they are demonstrated by this experiment?

3. Using your understanding of colligative properties explain this outcome? Make sure to describe why you would expect the NaCl and Sucrose to respond differently.

Exercise 6.2: Freezing Point Depression Experiment

Graphing 6.2.1:

1. Calculate mean and standard deviation for each of the solutions at each of the time points for the data in Data Tables 6.2.1 through 6.2.5.
2. Prepare one graph for the data in each of the data tables.
3. Graph mean temperature versus time including the error bars.
4. Use the freezing point plateau to identify the freezing point for each solution.
5. Record the mean freezing point for each solution in Data Table 6.2.6.

Calculations6.2.1:

1. Calculate the freezing point depression, ΔT, for each of the solutions.
2. Subtract the mean freezing point for each solution from the freezing point of water: ΔT = freezing point of pure water – freezing point of test solution
3. Record your results in Data Table 6.2.7.

Graphing 6.2.2:

1. Create a graph of freezing point depression (ΔT) versus percent solution.
2. Place freezing point depression (ΔT) on the Y-axis
3. Place % solution on the X-axis
4. Place the data for both the NaCl and Sucrose on the same graph.

Questions 6.2.

1. What was the freezing point depression sequence, highest to lowest, for the four different solutions? Which solute has the greater colligative effect?

2. How does the freezing point depression of Sucrose compare to the freeing point depression for NaCl?

3. Using your understanding of colligative properties explain this outcome? Make sure to describe why the NaCl and Sucrose to respond the way they did.

4. What would you predict to be the freezing temperature of a combined solution containing 10% NaCl and 10% Sucrose? Explain your reasoning for this prediction.

5. How does your freezing point data relate to the temperature of the three ice baths?

Exercise 6.4: Ice Cream Taste Test

Questions.

1. Rank the ice cream brands you tasted highest to lowest based on average score. Which ice cream brand scored the highest on your taste test? Which was the lowest?

2. Was there a correlation between the cost of the ice cream and the taste rankings? Was the correlation what you expected?

3. Compare the ingredients list for each of the ice creams tasted. Do the ingredients give you an indication why certain ice creams rated higher or lower in the scale?

Process of Science Questions and Conclusions:

Earlier you created a key questions, hypotheses, predictions, and explanations for this prediction for each of the experiments in this laboratory exercise.

Based upon your data and the questions you have answered related to this exercise you should be able to complete the process of science questions and conclusions.

Answer the following questions.

1. Did your data support or falsify your hypothesis?
2. How did you come to this conclusion?
3. Did these results change your thinking about this topic? How?
4. What changes would you make to your hypothesis based on this new data?
5. What changes would you make to the experiments to better clarify your results?