Name ______________________ Date __________ Class __________

Thermodynamics of Homemade Ice Cream

Lab 69

APPLICATION

Text reference: ***Chapter 23***

Introduction

It's 35°C in the shade and to cool off, you are eating an ice cream cone. As you sit there, you wonder just how ice cream is made. One area of chemistry that helps explains the making of ice cream is thermodynamics. There are three laws of thermodynamics:

1. The total amount of energy in the universe is constant.
2. The entropy of the universe is always increasing.
3. Everything with a temperature above zero kelvins has energy.

You may recognize the first law of thermodynamics as the law of conservation of energy. The second law may be more familiar to you when it is expressed in everyday language: heat always flows from a warmer object to a cooler object. In making ice cream, it is this second law that is of interest.

Another aspect of chemistry involved in producing ice cream deals with the physical properties of solutions, which differ from those of pure solvents. As you learned in Chapter 15, the presence of solute particles in a solution will raise the boiling point or lower the freezing point of the solvent, depending on the number of particles dissolved in a given mass of solvent. The latter characteristic applies to ice cream because the ice cream mixture is mainly a solution of sugar in water, and its freezing point is depressed below 0°C.

Before refrigerators were invented, ice cream was made using ice. In order to solidify by this method, the "hot" ice cream mixture has to lose energy to the "cold" ice. Since ordinary ice is only at 0°C, however, the lowest temperature that the ice cream mixture can reach is 0°C. With the system at thermal equilibrium, the ice cream mixture would still be a liquid.

To freeze the ice cream mixture, it is necessary to use "colder" ice. How do you do that? Again, what you know about colligative properties provides the answer: you make a solution. A salt-ice mixture has a lower freezing point than pure ice, so it acts as "colder" ice. The more salt added to the ice, the lower the freezing point. The ice cream mixture can then lose more energy to the salt-ice mixture and freeze before thermal equilibrium is reached.

In this investigation, you will take advantage of these principles to make homemade ice cream. You will prepare a salt-ice mixture and use it to freeze an ice cream mixture provided by your teacher. Because you should never taste anything in a chemistry laboratory, you will do this investigation in a food science (home economics) lab or nonscience room. Then, yes, you can eat your ice cream!

Materials (class of 30 in pairs)

30 aprons
15 baby-food jars with lids (4 oz. size)
ice cream mixture
15 large coffee cans with lids
30 kg crushed ice
5 kg rock salt (NaCl)
15 thermometers
15 cloth towels
30 spoons

Time Required

40 minutes.

Advance Preparation

To make the ice cream mixture, combine:

4 eggs
300 mL sugar
1.0 L whole milk
1.0 L half-and-half
2 mL vanilla flavoring
1 box instant pudding

Ask students and faculty to collect baby-food jars and coffee cans with plastic lids. Cans can be washed and saved to be reused.

Arrange to use a food science (home economics) lab or nonscience classroom for the investigation. The investigation can be done at home if you give students the recipe for the ice cream mixture, scaled to smaller proportions.

Measure the mass of the salt and of the ice for each pair of students.

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Discuss the concept of freezing point depression with the students. Make sure they understand that the ice cream mixture and the salt-ice mixture have freezing points below 0°C for the same reason: dissolved solutes.

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Pre-Lab Discussion

Read the entire laboratory investigation and the relevant pages of your textbook. Then answer the questions that follow.

1. How would you define the second law of thermodynamics? Heat always flows from a warmer object to a cooler object.
2. What is thermal equilibrium? Thermal equilibrium is reached when two substances are at the same temperature.
3. What is a colligative property? A colligative property is one that depends on the number of moles of particles involved.
4. How does adding salt to ice make ice "colder"? The salt depresses the freezing point of water so that the salt-ice mixture has a lower freezing point, thereby making it "colder."
5. Why is the salt-ice mixture needed to freeze the ice cream mixture? The salt-ice mixture is needed because the freezing point of the ice cream mixture is lower than 0°C.
6. Why must a towel be used when rolling the can? The towel will protect the hands and insulate the salt-ice mixture.
7. Can the ice cream mixture be rolled too long? Why? No, it cannot be rolled too long because eventually it will reach thermal equilibrium.
8. What would be the product if pure ice was used instead of the salt-ice mixture? Why? The product would be more like a milk shake. The temperature would not get low enough to freeze the ice cream mixture.

Problem

How can you lower the freezing point of water in order to freeze an ice cream mixture?

Materials

apron
clean baby-food jar with lid
ice cream mixture
coffee can with lid
2 kg crushed ice
300 g rock salt (NaCl)
thermometer
cloth towel
2 spoons

Safety

Wear an apron during this investigation. Do this investigation only in a food science (home economics) lab or a nonscience classroom. Make sure the baby food jar is tightly closed so the salt-ice mixture can't contaminate it. Use a towel when rolling the can to prevent cold burns

Safety

Because eating in the chemistry lab is not safe, this investigation should be done in a food science (home economics) room or a nonscience classroom. If work is done in a nonscience room that has no sinks, students can wash their hands in the restrooms. Bring the ice into the room in nonlaboratory containers. Collect leftover ice and water to dispose of later. If students must work at home they should do so only under adult supervision. Make sure that the students' Safety Contracts are signed by a parent or guardian.

Do not use laboratory glassware or salt from laboratory supplies. Students should wear aprons to protect their clothing, and wash their hands before and after this investigation. Check the class for food allergies and other problems. Students who are lactose-intolerant, for example, should not eat the ice cream. Towels should be used to protect hands when rolling the cold cans. Students need to be reminded to wipe off the salt mixture before opening the baby-food jar and eating the

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Note the caution alert symbols here and with certain steps of the Procedure. Refer to page *xi* for the specific precautions associated with each symbol.

Procedure

1. Work in the food science (home economics) lab or a nonscience classroom. Put on an apron and wash your hands with soap and water. Describe the ice cream mixture before you begin, and record your observations in the Data Table.
2. Use a spoon to fill a clean baby-food jar three-fourths of the way with the ice cream mixture. Seal the jar tightly with the lid. (If the jar leaks, your ice cream will be salty.)
3. Use another spoon to fill a large can about one-third full with half of the ice and half of the rock salt. Describe the salt-ice mixture. Measure and record its temperature.
4. Put the closed baby-food jar in the can and surround it with the rest of the ice and salt. Put the lid on the can. See Figure 69–1.
5. Wrap the can in a towel to insulate it and to protect your hands. Roll the can back and forth on a table, countertop, or floor for about 15 minutes. Unwrap the can and describe it.
6. Take the lid off the can and describe the salt-ice mixture. Measure and record the temperature of the salt-ice mixture. Remove and rinse the baby-food jar, open the cap, and wipe the rim free of salt.
7. Describe the appearance of the ice cream mixture. Test the product.
8. Wash the jar, can, lids, and spoons. Pour the salt-ice mixture down the drain with plenty of water. Clean up your work area and wash your hands before leaving the room.

Observations (sample data)

Material	Observation
initial ice cream mixture	a fairly dense liquid
initial salt-ice mixture; temperature	looks like dirty ice −10°C
can after it is rolled	colder, icy, wet
final salt-ice mixture; temperature	some ice has melted −10°C (same as initial)
final ice cream mixture	solution is now semi-solid

Teaching Tips

Putting the ice cream mixture into pitchers will make it much easier to pour into the students' baby-food jars.

The observed freezing point depression depends on the amount of salt used. It is usually about −7°C to −10°C.

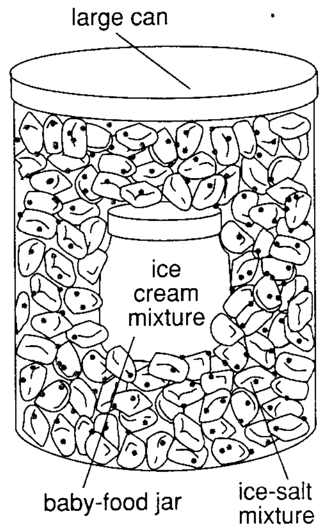

Figure 69–1

Waste Disposal

Excess ice can be melted and poured down the sink. Excess salt should be emptied into the waste basket. The salt-ice mixture may be flushed down the drain with plenty of water. ■

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Calculations (based on sample data)

1. Calculate the theoretical freezing point depression of the ice-salt mixture used in this investigation.

$$\frac{300\text{ g NaCl}}{53.5\text{ g/mol}} = 5.61\text{ mol NaCl}$$

$$\text{molality} = \frac{\text{mol solute}}{\text{kg solvent}} = \frac{5.61\text{ mol NaCl}}{2\text{ kg ice}} = 2.80\ m$$

NaCl dissociates into two ions, so $i = 2$ and $k_f = -1.86°C/m$ for water, so $\Delta T_f = k_{fw}mi = (-1.86°C/m)(2.80\ m)(2) = -10.4°C$

2. Compare your actual freezing point to the one calculated. Determine the percent error.

$$\text{percent error} = \frac{-10.0°C - (-10.4°C)}{-10.4°C} \times 100\% = 4.1\%$$

Critical Thinking: Analysis and Conclusions

1. Discuss the reason for the heat transfer that occurs as the ice melts and the ice cream mixture freezes. *(Drawing conclusions)* The ice cream mixture is above 0°C. The salt-ice mixture is below 0°C. Heat flows from warmer to cooler objects, so the energy from the ice cream mixture flows to the salt-ice mixture. The ice cream mixture gets colder, and the salt-ice mixture begins to melt.

2. How can you account for the percent error in the investigation? *(Interpreting data)* Sources of error include built-in errors of the thermometer and balance used to measure temperature and masses, respectively, and heat absorption by the ice from the environment, which prevents the lowest temperature from being reached.

3. How could you speed up the freezing of the ice cream mixture? *(Making inferences)* Add more salt to the salt-ice mixture to lower its freezing point. Precool the ice cream mixture so that not as much energy needs to be transferred to reach the freezing point.

Critical Thinking: Applications

1. Why are ionic compounds such as salt put on sidewalks in winter? *(Applying concepts)* Ionic compounds lower the freezing point of water, causing snow and ice on sidewalks to melt.