Making in the Classroom

Exothermic & Endothermic Reactions

Theme

What is the theme or topic to be presented?

Exothermic and Endothermic reactions as demonstrated through the creation of hand warmers and ice cream.

Learning Objectives

Students will be able to:

- Apply the processes of exothermic and endothermic reactions to the creation of useable objects.
- Explain the exothermic and endothermic reactions involved in the making of ice cream and hand warmers.

Chemistry Standards:

Year 11 4.4 Design and carry out experiment to describe the exothermic reaction and endothermic reaction

Key Vocabulary:

- Exothermic
- Endothermic
- Molality

Ideas for Building Materials (per student):

Additional materials are necessary for the "lowering the freezing point" experiment that enhances this lesson, the materials list for that activity can be found in the lesson overview below.

For the hand warmers:

- 1 quart sized ziploc bag
- 1 snack sized ziploc bag
- ½ cup calcium chloride ice-melt pellets (lab calcium chloride pellets also work, they're just more expensive)
- enough water to fill the snack sized ziploc

For the ice cream:

- 1/2 cup milk
- 1/2 cup heavy cream
- 1/4 cup sugar
- 1/4 teaspoon vanilla
- 1/2 to 3/4 rock salt (table salt will work, but it will take MUCH longer)
- 2 cups ice
- 1-quart Ziploc bag
- 1-gallon Ziploc bag
- thermometer
- measuring cups and spoons

Lesson Overview

Teacher's Note: *These activities build on students' knowledge of exothermic and endothermic reactions. These topics should be taught prior to these activities, so that students can apply their knowledge to these two making activities.*

Introduction/Exploration: Properties of Materials

Ask students about ice cream and its various ingredients. What has to happen to those ingredients to make ice cream? What happens when we take too long to eat ice cream on a hot day? (The ingredients return to their original liquid state.)

Demonstration:

Show students a Ziploc bag with actual ice cream in it, and another Ziploc bag with a milk/sugar mixture that was frozen. Tell students what is in each bag. (*You will need to make these ahead of time.*)

- What do you notice?
- What is different about the contents of the bags?
- How might the process for making each of them be different?
- How could we better control the production of ice cream?

Ice cream is essentially a cream based solution. In our demonstration, we see that simply freezing the ingredients creates ice crystals. To make ice cream smooth and creamy, we churn it as it freezes in order to break up the ice crystals that form. In order to do this we need to be in control of the freezing process. Today, manufacturers use special insulated machinery to produce

large batches of ice cream. To make small batches, we use a rock salt water solution. Why would we add salt to the water solution? Let's do some experiments with freezing points to determine how to lower water's freezing point and why we might want to do that.

The extent to which a solution's freezing point is lowered depends on three factors:

- The molality (*m*) of the solution as expressed in moles of solute/kg of solvent
- The van't Hoff factor (*i*) of the solute - sugar's van't Hoff factor is $i = 1$, and salt's van't Hoff factor is $i = 2$
- The molal freezing-point-depression constant of the solvent; for water this is $Kf = 1.86°$ C/m where *Kf* = the freezing point depression constant

To predict how much a solute's freezing point will be lowered by adding a given solvent, you can use the equation: $\Delta T = (Kf)(m)(i)$ where:

- ΔT is the freezing point depression in degrees Celsius (° C)
- Kf is the molal freezing-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

You can either demonstrate the experiment below, or have students complete it themselves. If students are completing the lesson themselves this chemistry lesson will need to be split into two parts, with the freezing point activity taking part a class session before the ice cream/hand warmer experiment.

Lowering the Freezing Point

Materials:

- Thermometer capable of reading at least -10° C
- Large 12-oz Styrofoam cup or 400mL beaker
- 100 mL graduated cylinder
- Gram balance (accurate to 0.1g)
- Six 250 mL beakers (or six disposable cups)
- Seven test tubes, 18 mm by 150mm
- 500 g of table salt
- 360 g of granulated sugar
- Water
- Ice

- Stirring rod or spoon for mixing solutions
- Small spoon or scoop for scooping up salt and sugar
- Permanent marker
- Test tube stand (optional but helpful)

Procedure—Part 1: Prepare the ice bath

1. Fill the Styrofoam cup three-quarters full of ice
2. Cover the ice with ¼ to ½ inches of table salt and stir so the salt is dissolved
3. Using your thermometer, check to make sure that the ice-salt mixture is at least -10°C.
4. 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 you continue your experiment.

Procedure—Part 2: Finding the Freezing Points

You're going to prepare six test liquids and measure each of their freezing points. You also must measure the freezing point of a test tube of water to establish its freezing point in your lab. For each test tube follow this procedure:

1) First establish your control. Add 100mL of water to a test tube
2) Place your test tube in the ice bath. As soon as you see ice crystals forming, take the temperature of the liquid. Note that due to differences in water, this temperature might not be 0°C.
3) Next, make your first solution. Mark a test tube and beaker with a '1'.
4) Place your measuring beaker on the scale and press zero/tare. If your scale doesn't have this button, follow the manufacturer's directions for taring your scale.
5) Add 2.9g of table salt to the beaker
6) Take the beaker off the scale and add 100mL to the beaker. With a spoon or stirring rod, gently stir the mixture.
7) Once the salt is dissolved, fill beaker 1 halfway full with the solution.
8) Place the beaker in the ice bath, and record the temperature. When you start to see the first ice crystals form on the inside, record the temperature again, this is the test liquid's freezing point. Make sure to rinse and dry your thermometer thoroughly so as not to contaminate other liquids.
9) Repeat steps #3 through #8 for each of the remaining test liquids, making sure to use a different test tube and beaker for each test solution:

a) Test liquid #2= 5.8g salt in 100 mL of water
b) Test liquid #3= 11. g salt in 100 mL of water
c) Test liquid #4=17.1g sugar in 100 mL of water
d) Test liquid #5 =34.2g sugar in 100 mL water
e) Test liquid #6= 68.5g sugar in 100 mL water

Record the freezing point depression and molality for each of your substances. How do the sucrose and sodium solutions compare in terms of molality and freezing point?

1. Next, find the number of moles of solute for each of your solutions. Note that 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. The molecular weight of salt is 58.443 g, and the molecular weight of sucrose is 342.3 g. Note that the molecular weight of 100mL of water is .1kg.
2. Next, calculate the molality, which is moles of solute per kg of solvent.
3. Note how the molalities of the salt/water solutions and sucrose/water solutions compare.
4. Next, calculate the expected freezing point depression using the formula above for ΔT. How do your calculations compare with what you actually observed? Can you come up with a statement that expresses a causal relationship between the molality of a solution and its freezing point depression?

Building Skills: Design, Test, Repeat

Using what we know about the molality of sodium and sucrose solutions, let's apply our knowledge and make some ice cream (while making scientific notes and taking measurements of course!).

Make the Ice Cream:

1. Add 1/4 cup sugar, 1/2 cup milk, 1/2 cup whipping cream, and 1/4 teaspoon vanilla to the quart Ziploc bag. Seal the bag securely.
2. Put 2 cups of ice into the gallon Ziploc bag.
3. Use a thermometer to measure and record the temperature of the ice in the gallon bag.
4. Add 1/2 to 3/4 cup salt (sodium chloride) to the bag of ice.
5. Place the sealed quart bag inside the gallon bag of ice and salt. Seal the gallon bag securely.

6. Gently rock the gallon bag from side to side. It's best to hold it by the top seal or to have gloves or a cloth between the bag and your hands because the bag will be cold enough to damage your skin.
7. Continue to rock the bag for 10-15 minutes or until the contents of the quart bag have solidified into ice cream.
8. Open the gallon bag and use the thermometer to measure and record the temperature of the ice/salt mixture.
9. Have students make a prediction of the freezing point depression based on the previous demo. (Prompt students: We calculated just water and salt before, what's different here? How might this impact the freezing point? Will it be exactly the same as the previous experiment?)
10. Using the equations above and the data collected during the previous experiment, calculate the freezing point depression of the water/salt solution.

Once the ice cream has been made, notes have been recorded and the ice cream has been eaten, discuss with students the endothermic reaction that took place.

Class discussion:

- How accurate was your prediction of the freezing point depression? How accurate was your calculation?
- What reaction took place in this experiment? How do you know? (Discuss endothermic reactions)
- How can you describe this in terms of this reaction? What was happening on a molecular level?

Now let's take what we learned from the ice cream experiment and reverse it to create and exothermic reaction. What are some examples of exothermic reactions in real life? What might we make in the classroom that is an exothermic reaction?

Make an Exothermic Reaction:

1. Fill a large ziploc bag one quarter of the way full with calcium chloride ice-melt pellets
2. Fill a smaller ziplock bag halfway with water (measure the temperature first), close tight, and place inside the first bag.
3. Squeeze the smaller bag until it breaks open, to create a heat-producing reaction between 20 minutes and an hour.

4. After five minutes, measure the temperature of the solution and record it. Do this again in another five minutes for a total of three measurements.
5. Using the equations above, calculate the freezing point depression.

After the experiment, have students reflect on what they made:

- How can you describe this in terms of an exothermic reaction? What was happening on a molecular level?
- Think about what you just made: Why would we want this product? How could this be marketed? Who would want this?

Conclusion: Think and Share

Ask students to describe what happened in each experiment. They should have been taking consistent measurements of the freezing point, and recording their data. Have them compare the measurements between the two experiments and ask them to describe the exothermic and endothermic reactions they observed.

A description of how the ice cream experiment works:

When a substance freezes, the particles arrange themselves into an orderly pattern. This arrangement is called a crystal. When sodium chloride is added to the water, a solution is formed. The formation of the solution interferes with the orderly arrangement of the particles in the crystal. Therefore, more kinetic energy (heat) must be removed from the solvent (water) for freezing to occur. This results in a lower freezing point. Furthermore, the more particles of solute (salt) added, the more kinetic energy must be removed. The greater the concentration of solute, the lower the freezing point of the solvent.

Accommodations:

Perform the "lowering the freezing point" activity as a demonstration.

Build Complexity:

Have students perform the "lowering the freezing point" activity on their own during a separate lesson.

Additional Resources

Exothermic v. Endothermic reactions
BBC Bitesize Exo and Endothermic Reactions
The Science of Ice Cream in a Bag
How Commercial Hand Warmers work
Explainer TV Ice cream in a bag