HIDING IN ICE
Exploration

Problem

Does ice produce the same temperature change in warm water as an equal mass of cold water?

Materials

Calorimeter (two nested insulated cups with a cardboard lid), stirring rod, thermometer, ice cubes, cold water (obtained from an ice/water mixture), warm water (from the tap or use a Bunsen burner, microwave or coffee pot to obtain), balance or graduated cylinder

Procedure

1. Devise a procedure to find out whether ice and ice water have the same effect on lowering the temperature of warm water. Because you want the exchange of energy to occur only between the ice or cold water and the warm water, you must use a calorimeter or insulated cup. Make very careful measurements. Record all data in an organized fashion. Make sure your sample of cold water contains no ice.

2. Some locations on the human body are sensitive to temperature, such as on the inner arm, and can be used to perceive differences in surface temperature on the skin. Place a drop of the liquids listed below on separate areas on your inner arm. Compare the perceived temperatures for each of the liquids on your skin.

   a. Water

   b. Alcohol

   c. Cooking oil

   d. Nail polish remover

Developing and Using Scientific Ideas

1. Compare the heat lost by the warm water to the heat gained by the cold water in the first part of your experiment.

2. How much energy did the warm water lose while the ice melted?

3. How much energy did the water that came from the melted ice gain as it warmed to the final temperature? How does this compare with the amount of energy the warm water lost?

4. Somehow the warm water appears to have lost more energy than the ice gained. The Law of Conservation of Energy reminds us this cannot be true. How might you account for this “missing energy?”

5. How would you explain the reason for the sensations of feeling different temperature from different liquids on your arm?

6. Why do you get a chill when you get out of a pool or shower?

Extending the Activity

1. Take a small amount of water and alcohol that has been setting out in an open container long enough to have reached an equilibrium temperature with room air. Predict how the temperature of these liquids will compare with air temperature.

2. With temperature probes connected to a CBL or computer start taking the temperature in air, then dip the probes into the liquid for approximately 30 s. Then remove the probes from the liquids and record their temperatures until the probes are dry and return to air temperature. Show or print comparative temperature profiles for the above scenario.

3. How would you explain the temperature profiles from the above graphs?

IT'S JUST A PHASE
Concept Development

Problem

How much energy is involved in a phase change?

Materials

Thermometer or temperature probe with computer or CBL, immersion heater, insulated cups, graduated cylinder, ice cubes, water, BB-board

Procedure

Part A

You have learned in UNIT II LEARNING CYCLE 4: HEAT AND TEMPERATURE that when two substances of different temperatures are brought together in an insulated environment that the heat gained by the cooler substance is equal to the heat lost by the warmer substance. The Law of Conservation of Energy supports this observation and is a generalization for any interactions in a closed system. A system can always be defined in such a manner to include any objects that are interacting with each other.

When you put ice into a container of warm water in the exploration activity, HIDING IN ICE, you noticed that ice had a greater effect in reducing the temperature of warm water compared to an equal amount of water that was as cold as the ice (0º C). This implies that some energy was required to just melt the ice, in addition to raising the temperature of the water that came from the melted ice. This energy, to melt the ice, does not contribute to the changing of the temperature of the water and is called the latent heat of fusion. It is called latent because it has this "hidden" quality of not contributing to the observable phenomenon of a change in temperature.

1. In this activity you are to measure the energy that is required to melt one gram of ice. You should start with a measured amount of water at a temperature significantly above room temperature and then add ice to the water. You can determine the mass of the ice by measuring the combined mass of the warm water and the water that came from the melted ice after you have determined a final temperature of the water mixture and subtracting the mass of the warm water. Show you data in an organized manner.

2. Proceed to calculate the heat required to just melt the ice. Recognize that some of the heat that is lost by the warm water goes into melting the ice and some goes into warming the water that comes from the melted ice. Show your calculations in an organized manner.

Developing and Using Scientific Ideas

1. How much heat went into the process of warming the water that came from the melted ice to the final temperature of the mix?

2. How much heat went into the process of melting the total amount of ice? How much was this per gram of ice?

3. When you add ice to a can of soda at room temperature, does a large amount or small amount of ice melt? Explain your reasoning.

Part B

In the activity, HIDING IN ICE, you placed several liquids on you inner arm and found that it felt colder than the air in the room, although the liquids had sat out in the room long enough to reach equilibrium temperature with the room. You may have observed that the liquids disappeared after some time, indicating that they had evaporated. This process also requires heat and so a source of heat would be your body. When heat leaves your body, the temperature is likely to be reduced. This is what gave you the cooler sensation. When liquids boil, they evaporate rapidly at the boiling temperature. If you add heat to boiling water the temperature of the water does not go above 100º C at standard pressure. This energy does not contribute to the changing of the temperature of the water and is called the latent heat of vaporization. It is called latent because it also has this “hidden” quality of not contributing to the observable phenomenon of a change in temperature.

1. In this activity you are to determine how much energy is involved per gram of water in causing the water to evaporate. Use an immersion heater as a heat source to boil water. Use the power of the immersion heater that is stamped on the device and the boiling time to determine the energy used to evaporate a measurable amount of water. How will you know how much water has evaporated? Record your data in an organized manner.

2. Proceed to calculate the heat required to evaporate the water. Show your calculations in an organized manner.

Developing and Using Scientific Ideas

1. From your experiment, how much energy was required to evaporate one gram of water?

2. Some people, under the same conditions, will perspire more than others. In a warm room, who will feel the heat the most, the ones that perspire or the ones that do not perspire? Explain your reasoning.

3. When you step out of a swimming pool or a shower, you feel cooler than when you stepped into the pool or shower. Explain why this would occur.

4. Under certain weather conditions a warm front will collide with cooler air and cause moisture to condense (water vapor turning into liquid water). Will this cause air temperature to increase or decrease? Explain your reasoning.

Part C

1. Scientists develop models to help explain observations and make further predictions of the behavior of systems. One model for the structure of matter is that all matter is made up of very small particles. You will use a BB-Board in an effort to demonstrate the three common phases of matter – solid, liquid, and gas.

2. Do some experimenting with the BB-Board and model the three common phases of matter. Observe the orientation of the BB-Board, arrangement of the BBs, and your actions on the board in order to model each of the states of matter.

3. Draw a diagram of the arrangements of the BBs for each phase of matter. Use the space below for your drawings.

4. Describe any motion associated with each phase of matter.

5. Describe the energy that you apply to the system for the model to remain in each phase.

Developing and Using Scientific Ideas

1. In which phase of matter do you believe the energy content to be the greatest? Explain your reasoning.

2. Your board has a barrier with a small opening. What characteristic(s) of matter does this feature help explain? Explain your reasoning

3. How does the BB-Board help account for the "hidden energy" in the exploratory activity HIDING IN ICE?

4. What properties or behaviors of matter does the BB-Board explain quite well?

5. What are some properties or behaviors of matter that the BB-Board does not explain?

6. Entropy is a measure of the disorder of a system. Which phase of matter appears to be the most disordered? Explain your reasoning. As a system changes phase from solid to liquid to gas, what happens to the entropy of the system?

Extending the Activity

1. In this activity you will predict the temperature vs time graph for heating a quantity of ice from a freezer with a starting temperature below 0º C and reaching boiling. You will want to have it boil until a measurable amount of water has been evaporated in the boiling process. Sketch a graph of your prediction of the temperature vs time graph.

2. Prepare a 250 mL beaker with 150 mL of water. The thermometer must be frozen near the top of the ice as shown in Figure 5.1. Care needs to be given to having the end of the thermometer or temperature probe remain in contact with the ice, otherwise some unusual fluctuations of temperature may result when there is still ice to be melted. Use a piece of cardboard with a hole in the middle to support the thermometer. Wind a rubber band around the thermometer right above the cardboard if the thermometer has a tendency to slip. Place the beaker in the freezer until the temperature of the ice is the same as that of the freezer between -5^{o}C and -10^{o}C.

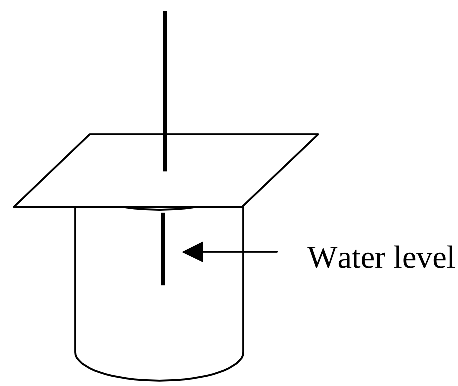

Figure 5.1

3. Prepare a Bunsen burner or other heat source to provide a constant temperature at a temperature significantly above the boiling temperature of water. Quickly bring the ice with a thermometer or temperature probe imbedded in it to the heat source. Start reading the temperature immediately when the ice is placed above the heat source. The thermometer will read the temperature of the substance in immediate contact with the thermometer. Care should be taken to have the thermometer remain stuck to the ice to keep reading the ice temperature as long as possible.

4. Plot the temperature vs time graph for the entire event. Based on how much water was evaporated in the boiling process, estimate the time it would have required to evaporate the entire amount of water coming from the ice cube.

5. Compare the energy needed to melt the ice compared to the energy needed to evaporate it. Approximately how many times more energy does evaporating take compared to melting.

6. Compare the energy needed to evaporate the water with the amount of energy needed to bring the temperature of the water from freezing to boiling.

CONCEPT ENHANCER

Reviewing Your Observations

In the previous learning cycle, HEAT AND TEMPERATURE, you saw that when you added heat to a substance that the temperature increased. Some substances, such as water, absorbed more energy for a one-degree change in temperature than other substances. However, in the activities, HIDING IN ICE and IT'S JUST A PHASE, you noticed that when energy was added to ice it did not change in temperature until all the ice was melted. A comparable observation was made when water reached the boiling temperature. Heat was added to water when it started to boil, but the temperature remained at near 100º C during the entire boiling process. The effect of adding heat to a substance and not causing a change in temperature is referred to as latent or "hidden" heat.

As you saw in IT'S JUST A PHASE, this energy can be measured and is usually expressed in J/kg. The accepted value for the latent heat of fusion for water is 3.3×10^5 J/kg and the accepted value for the latent heat of vaporization for water is 22.6×10^5 J/kg. Thus the latent heat of vaporization is 6.8 times as great as the latent heat of fusion for water. Figure 5.2 shows the relative amount of energy involved in first melting 1.0 kg of ice, then warming it up to 100º C and then evaporating the 1.0 kg of water. The reactions are reversible showing that it is consistent with the Law of Conservation of Energy as well. In other words, if 1.0 kg of water condenses from a gas into a liquid it will give off 22.6×10^5 J of energy.

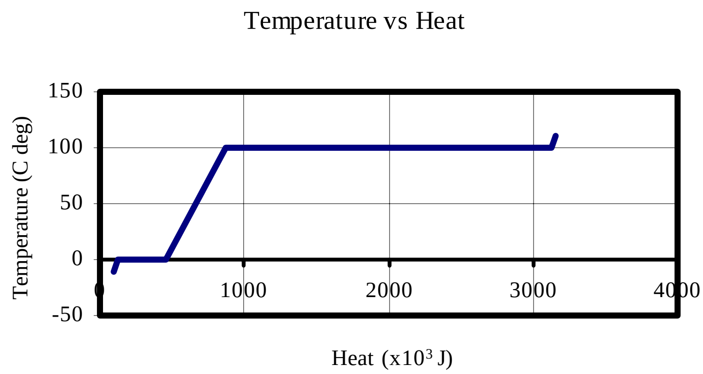

Figure 5.2

A Theoretical Explanation

The internal energy of molecules that make up a substance is the total energy of these molecules in the form of kinetic energy – energy of motion and potential energy – energy of position. When energy is added to a substance, the internal energy of the molecules increases. In the UNIT II LEARNING CYCLE 4: HEAT AND TEMPERATURE, you observed that this increase in internal energy was observed as an increase in the temperature of the substance - a measure of the molecules' average kinetic energy. On a molecular level, when water is in the solid phase as ice the molecules are more or less fixed with the kinetic energy associated with a given temperature in the form of vibrational motion. Potential energy is present in the collection of particles in a solid or liquid in the form of attractive bonds. These bonds hold the particles together to form either a rigid solid structure or less rigid and flowing liquid structure. When energy is added into this system, the vibrations become more amplified which eventually could cause the particles to be far enough part that the bonds between them can break. The position of these bounded particles relative to one another is a reflection of their potential energy with a high potential energy indicating a large average separation. Finally some molecules break free from the rigid form and are free to slide around in the material. As more energy is added to the ice, more and more of the molecules break free from the rigid solid structure. The average vibration rate and amplitude of the molecules in the solid structure does not change, meaning the temperature of the material does not change. When more energy is added to the material, the random vibration of some molecules will cause another molecule to have enough energy to break free from the solid and move into the more energetic liquid phase. The level of kinetic energy of the molecules does not change because the energy added tends to raise all molecules into the liquid phase before the kinetic energy of the molecules in the liquid phase increase. If some molecules would rise to a higher level of kinetic energy, then that material would be at a higher temperature, but heat tends to flow from high temperature material to lower temperature material. Hence, the energy would go into melting more ice. Finally, when all the molecules have reached the liquid phase, then their average linear kinetic energy will increase, causing the temperature to increase.

A similar scenario occurs when liquid water reaches 100º C (boiling) and goes into the vapor state. Each molecule must receive 6.8 times the energy to break the liquid-vapor bond compared to breaking the solid-liquid molecular bond. Also, it takes 5.4 times the energy to break the liquid-vapor bond as it does to warm the water from the freezing temperature to the boiling temperature.

New Definition of Heat

The existence of phase changes requires that the definition of heat be expanded. Heat is the process by which energy is transferred from two objects at different temperatures or two objects at the same temperature when one of them is undergoing a phase change. In other words, heat added to or removed from a substance may involve either a temperature change, a phase change, or both.

BB-Boards

Did the BB-board demonstrate the various energy states and the energy required to move the BBs from one state to the next? The BBs would be stationary or stay in a rigid pattern when little shaking energy was transmitted to the board. To get the BBs to slide over one another, significantly more energy was required. If you kept the board in a vertical plane, then you would have to exert lots of energy to get any BBs to pass through the opening in the board and remain in the vapor state. Therefore, you could use the BB-board to make the abstract motion of the molecules more concrete. In science when this type of mechanical model is proposed, usually there are shortcomings of the mechanical model. After all, if there were no shortcomings, then it would be the real thing and not the model. If you tilted the board to get some BBs into the "vapor" state, then you changed the relative forces pulling them together, which is not possible.

Applications

Some applications of the energy associated with the change of phase is related to a cooling effect. When you placed water or alcohol on your arm, you felt this spot on your arm to be cooler than the part of the arm exposed to air. Some of the liquid evaporated. Therefore, some of the water molecules received the energy associated with the latent heat of vaporization. They did so because the molecular motion of the molecules in the liquid are totally random and by some probability during collisions, some near the surface got the energy to break free from the rest of the molecules in the liquid and move into the vapor state. Now if no energy was added to the system, then during the collision that gave one molecule the extra energy to escape, some other molecule's motion was slowed down. This is an application of the Law of Conservation of

Energy at the molecular level. So for every molecule that gains the energy to escape, the rest of the molecules have lost that amount of energy. If they lose kinetic energy, then the temperature will decrease causing the skin to feel cooler in that area. So when water or some other liquid evaporates from your skin, there will be a cooling effect. Liquids such as cooking oil do not evaporate as easily; hence do not give the cooling effect as experienced with water.

In a similar manner, if the humidity is high, then sometimes water molecules will condense (go back to the liquid state). When this happens the heat of vaporization is given up by the vapor molecules to the material with which they are in contact, causing the surface of that material to become warmer. When large quantities of water vapor condense in the atmosphere, then large quantities of thermal energy are released and cause hot air turbulences as this warm, less dense air rises in the atmosphere and collides with cooler air on the way up. Thus, evaporation is a cooling process and condensation is a warming process.

Orchard growers sometime spray water on the fruit trees in the wake of freezing weather. The juices in fruits freeze at lower temperatures than water. So if orchard growers can keep the temperature of the fruit at 0º C, then the fruit would be saved. By spraying a layer of water onto the fruit trees, the water needs to loose 3.3×10^5 J of energy per kg of water in order to freeze the water. This energy will keep the temperature of the ice at 0º C until all the sprayed water freezes and hopefully keep the temperature of the fruit above its freezing temperature. In the activity WE ALL SCREAM FOR ICE CREAM, you will see further applications of the latent heat of fusion associated with the process of making ice cream. You will also have an opportunity to see what happens when you heat a mixture of liquids to their boiling temperatures. What kind of temperature profile will this phenomenon create?

CONCEPTUAL PRACTICE

1. A scout canteen is carried in a canvas pouch. Why are the scouts instructed to "wet down" the canvas pouch? Give your explanation at the molecular level.

2. Why do citrus grove owners spray the fruit with water when freeze warnings are issued?

3. If you have a glass of ice water sitting on a table, often there will be condensation of water on the outside surface of the glass. Does this contribute to the cooling of the contents inside the glass or does it create a heating effect. Explain our reasoning.

4. Does pouring ice-cold lemonade into an insulated cup make good sense for keeping it cool? Describe two ways in which this contributes to keeping the contents cool.

5. Suppose you are outside in Phoenix, Arizona when the temperature is 95º F and the relative humidity of 20% and your friend is in New Orleans, Louisiana also at 95º R, but a relative humidity of 80%. Who will feel warmest? Explain your reasoning.

6. Before the development of the modern refrigerator, people used iceboxes to keep their food supplies cool. Iceboxes were typically constructed from wood with an area where a block of ice would be placed and the water from the ice allowed to drain. Explain why the iceboxes were quite affective for refrigerating foods.

7. Sublimation is defined as turning directly from a solid to a gas (without melting). Dry ice is one common substance that sublimes. Do you think energy is absorbed or given off when a substance sublimes? Explain your reasoning.

WE ALL SCREAM FOR ICE CREAM
Application

Problem

How can you use your knowledge of heat and temperature to account for the energy changes that take place when making ice cream?

Materials

1 gallon zipper type freezer bag, 1 quart zipper type freezer bag, 1/2 cup of heavy whipping cream, 1/2 cup of milk, 1/4 cup of sugar, 1/4 teaspoon of vanilla, 3 cups of crushed ice, 1/2 cup of rock salt or kosher salt, small dish, spoon and mittens (optional)

Procedure

In this activity you will be conducting a tasty experiment. You are to enjoy the experiment, but like a true scientist, you are to make some measurements related to the experiment. Read through the instructions for this activity. Then determine how you can make some quantitative measurements related to this activity. You should include measuring the amount of energy involved in freezing the ice cream.

1. Carefully open the small zipper type bag. Do not break the seal at the corners. Put the cream, milk, sugar, and vanilla in the small bag and mix the ingredients well. Carefully remove most of the air from the bag and seal it. Check again to make sure the bag is completely sealed.

2. Mix the salt and ice in the larger bag.

3. Place the smaller bag inside the larger bag and squeeze the air out of the larger bag. Seal carefully.

4. Knead/mix the bags continuously and vigorously for 10 minutes or until the consistency of the ice cream suits your taste. This is where the mittens might come in handy!

5. Remove the small bag from the large bag and scoop the contents into a small dish.

6. Make all the measurements necessary to calculate the energy needed to freeze the ice cream mix. Then enjoy the by-product of the experiment!

Developing and Using Scientific Ideas

1. Describe two energy transfers in making the ice cream.

2. Did you observe two materials reaching thermal equilibrium? Explain.

3. Where was a phase change observed in this lab?

4. Why did you have to add salt to the ice?

5. Where might you see an additional practical application of the addition of salt to some material?

6. What is the purpose of the kneading/mixing action?

Extending the Activity

1. In this activity you will heat a mixture of alcohol and water, starting from room temperature, to the boiling point of water. Sketch a graph of your prediction of this temperature vs time graph. Note that the boiling temperature of alcohol is less than the boiling temperature of water.

2. Prepare a 25% isopropyl alcohol with water solution and heat the mixture with an immersion heater, noting the power rating of the heater. Pour the mixture into an insulated cup covering the heating coil, but not more than ¾ of a cup. "Insert Safety Icon Here":   The immersion heater coil should be in water at all times. Failure to do so will result in severely damaging the heater. When the liquid begins to boil, it should not spill over the top of the cup. Stir the element near the bottom of the cup to agitate the solution until it boils, at which time there will be enough turbulence to keep the temperature uniform throughout the liquid. "Insert Safety Icon Here": You

should wear an insulated glove to keep your hand from getting too hot. If you have a temperature probe, use it to plot this graph. Otherwise you will need to read the temperature from a thermometer at regular time intervals.

3. After you have completed plotting the graph, give your interpretation of the graph and how it relates to your observations of this activity.