

## HEAT

### PROBLEM PRESENTATION / EXPLORATION

- A. How does the temperature of water change as chemicals are added to it?
1. Arrange three test tubes in a test tube rack.
  2. Add 5 mL of water to each test tube and insert a thermometer in test tube A.
  3. After one minute record the temperature of the water.
  4. Using a plastic spoon add 3 pellets of chemical A to the test tube. Record the starting time and temperature.
  5. Now read the water temperature every 15 seconds for a total of three minutes.
  6. In the second test tube insert a thermometer and record the starting temperature of the water after one minute.
  7. Using a plastic spoon add one half spoonful of chemical B to test tube B.
  8. Read the water temperature every 15 seconds for a total of three minutes.
  9. In the third test tube insert a thermometer and record the starting temperature of the water after one minute.
  10. Using a plastic spoon add one half spoonful of chemical C to test tube C.
  11. Read the water temperature every 15 seconds for a total of three minutes.
- B. Endothermic vs. Exothermic
1. Obviously, all chemicals don't act the same way when dissolved in water. The sodium hydroxide (chemical A) dissolved and released energy in an exothermic process; the ammonium nitrate (chemical B) removed energy from its surroundings (an endothermic process) as it dissolved ; and the table sugar (chemical C) did neither as it dissolved.
  2. After the students have had some hands-on experience with exothermic and endothermic reactions you might like to demonstrate a very interesting one for them.
    - a.) Set the top of a Petri dish on the demonstration table. Place 1 mL of water in the dish.
    - b.) Place 20 g of  $\text{Ba}(\text{OH})_2 \cdot 8 \text{H}_2\text{O}$  in a clean, dry 50 mL beaker. To this same beaker add 10 g of  $\text{NH}_4\text{Cl}$ .
    - c.) Place the beaker in the water in the Petri dish.
    - d.) Carefully, stir the mixture inside the beaker with a stirring rod. [ No water is added to the beaker.]
    - e.) Wait several minutes and carefully lift the beaker. Because this reaction is so endothermic, it removes enough energy from the water that the water freezes.
    - f.) *DISPOSAL: Dissolve the reaction mixture in the beaker in the smallest possible volume of water. Add 5 volumes of 10% aqueous sodium sulfate. Set aside for one week. Filter. Discard the filtrate at the sink. Discard the solid with ordinary trash.*
  3. Another very interesting demonstration that is not as messy and with no disposal problems illustrates a spectacular exothermic reaction.
    - a.) A portable hand-warmer can be purchased from Wal Mart for three or four dollars that appears to be a clear liquid in a flexible plastic package. (The brand name for this warmer is Heat To Go<sup>®</sup>. It is made by Sunbeam.)
    - b.) Inside the plastic package is a little metal clicker. Upon clicking it an instantaneous reaction takes place. White solid crystals start to come out of solution.
    - c.) At the same time a large amount of heat is released. The directions on the package indicate that the hand warmer will stay hot for up to an half hour.
    - d.) The solution inside is a supersaturated solution of sodium acetate. Upon disturbing the equilibrium by clicking the metal disk the excess

solute comes out of solution. Since dissolving is an endothermic process, the reverse is an exothermic process.

- e.) In addition to the spectacular reaction this process is entirely reversible. By dropping the pouch into boiling water (or placing into a microwave oven) the white solute will go back into solution. Allowing the pouch to cool leaves the original clear solution ready to be released when the metal disk is clicked again.

### CLASS RESPONSE / CONCEPT INVENTION

- A. Heat vs. Temperature
- Quite often students confuse temperature and heat.
    - Heat is the measure of the quantity of energy in a system.
    - Temperature is the measure of the intensity of that energy in the system
  - If you have a bathtub full of water and a bathroom sink full of water, both having a temperature of 30°C, which will be able to melt more ice cubes?
    - Both have the same intensity of energy meaning that for each cm<sup>3</sup> of water in both cases there is the same amount of thermal energy concentrated; therefore, they both have the same temperature.
    - But, it is obvious that the bathtubfull of water could melt a lot more ice cubes that the sinkfull of water can because the bathtub contains a lot more energy or heat than the sink.
  - From the above example it should be clear that one can not measure the amount of heat a system contains by measuring just its temperature.
  - Different instruments are needed to measure temperature and heat.
    - A thermometer is used to measure temperature.
    - A calorimeter is used to measure heat.
- B. Heat can only be measured when energy is being transferred from one object to another.
- To measure temperature we simply stick a thermometer into the substance and read the intensity or concentration of the thermal energy in the substance.
  - Unfortunately, there is no instrument that we can stick into a substance and determine its heat content.
  - The best we can do is to measure the amount of energy that is being transferred from the hot source to the cold source.
  - Heat will always flows spontaneously from the hot source to the cold source. In the case of the ice cubes and the bathtubfull of water, energy from the water (hot source) flowed into the cold source (ice cube) which melted the ice cubes and then even heated the ice cold water up to produce warm water.
  - Just for the record, there is no such thing as a substance called COLD. Cold is merely the lack of heat or energy.
  - To measure the heat being transferred from one object having a lot of energy (hot source) to an object having less energy (cold source) we use a calorimeter.
  - The Law of Conservation of Energy says that in all reactions energy is neither created nor destroyed. Analyzed in terms of the ice cubes and bath water from the above example, this means that the energy lost by the hot bath water was gained by the ice cubes. In other words, no energy was lost, it simply was transferred from one place to another.
- C. The Law of Heat Loss and Heat Gain
- We know that temperature is measured in °C. Since temperature and heat are different, we can not measure heat in °C, rather, it is measured in calories (or joules).
  - A calorie is defined to be the amount of energy needed to raise a gram of water by one °C.
  - Place 50 grams of water in a Styrofoam<sup>®</sup> cup, measure its temperature with a thermometer, and record.

4. We need some type of heat source for our experiments. Probably the best would be one of those immersion heaters made to put into a single cup to heat water for making coffee. They cost about \$2.50 apiece. Candles could also be used. If candles will be used, the water must be put into a beaker rather than a Styrofoam<sup>®</sup> cup.
5. Place the heater in the cup and allow it to put heat into the water for a constant time in each experimental trial. (Probably one minute will be enough. It depends on how much heat your heater puts out. It would be nice to get a change in temperature of at least 10°C.)
6. Record the change in temperature for this standard amount of heat being added to 50 grams of water. After determining the change in temperature pour the water down the sink.
7. Repeat the experiment using 100 grams of water and record the results.
8. Finally, repeat the experiment using 150 grams of water.
9. What pattern seems to be developing? **[With the quantity of heat being added constant, the change in temperature gets smaller as the mass of the water gets larger. In other words, the mass is inversely proportional to the change in temperature.]**
10. This time lets hold the amount of mass constant and develop the relationship between the change in temperature and the quantity of heat.
11. Place 100 grams of water in three Styrofoam<sup>®</sup> cups and record their initial temperatures. (They should all be allowed to come to the same temperature if they are not so when poured into the three cups.) Place the heater in cup #1 for 30 seconds and record the rise in temperature.
12. Place the heater in cup #2 for 60 seconds, record the temperature. Place the heater in cup #3 for 90 seconds, record the temperature.
13. What pattern seems to be developing? [With the mass of water remaining constant, as the amount of heat added goes up, the change in temperature also increases.] In other words, **if the mass is held constant the quantity of heat is directly proportional to the change in temperature.**
14. The third relationship is more cumbersome to carry out. This time we want to make the change in temperature remain constant for the three experiments. Lets pick an arbitrary change in temperature that we want to use. Lets pick 10°C.
15. Place 50 grams of water in the Styrofoam cup. Measure its initial temperature and leave the thermometer in the cup as the heater is introduced. Lower the heater and watch the change in temperature while your partner watches the time. When the temperature has risen 10°C record how much time the heater has been putting heat into the water. The measure of time will substitute for our measure of heat since we are assuming that the heat being put into the water is constant with respect to time.
16. Pour out the water from the first trial and add 100 grams of fresh water. Repeat the procedure from step #15 with 100 grams of water. Make sure that you do everything in the same way for all three trials. Record how long it takes for the 100 grams of water to increase 10°C. Carry out the same procedure for 150 grams of water.
17. What pattern seems to be developing? [With the change in temperature being held constant, as the mass of water increases so does the amount of heat added. In other words, **if the change in temperature is held constant, the quantity of heat added is directly proportional to the mass.**]
18. So far, we have only investigated the relationship of the quantity of heat, the change in temperature, and mass with one substance, water. Do the relationships we have developed hold true for other substances? The answer is yes. But before we sum up all of our findings into a neat package, one small detail must be considered. We need to look at the idea of specific heat.

## D. Specific Heat

1. Would equal masses of **different** substances contain the same amount of energy if heated to the same temperature?
2. For this comparison you will need 100 g of pennies, 100 g of nickels, 100 g of aluminum nails, and 100 g of water. Make sure you use pennies minted after 1982 so that all of the pennies will have the same composition. As we have seen in other experiments the government mint changed the composition from about 95% copper and 5% zinc to 95% zinc and 5% copper in 1982. Since each penny weighs about 2.5 g, it will take about 40 pennies to make up 100g . Stack the pennies one on top of each other and wrap masking tape lengthwise around them so that you will have a cylinder of pennies. It will probably take about 20 nickels to weigh 100 g. Wrap the stack of nickels in the same fashion as you prepared the pennies. Weigh out 100 g of aluminum nails and place some masking tape around them to keep them in a bunch. To get 100 g of water simply measure out 100 mL.
3. A large Styrofoam calorimeter should be prepared by weighing out 300 g of room temperature water and pouring it into the cup. A thermometer must also be introduced into the cup and the initial temperature noted. The calorimeter should be emptied after each trial and filled with new water before testing the other substances.
4. A large beaker of water needs to be heated up to boiling over a Bunsen burner. The roll of pennies, roll of nickels, and the bunch of nails should be placed into the boiling water and left there for at least five minutes to insure that they have heated up to the boiling point of water (100°C).
5. With tongs reach into the boiling water and pull out the pennies, quickly pat them dry with a paper towel and quickly lower them into the first calorimeter cup. Take care not to splash any of the water out of the cup. Immediately note the rise in temperature and record the highest temperature the thermometer reaches. This will probably be in less than a minute.
6. Repeat the procedure of step #5 with the roll of nickels and bunch of nails in separate calorimeters.
7. Finally, quickly measure 100 mL of the boiling water into a graduate cylinder and add it to the fourth calorimeter cup.

Substance (100 g)	Initial T (°C)	Final T (°C)	$\Delta T$ (°C)
Pennies			
Nickels			
Nails			
Water			

8. We assume that the quantity of heat that each of the substances above gave up was all absorbed by the water in the calorimeter cup. From the above table we see that equal masses of different substances heated to the same temperature do not contain the same amount of heat since each substance made the 100 g of water at room temperature heat up to different final temperatures.
9. The property of matter that describes how much heat it takes to raise the temperature of 1 gram by 1°C is known as the substance's specific heat. (abbreviated with a small **c**) .
10. From the data in the table we can see that water has the largest specific heat, followed by aluminum nails, followed by nickels, and finally last the pennies.

E.  $q = mc\Delta T$ 

1. Finally we are ready to summarize all of the experiments that we have done and put them into an equation that can be used to determine the heat absorbed or lost by any substance.

2. We have seen that the mass, the change in temperature, and now the specific heat all are important in determining the quantity of heat lost or gained by a substance.
  3. Mathematically they can be combined into  $q = mc\Delta T$ .
    - a.) We see that the mass is directly proportional to the quantity of heat absorbed or lost.
    - b.) We see that the change in temperature is directly proportional to the quantity of heat absorbed or lost.
    - c.) We see that the mass and change in temperature are inversely proportional.
    - d.) For every different substance there is a constant specific heat that does not vary.
- F. The importance of  $q = mc\Delta T$  can be seen in the following investigation.
1. Of almonds, cashews, and walnuts which has the greatest number of calories. In other words, if burned which would release the most amount of heat?
  2. We can set up the experiments to find out the answer to this problem.
  3. We will burn equal masses of the three types of nuts. The heat lost by the nuts will be collected by heating up a known quantity of water. By measuring the change in temperature of the water we will be able to calculate the quantity of heat given off by each of the different types of nuts. (Remember, the heat lost by the nuts equals the heat gained by the water.)
  4. We will need a beaker with 100 g of water, a thermometer, the three kinds of nuts, a paper clip, some clay, a tin can, a nail, and a hammer.
  5. Prepare the small tin can by removing either the top or the bottom with a can opener. With the nail, punch at least ten holes through the can.
  6. Bend a paper clip so that it has a flat triangular base with the short prong bent upward. This will be used to spear the nut. Firmly place the paper clip base on the wad of clay. The clay can be used to adjust the height so that the flame hits the top of the can.
  7. The beaker with the water should be placed on top of the can. The initial temperature reading must be taken and recorded.
  8. The nut must be ignited with a match. Quickly the can should be lowered over the burning nut. The flame should be directed at the top of the can upon which sets the beaker of water.
  9. Monitor the change in temperature, recording the highest temperature reached by the water. Check to see that all of the nut has burned and not fallen onto the table.
  10. Using  $q = mc\Delta T$  calculate the amount of heat gained by the water. [ $m = 100$  g;  $c = 1$  cal/g °C;  $\Delta T$  will be determined by finding the difference between the initial temperature and the final temperature.]
  11. Determine which type nut releases the most heat. [Walnuts should have the most, and the cashews the least.]
  12. As the students can see, we have an indirect way of measuring the amount of heat transferred in reactions by capturing it in a calorimeter and then using  $q = mc\Delta T$  to determine the quantity of heat lost or gained.
  13. Other interesting fuels are Cheeze Puffs<sup>®</sup>, marshmallows, and some breakfast cereals.

### CONCEPT EXTENSION

- A. Does Sand or Water Hold More Heat?
  1. It would be very bothersome to determine whether sand or water had the larger specific heat by repeating the experiment we did with the pennies, nickels, and nails. But there is an easy way to make the comparison between sand and water.
  2. Partially inflate a balloon and then add 200 g of water. Tie off the balloon. To a second balloon add 200 g of sand, blow it up to about the same total volume as the water balloon, and tie it off. Finally inflate a third balloon with

- air to about the same volume as the other two balloons.
3. Ask the students to predict what they think will happen when a flame is brought near each of the three balloons.
  4. Tell them you will volunteer to test the balloon having only air. As the flame comes near the balloon the balloon will burst due to the heat rupturing the stretched surface of the balloon.
  5. Have a student put on safety glasses and hold a lit match under the balloon with the sand. Allow the flame to almost touch the balloon. Observe what happens.
  6. Have another student put on an apron and hold a lit match under the balloon with the water. Once again, allow the flame to almost touch the balloon. Observe what happens.
  7. The balloon with water will not burst. The balloon with sand will heat up and burst. Ask the students to explain why this apparently happens. [The specific gravity of water is very high, so high that it can absorb the heat from the match and not increase the temperature of the system enough to rupture the balloon. On the other hand, the sand can not absorb very much heat and soon the heat will all be going into the rubber of the balloon which means the balloon will burst and all the sand will scatter.
- B. Boil Water in a Paper Bag
1. Most students will not believe that you can boil water in a paper bag, but you can. The specific heat for water is so high that the temperature of the bag never reaches its kindling temperature.
  2. The bag may look a little worse-for-wear but it will not catch on fire while there is still liquid water inside absorbing the energy from the flame.
  3. Do not try plastic bags.
- C. Predict the final Temperature When Hot and Cold Water are Mixed
1. In a final challenge have the students predict what the final temperature will be when
    - a.) 60 g of water at room temperature (22°C) are mixed with 60 g of water at 50°C [36.0°C]
    - b.) 30 g of water at room temperature (22°C) are mixed with 60 g of water at 50°C [40.6°C]
    - c.) 30 g of water at 50°C are mixed with 60 g of room temperature [33.2°C] water [31.3°C]
    - d.) 40 g of water at 50°C are mixed with 60 g of room temperature (22°C) water [33.2°C]
  2. Each of these can be intuitively solved but for that student who has had algebra the equation  $q = mc\Delta T$  could be used to help solve this problem.
- D. Have a contest to see who can, by adding some substance found around the house, make water freeze at the lowest temperature. If they need a suggestion, ask them what you add to the ice when you make home-made ice cream to lower the temperature in the ice-cream freezer? [Salt]
1. To make the competition fair, everyone must use 100 g of water.
  2. The lowering of the freezing point must be checked with a Celsius thermometer inserted into the water as it is freezing.
  3. What is the best liquid substance that can be found; what is the best solid substance that can be found. What other strategies can be used to lower the freezing point below 0°C ?
- E. Making Ice-Cream in a Tin-Can
1. Ingredients
 

a. 1 c milk	b. 1/2 tsp. vanilla extract
c. 1 c whipping cream	d. nuts or fruit as desired
e. 1/2 c sugar	f. 1 egg (optional)
g. 1 c rock salt	h. 1 lb. coffee can & plastic lid
i. spatula	j. 2 lb. coffee can & plastic lid
  2. Place all ingredients in a 1 lb. coffee can and place tight-fitting plastic lid on can.

3. Place the 1 lb. can inside a 2 lb. coffee can
4. Pack crushed ice in the 2 lb. can around the 1 lb. can.
5. Pour at least 3/4 cup of rock salt evenly over ice. Place lid on can.
6. Gently roll the can back and forth on a table or floor for 10 minutes.
7. Open 2 lb. can. Remove 1 lb. can.
8. Open 1 lb. can and use a rubber spatula to stir mixture scraping sides of can. Replace the lid.
9. Drain ice water from 2 lb. can.
10. Roll back and forth for five more minutes.
11. Enjoy. Makes about three cups of ice-cream.

F. Ziploc<sup>®</sup> Bag Ice Cream

1. Ingredients
  - a. 2 sandwich Ziploc<sup>®</sup> bags
  - b. 2 1-gallon-size Ziploc<sup>®</sup>
  - c. 1/2 c cream or half-and-half
  - d. 1/4 c milk
  - e. 2 Tbs. sugar
  - f. 1/8 tsp. vanilla
  - g. 1 beaten egg (optional)
  - h. 3 c crushed ice
  - i. 1/2 c rock salt
  - j. mixing bowl
2. Make sure everything is cold, including the mixing bowl.
3. Mix the cream, milk, sugar, vanilla, and egg in the mixing bowl
4. Pour this mix into the double sandwich-size Ziploc<sup>®</sup> bag. The bags need to be double thickness to prevent any leaks. It goes without saying that the bags should be sealed tightly.
5. Pour the crushed ice and rock salt into the double gallon sized Ziploc bag.
6. Place the small bag of ice cream mix inside the large bag of ice and salt. Once again, make sure everything is sealed tightly.
7. Watch what happens while you gently rock the bag for about five minutes (don't rock too hard, or you'll end up with salty ice cream!)
8. When the ice cream looks frozen enough, remove the small bag and rinse it in cold water to remove any salt on the outside.
9. This makes about one big scoop of ice cream. If you prefer, it can be put into the freezer to let it get even harder.