Activity 5 Solutions: Thermal Energy, the Microscopic Picture

5.1 How Is Temperature Related to Molecular Motion?

1) **Temperature** Your instructor will discuss molecular motion and temperature.

   a) At a particular temperature, do all of the molecules move at the same speed?

      No, there is a range of speeds.

   b) How does the average speed of molecules at a higher temperature differ from their average speed at a lower temperature?

      On average, molecules at a higher temperature have a faster speed than molecules at a lower temperature.

   c) Watch the demonstration of diffusion of food coloring in beakers of warm and cold water. Explain the differences in the diffusion rates.

      Food coloring spreads (or diffuses) more quickly in warm water. This demonstrates that the warm water molecules, on average, are moving faster than cold water molecules.

2) **Evaporative Cooling**

   What happens to the temperature of a liquid as it evaporates? Your instructor will demonstrate a cool tube (a cryophorus tube) that contains water.

   a) What happens when one end of the tube is cooled with liquid nitrogen?

      Water in the cool tube's bulb freezes.

   b) The middle of the tube remains near room temperature. Explain why the water in the tube's bulb freezes.

      This shows that a liquid cools as it evaporates. The faster moving water molecules leave the water surface in the upper bulb and form water vapor in the tube. The slower moving molecules remain in the liquid in the upper bulb. Thus, the average speed of the liquid molecules is reduced and the remaining liquid is cooler. The faster molecules in the upper bulb that have evaporated move throughout the cool tube. Those molecules in the end of the tube cooled by liquid nitrogen condense and freeze there and are trapped. The faster molecules continue to evaporate and leave the upper bulb, until the remaining molecules in the bulb have so little energy that the liquid in the bulb freezes.

   c) Group Discussion Question: When you put a pot of water on the stove to heat to boiling, why does the water come to a boil faster if you put a lid on the pot?

3) The Dippy Duck

The dippy duck contains liquid freon, which evaporates easily at room temperature. Wet the head of the duck and place the cup of water in front of the duck's head. Explain what happens to the dippy duck in terms of evaporative cooling and the center of mass of the duck.

Water evaporates from the duck's head, cooling it. Cooling the freon gas inside the duck's head causes the gas molecules to condense. This reduces the volume of the gas and liquid freon flows up the tube from the duck's tail to fill the space previously taken up by the gas. As the freon moves up, the center of mass is raised until the duck topples over into the cup of water. While the duck's head is in the water, freon flows from the head back into the tail, changing the center of gravity, and the duck stands up again. The process repeats.

4) Rates of Evaporation

a) Note the temperature of each thermometer while it is immersed in liquid. Remove the thermometers from the test tubes and allow the thermometers to lie on your table for several minutes. Then check and record their temperatures.

	Initial Temp	Final Temp	Temp Change
Alcohol	__________	__________	__________
Oil	__________	__________	__________
Water	__________	__________	__________

b) Explain the differences in temperature change.

Alcohol cools the thermometer the most, followed by water, then oil. Alcohol is the most volatile (evaporates the most quickly), and thus shows the most evaporative cooling. This technique of comparing wet bulb and dry bulb temperatures in air is how humidity can be determined.

c) Group Discussion Question: What change could you make to the dippy duck experiment to make the duck's head dip faster?

5.2 Temperature and Phase Changes

5) Volume, Temperature, and Phase Change

a) What happens to the volume of most substances when they are heated?

Most substances expand (increase in volume) when heated and decrease in volume when cooled.

b) Do all substances expand when heated? At the beginning of class, your instructor placed a beaker full of ice water on your table. What has happened to the volume of the ice as it melted?

Ice is an exception to the rule stated above. As ice is heated and melts into water, it decreases in volume. The water did not spill over the top of the beaker, so water from the melted ice had less volume than the solid ice. Eventually, evaporation would lower the water level in the beaker.

6) **Phase Changes**

a) Your instructor will demonstrate weights on a wire supported by an ice cube. What happens? What causes the change of phase of the ice from solid to liquid water?

The force of the wire on an area of the ice cube exerts pressure on the ice. The pressure lowers the freezing point of the ice and causes the ice to melt. As the wire melts through the ice, the water above the wire refreezes into ice.

b) Would this demonstration work as well with a wide wire? Why or why not? (Hint: pressure = force/area of the wire)

No, because the force of the wide wire on the ice due to the weights is spread over a larger area. This reduces the pressure exerted on the ice.

c) Group Discussion Question: When the temperature is well below freezing, ice skaters find it more difficult to skate. Why is this?

7) **Heat Capacity**

Your instructor will discuss the heat capacity of objects.

a) What is the heat capacity of a cube of copper, if 6,500 joules of heat are required to increase the temperature of the copper cube by 15 ^{o}C?

$$H_{cap} = \frac{Q}{\Delta T} = \frac{6{,}500\ \text{J}}{15\ ^{o}\text{C}} = 433\ \text{J}/^{o}\text{C}$$

b) What is the heat capacity of a cup of water if 75,000 joules of heat are required to increase the temperature of the water by 60 ^{o}C?

$$H_{cap} = \frac{Q}{\Delta T} = \frac{75{,}000\ \text{J}}{60\ ^{o}\text{C}} = 1{,}250\ \text{J}/^{o}\text{C}$$

8) **Measuring Specific Heat**

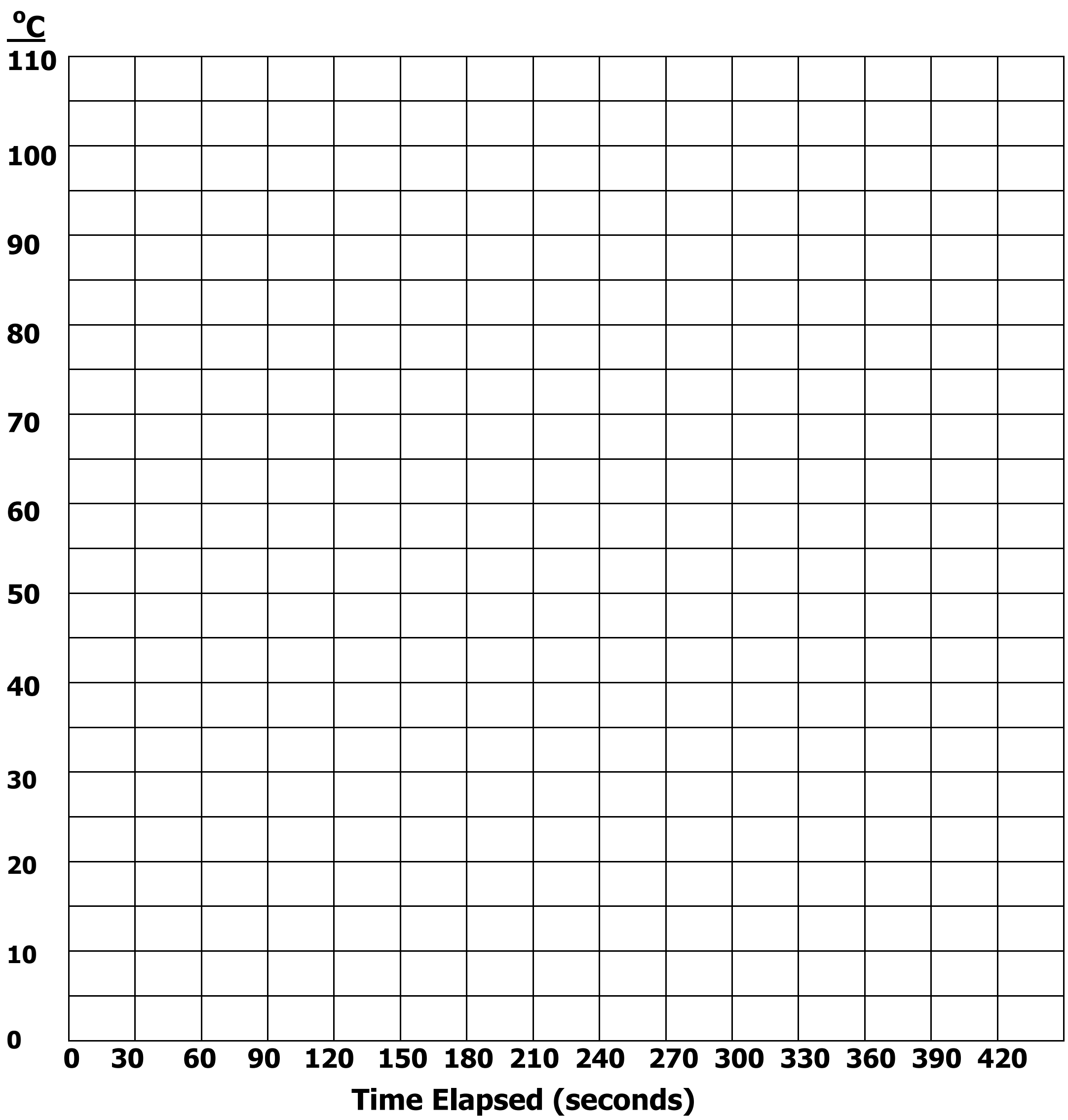
Your instructor will discuss specific heat (s_{heat}).

a) Empty the water from the hot pot on your table into a beaker. Measure 500 ml of water in a beaker and pour this water into the hot pot. Measure the temperature of the water before you turn on the pot. Record your measurement on the first line (0 seconds elapsed) of the table below.

b) Now, plug in the hot pot and set the timer for 8 minutes. Measure the temperature of the water every 30 seconds. Record your data in the table.

Time Elapsed (seconds)	Temperature (°C)	Time Elapsed (seconds)	Temperature (°C)	Time Elapsed (seconds)	Temperature (°C)
0		150		300	
30		180		330	
60		210		360	
90		240		390	
120		270		420	

c) Make a graph of your data on the grid below.



d) Group Discussion Question: Would this graph have a different appearance if you had added the same amount of heat to a larger volume of water? In what ways would the graph change?

9) Calculating the Specific Heat of water

Next, we calculate the specific heat of water using data from your experiment.

a) For how many seconds did you heat the water? ____________

b) The hot pots are rated at 600 watts (600 J/sec). How many joules of heat Q were added to the water? ______________

c) What is the mass M of the water in grams? (One ml of water has a mass of 1 gram.) _____________

d) What was the change in temperature of the water, ΔT, in Celsius degrees? ($\Delta T = T_{final} - T_{initial}$) _______________

e) Calculate the specific heat of water s_{heat} by organizing the equation

$$Q = s_{heat} \times M \times \Delta T \quad \text{as} \quad s_{heat} = \frac{Q}{M \, \Delta T}$$

e) Group Discussion Question: Your instructor will give you a value for the specific heat of water. How well does your calculated value agree with the accepted value of specific heat of water? What sources of error may be present in your experiment?

10) Latent Heat

Your instructor will discuss latent heat.

a) To find how many calories of heat are required to convert 700 grams of water at a temperature of 40 ^{o}C into steam at 100 ^{o}C, follow the three steps below.

Step 1: Find the heat required to raise the temperature of the water to water to 100 ^{o}C. The specific heat of liquid water is 1.00 calories/gram ^{o}C. Hint: use the equation $Q = s_{heat} \times M \times \Delta T$

$$\mathbf{Q = \frac{1.00\ cal}{g\ ^{o}C} \times 700\ g \times (100\ ^{o}C - 40\ ^{o}C) = 42{,}000\ cal}$$

Step 2: Find the heat required for the phase change of 700 grams of water at 100 ^{o}C into steam at 100 ^{o}C. The latent heat of evaporation of water is 540 calories/gram. Hint: use the equation $Q = L_{heat} \times M$

$$\mathbf{Q = \frac{540\ cal}{g} \times 700\ g = 378{,}000\ cal}$$

Step 3: Find the total heat required to heat the water to 100 ^{o}C and the heat required to convert the liquid water into steam.

$$\mathbf{Q_{Total} = 42{,}000\ cal + 378{,}000\ cal = 420{,}000\ cal = 4.2 \times 10^{5}\ cal}$$

11) Boiling Liquid Freon

a) Can you make the freon in the dippy duck boil by heating it in the palm of your hand? ____ (Warning: putting the dippy duck in hot water will break it.)

b) Measure the temperature of the boiling freon in the dippy duck with the infrared thermometer. At what temperature does the freon boil? ________

c) Group Discussion Question: Why is the low boiling temperature of freon important to making the dippy duck work well?

12) Boiling Liquid Nitrogen

Your instructor will pour liquid nitrogen into an empty styrofoam cup on your table. **Caution:** liquid nitrogen can cause injury if it comes in contact with your skin.

a) What is happening to the liquid nitrogen in the cup?

The liquid nitrogen boils and changes phase from a liquid to a gas. Liquid nitrogen is stored at a temperature just below the temperature at which it boils.

b) What is the source of thermal energy that causes the liquid nitrogen to boil?

Thermal energy from the surroundings (the cup, the air, etc.) flows into the liquid nitrogen.

c) What happens to the temperature of the liquid nitrogen as it boils?

The nitrogen that is in the liquid phase remains the same temperature. This might seem like a contradiction to evaporative cooling, since the liquid nitrogen should become colder as the molecules with more kinetic energy leave the liquid first. This is true, but thermal energy is added to the liquid from the environment at a rate greater than the rate at which thermal energy removed by the molecules going into gaseous phase.

d) Measure the temperature of a water balloon with the infrared thermometer. ______________

e) Carefully place the water balloon into the cup of liquid nitrogen. After 30 seconds, carefully remove the balloon. Measure the balloon's temperature. _______________

f) What happened to the water in the balloon? Why?

The water froze because some of the thermal energy of the water has gone into the liquid nitrogen.

g) What happened to the rate of boiling of the liquid nitrogen when you added the water balloon to the cup?

The liquid nitrogen boiled more rapidly due to the transfer of thermal energy from the water balloon.

h) Group Discussion Question: Measure the temperature of the water balloon again after it has been out of the liquid nitrogen for a few minutes. Has the temperature changed substantially? Why or why not?