Heat Transfer and Heat Capacity

Strand Phases of Matter and Kinetic Molecular Theory

Topic Investigating properties of matter

Primary SOL CH.5 The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include
- d) phase changes;
- e) molar heats of fusion and vaporization;
- f) specific heat capacity.

Related SOL CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include
- a) designated laboratory techniques;
- b) safe use of chemicals and equipment;
- g) mathematical manipulations including SI units, scientific notation, linear equations, graphing, ratio and proportion, significant digits, and dimensional analysis.

Background Information (Heat transfer and phase change)
Transitions between solid, liquid, and gaseous phases typically involve large amounts of energy compared to the specific heat. If heat were added at a constant rate to a mass of ice to take it through its phase changes to liquid water and then to steam, the energies required to accomplish the phase changes (called the latent heat of fusion and latent heat of vaporization) would lead to plateaus in the temperature vs. time graph.

Heat of fusion is the energy required to change a gram of a substance from the solid to the liquid state without changing its temperature is commonly called its "heat of fusion." This energy breaks down the solid bonds, but leaves a significant amount of energy associated with the intermolecular forces of the liquid state.

Heat of vaporization is the energy required to change a gram of a liquid into the gaseous state at the boiling point is called the "heat of vaporization." This energy breaks down the intermolecular attractive forces, and also must provide the energy necessary to expand the gas.

Materials
- Heating Curve
- What Are You Eating?

Vocabulary
accurate, calorimetry, heat capacity (C_p), heat of fusion (ΔH_{fus}), heat vaporization (ΔH_{vap}), specific heat, vaporization

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)
Part 1: Heating Curve

Introduction

1. Review concepts related to heat transfer.
2. Have students brainstorm phase changes they know.

Procedure

1. Pass out the attached “Heating Curve” lab worksheet, and let students read it over. Go over the procedures and safety issues involved in the lab: Hot plates can become very hot, so be careful not to touch them. Exercise care with hot water and beakers; use wire mesh to set beakers down. Wear goggles and aprons, and tie back long hair. Keep cords away from heat sources.
2. Have students acquire materials and perform the lab. Provide guided instruction and assistance as needed.

Observations and Conclusions

1. Discuss the inquiry questions from the lab and the lab-report format.
2. Using the graph from the lab, explain ΔHfus and ΔHvap. Work some sample problems together as a class.

Part 2: What Are You Eating?

Introduction

1. Review SOL periodic table information.

Procedure

1. Pass out the attached “What Are You Eating?” lab worksheet, and let students read it over. Go over the safety issues involved in the lab. Have groups choose the food with which they will work.
2. Have students acquire materials and perform the lab. Provide guided instruction and assistance as needed. As students complete the lab, have them work in groups on the calculations and inquiry questions.
3. Using lab format, explain the “Specific Heat” section of the worksheet. Provide notes, and work some sample problems together as a class. Have students complete the worksheet.
4. Have students practice Cp problems in groups (10 min.). Answer questions, as needed.

Observations and Conclusions

1. Discuss the inquiry questions from the lab and the lab-report format.
2. Using the graph from the lab, explain ΔHfus and ΔHvap. Work some sample problems as a class.

Assessment

- **Journal/Writing Prompts**
  - Discuss the inquiry questions from the lab and the lab-report format.
  - Using the graph from the lab, explain ΔHfus and ΔHvap.
- **Other**
  - Finish the labs and analyses to turn in at the next class period.
  - Practice C_p problems to turn in at the next class period.

Extensions and Connections (for all students)

- Have students practice ΔH_{fus} and ΔH_{vap} problems in groups. Check answers quickly.
- Lab Rubrics
  - Heating Curve Lab
    ____ 50 points total Construct a heating curve
    Two graphs, checked for accuracy (15 pts ea.)
    Safe and managed completion of the lab during class (20 pts)
    ____ 20 points total Phase changes and energy transfer
    Inquiry questions following lab answered correctly (2 pts ea.)
    ____ 30 points total ΔH_{fus} and ΔH_{vap} calculations
    Problems given on extra sheet completed correctly (5 pts ea.)
  - What Are You Eating? Lab
    ____ 40 points total Practice of safe lab procedures and efficient time management
    Completion of lab and clean up
    ____ 20 points total Data recorded in lab notebook
    At least two samples neatly recorded (10 pts ea.)
    ____ 20 points total Analysis and comparison of own data
    Correct completion of lab questions (5 pts ea.)
    ____ 10 points total Comparison among class data
    Other data present and commented on
    ____ 10 points total Clear summary
    Summary present and incorporating ideas addressed in lab

Strategies for Differentiation

- Have students use an electronic data management program to create a graph from the data collected during the lab.
- Have students use graphic organizer software to create webs to connect vocabulary words to states of matter and phase changes.
- Have students participate in creating a class data table of the actual heat or energy calculated from their food source.
- Have students use the lab values they calculate to compare to the labels of similar foods and compare results to the food label on the package.
- Have students participate in creating a class data table of the actual heat or energy calculated from their food source.

Heating Curve

Name: ____ **Date:** __________________________

Prediction

What will the "heating curve" of water look like as you add constant heat to the water over time? Show your prediction on the graph at right, including appropriate title, labels, units, and scale.

Materials

Graphing calculator or computer
Data-collection device with temperature probe
250-mL beaker
100-mL graduated cylinder
Ring stand and clamp
Slit stopper
Hot plate or burner
Wire mesh
Ice
Safety goggles

Procedure

1. Collect the materials listed above. Put on goggles and aprons, and tie back long hair. *CAUTION! The hot plate will get quite hot, so be careful not to touch it. Exercise care with hot water and beakers. Use wire mesh on which to set beakers down. Keep cords away from the heat source.*
2. Set up the data collection device and temperature probe as instructed, and open the program on the calculator as directed.
3. Place the beaker with 35 mL water and ~3 ice cubes onto the hot plate. Suspend the probe in the water, being very careful not to let it touch the sides or bottom of the beaker.
4. Start the data-collection program, and turn the hot plate or burner on the highest setting. Record the temperature every 30 seconds in the following table:

Time (sec.)	Temperature (°C)	Time (sec.)	Temperature (°C)	Time (sec.)	Temperature (°C)
0		450		900	
30		480		930	
60		510		960	
90		540		990	
120		570		1,020	
150		600		1,050	
180		630		1,080	
210		660		1,110	
240		690		1,140	
270		720		1,170	
300		750		1,200	
330		780		1,230	
360		810		1,260	

Time (sec.)	Temperature (°C)
390	
420	

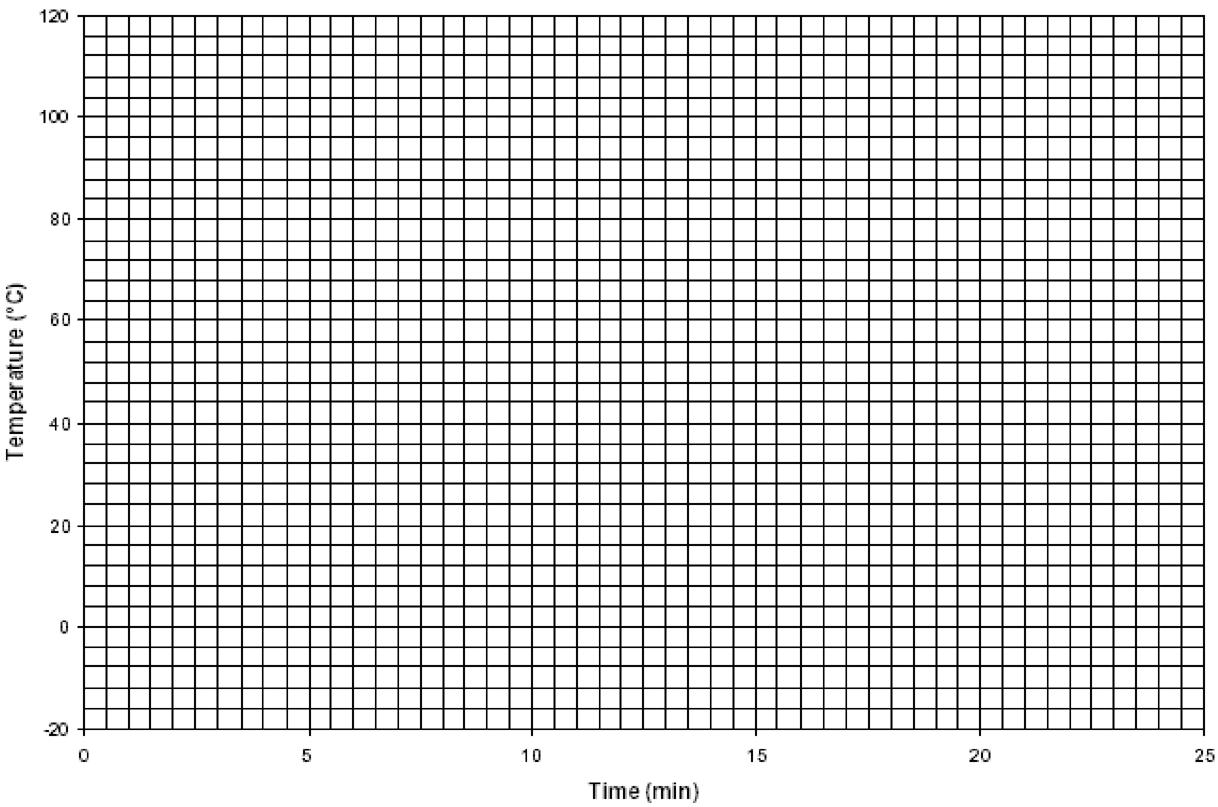
Time (sec.)	Temperature (°C)
840	
870	

Time (sec.)	Temperature (°C)
1,290	
1.300	

5. When the readings level off, take five readings at one temperature.
6. Then, turn off the heat, and carefully remove the beaker from the heat source, setting it on wire mesh. Clean up your area.

Questions

1. Recall the different states of matter (solid, liquid, gas). How do the water molecules differ in the liquid and gas states? Draw and explain.
2. Plot your temperature and time data on the graph below.



3. Label the phase changes on your heating curve above.
4. What happens to the molecules as they begin to boil relative to temperature?
5. Did you stop adding heat at any point during the lab? _______ As heat was added, what happened to the energy of the system?
6. If you were always adding constant heat, why did the temperature trend change?
7. What happens to the energy being absorbed from the heat source? Use the heating curve and your knowledge of atoms to explain.

ΔH_{vap} Practice: $\Delta H = m\ \Delta H_{vap}$

1. How much heat is needed to vaporize 250 g of water at 100°C and 101.3 kPa pressure?
2. When a quantity of water vapor at 100°C and 101.3 kPa is condensed to the liquid phase, 1.81 × 105 J of heat is released. What mass of water is condensed?
3. What quantity of heat in joules is required to vaporize 600 g of water at 100°C and 101.3 kPa?

What Are You Eating?

Name: ____ **Date:** __________________________

Instructions

You will be using a metal can filled with water as a "calorimeter." The change in the temperature of the water will tell you how much energy your food contains. *CAUTION! Be careful of the open flame and very hot food.*

Materials

Calculator-based labs (CBL)	Can	Paperclip	Safety goggles
Graphing calculator	Cold water	Food holder	
Matches	Marshmallows	Temperature probe	
Ring stand	Popcorn	Balance	

Procedure

1. Obtain and put on goggles and apron.
2. Follow CBL setup instructions found on the lab bench. A couple of steps will be different: Instead of 41 samples every 30 seconds, take 36 samples every 5 seconds. Also, instead of Y values being 10° to 105°C, use Y values of 5° to 50°C.
3. Choose which food your group wants to investigate. Repeat the procedure below three times for each type of food.
4. Carefully measure out 75 mL of cold water, and pour it into the can. Place the can on the ring stand.
5. Measure the initial water temperature with the temperature probe. Wait until the temperature stabilizes, and record it in the chart below.
6. Place the food on the paperclip, place it in the food holder, and mass the food plus holder. Record the initial mass in the chart below.
7. Slide the food holder underneath the can, leaving a 1-inch gap.
8. Have one member of the group light a match and quickly catch the food on fire.
9. Carefully watch the display on the probe as the temperature increases. Record the highest temperature you see. It will take a while to reach this temperature, as the temperature should continue to rise even after the food has stopped burning.
10. Mass of the holder with any remaining food once more, and record the mass below.
11. Empty the water in the can.
12. When the 3 min. is up, the probe will tell you it is "done." Enter past this screen, and a graph will appear. Hit enter again. This takes you to a screen that asks whether you want to repeat. Choose YES, and go back to step 4.

Food: ___________________________			
	Trial 1	**Trial 2**	**Trial 3**
Initial mass: food + holder (g)			
Final mass: food + holder (g)			
Initial water temperature (°C)			
Final water temperature (°C)			
Volume of water			

Specific Heat

Our goal is to calculate the heat (or energy) produced by the food we eat. We know the heat capacity of water (it's constant), and we need to find the mass of the water we used and the change in its temperature. Use the following formula:

$$\mathbf{H = mC_p\Delta\mathit{t}}$$

(heat = mass • heat capacity • change in temperature)

Data Analysis

1. For each sample, 75 mL of water was used. The density of water is roughly 1.0 g/mL. What mass of water did we use?

2. The change in temperature will be different for each trial.

   Δt = final temperature − initial temperature

   Trial 1: Δt = __________ − __________ = __________

   Trial 2: Δt = __________ − __________ = __________

   Trial 3: Δt = __________ − __________ = __________

3. Now we can calculate how much energy is in the food we eat. Use the equation at the top of the page to calculate the heat absorbed by the water (one calculation for each trial).

   First in joules (C_p = 4.18 J/g°C)

   Trial 1 Trial 2 Trial 3

4. Then in Calories (Cp = 0.001 Cal/g°C)

   Trial 1 Trial 2 Trial 3

5. To find out how much energy each gram of food contains, we need to know the mass of the food we used (initial mass − final mass).
   Trial 1 Trial 2 Trial 3

6. Then, divide the Calories you calculated in #3 by the mass from above to give you the energy content of each food sample.
   Trial 1 Trial 2 Trial 3

Questions

1. How accurate do you think this experiment was? What could be improved to make it more accurate?

2. Compare your data to at least one other group's data. If it's the same food, how close are the results? What makes them differ? If it's a different food, what causes the Calories to differ? What's different about the foods?

3. What foods (either types of food or specific examples—at least two for each) would give you more Calories than the food you chose? Fewer Calories? Why?

4. How do you think the calculations you did today are used in the food industry?