17 THERMOCHEMISTRY

SECTION 17.1 THE FLOW OF ENERGY—HEAT AND WORK (pages 505–510)

This section explains the relationship between energy and heat, and distinguishes between heat capacity and specific heat.

▶ Energy Transformations (page 505)

1. What area of study in chemistry is concerned with the heat transfers that occur during chemical reactions? thermochemistry

2. Where the use of energy is concerned (in a scientific sense), when is work done?
   Work is done when a force is used to move an object.

3. Circle the letter next to each sentence that is true about energy.
   a. Energy is the capacity for doing work or supplying heat.
   b. Energy is detected only because of its effects.
   c. Heat is energy that transfers from one object to another because they are at the same temperature.
   d. Gasoline contains a significant amount of chemical potential energy.

4. Circle the letter next to each sentence that is true about heat.
   a. One effect of adding heat to a substance is an increase in the temperature of that substance.
   b. Heat always flows from a cooler object to a warmer object.
   c. If two objects remain in contact, heat will flow from the warmer object to the cooler object until the temperature of both objects is the same.

▶ Exothermic and Endothermic Processes (pages 506–507)

5. What can be considered the “system” and what are the “surroundings” when studying a mixture of chemicals undergoing a reaction? Write your answers where indicated below.

   System: The mixture of chemicals itself is considered the system.
   Surroundings: Everything but the mixture of chemicals is the surroundings, but practically speaking, the immediate vicinity of the system.
CHAPTER 17, Thermochemistry (continued)

6. In thermochemical calculations, is the direction of heat flow given from the point of view of the system, or of the surroundings?
   The direction is given from the point of view of the system.

7. What universal law states that energy can neither be created nor destroyed and can always be accounted for as work, stored potential energy, or heat?
   the law of conservation of energy

Questions 8 through 12 refer to the systems and surroundings illustrated in diagrams (a) and (b) below.

8. Which diagram illustrates an endothermic process? _____ b

9. Is heat flow positive or negative in diagram (a)? ______________ negative

10. Which diagram illustrates an exothermic process? _____ a

11. Is heat flow positive or negative in diagram (b)? ______________ positive

12. What does a negative value for heat represent?
   It shows that a system is losing heat.

To answer Questions 13 and 14, look at Figure 17.2 on page 506.

13. A system is a person sitting next to a campfire. Is this system endothermic or exothermic? Explain why.
   The system is endothermic because the system is absorbing heat from the campfire.

14. A system is a person who is perspiring. Is this system endothermic or exothermic? Explain why.
   The system is exothermic because the system is cooling off by producing perspiration, which will evaporate, cooling the system.
Units for Measuring Heat Flow (page 507)

15. Heat generated by the human body is usually measured in units called ____________________.

16. Describe the chemical reaction that generates heat in the human body.
   The body breaks down sugars and fats into carbon dioxide and water.

17. What is the definition of a calorie?
   A calorie is defined as the quantity of heat needed to raise the temperature of 1 g of pure water 1°C.

18. How is the calorie (written with a lower case c) related to the dietary Calorie (written with a capital C)?
   One dietary Calorie is equal to 1000 calories or 1 kilocalorie.

19. Circle the letter next to the SI unit of heat and energy.
   a. calorie
   b. Calorie
   c. joule
   d. Celsius degree

Heat Capacity and Specific Heat (pages 508–510)

20. Is the next sentence true or false? Samples of two different substances having the same mass always have the same heat capacity. ________ false ________

21. Compare the heat capacity of a 2-kg steel frying pan and a 2-g steel pin. If the heat capacities of these objects differ, explain why.
   The frying pan has a greater heat capacity because its mass is greater.

22. Is the next sentence true or false? The specific heat of a substance varies with the mass of the sample. ________ false ________

SECTION 17.2 MEASURING AND EXPRESSING ENTHALPY CHANGES (pages 511–517)

This section explains how to construct equations and perform calculations that show enthalpy changes for chemical and physical processes.

Calorimetry (pages 511–513)

1. The property that is useful for keeping track of heat transfers in chemical and physical processes at constant pressure is called ________ enthalpy ________.
CHAPTER 17, Thermochemistry (continued)

2. What is calorimetry? _____________
   Calorimetry is the accurate and precise measurement of heat change for chemical and physical processes.

3. Use Figure 17.5 on page 511. Circle the letter next to each sentence that is true about calorimeters.
   a. The calorimeter container is insulated to minimize loss of heat to or absorption of heat from the surroundings.
   b. Because foam cups are excellent heat insulators, they may be used as simple calorimeters.
   c. A stirrer is used to keep temperatures uneven in a calorimeter.
   d. In the calorimeter shown in Figure 17.5, the chemical substances dissolved in water constitute the system and the water is part of the surroundings.

4. Is the following sentence true or false? For systems at constant pressure, heat flow and enthalpy change are the same thing. _____________ true _____________

5. Complete the table below to show the direction of heat flow and type of reaction for positive and negative change of enthalpy.

<table>
<thead>
<tr>
<th>Sign of Enthalpy Change</th>
<th>Direction of Heat Flow</th>
<th>Is Reaction Endothermic or Exothermic?</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta H$ is positive ($\Delta H &gt; 0$)</td>
<td>into system</td>
<td>endothermic</td>
</tr>
<tr>
<td>$\Delta H$ is negative ($\Delta H &lt; 0$)</td>
<td>out of system</td>
<td>exothermic</td>
</tr>
</tbody>
</table>

6. Name each quantity that is represented in the equation for heat change in an aqueous solution.

$$ q = \Delta H = m \times C \times \Delta T $$

- heat flow
- enthalpy
- mass of the water
- specific heat of water
- change in temperature

7. What happens to the temperature of water after calcium oxide is added? _____________
   The temperature increases.

8. A chemical equation that includes the heat change is called a _____________ equation.

9. Why is it important to give the physical state of the reactants and products in a thermochemical equation? _____________
   The heat change values differ when the products or reactants are in different states.
10. Complete the enthalpy diagram for the combustion of natural gas. Use the thermochemical equation in the first paragraph on page 517 as a guide.

\[
\begin{align*}
\text{CH}_4(g) + 2\text{O}_2(g) & \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(l) \\
\Delta H &= -890 \text{ kJ}
\end{align*}
\]

SECTION 17.3 HEAT IN CHANGES OF STATE (pages 520–526)

This section explains heat transfers that occur during melting, freezing, boiling, and condensing.

► Heats of Fusion and Solidification (pages 520–521)

1. Is the following sentence true or false? A piece of ice placed in a bowl in a warm room will remain at a temperature of 0°C until all of the ice has melted.

   __________

   true

2. Circle the letter next to each sentence that is true about heat of fusion and heat of solidification of a given substance.

   a. The molar heat of fusion is the negative of the molar heat of solidification.
   b. Heat is released during melting and absorbed during freezing.
   c. Heat is absorbed during melting and released during freezing.
   d. The quantity of heat absorbed during melting is exactly the same as the quantity of heat released when the liquid solidifies.

   __________

3. Use Table 17.3 on page 522. Determine \( \Delta H \) for each of these physical changes.

   a. \( \text{H}_2(\text{s}) \rightarrow \text{H}_2(\text{l}) \quad \Delta H = \quad 0.12 \text{ kJ/mol} \)
   b. \( \text{Ne}(\text{s}) \rightarrow \text{Ne}(\text{l}) \quad \Delta H = \quad 0.33 \text{ kJ/mol} \)
   c. \( \text{O}_2(\text{s}) \rightarrow \text{O}_2(\text{l}) \quad \Delta H = \quad 0.44 \text{ kJ/mol} \)

► Heats of Vaporization and Condensation (pages 522–524)

4. Is the following sentence true or false? As liquids absorb heat at their boiling points, the temperature remains constant while they vaporize.

   __________

   true
CHAPTER 17, Thermochemistry (continued)

Use the heating curve for water shown below to answer Questions 5, 6, and 7.

5. Label the melting point and boiling point temperatures on the graph.

6. What happens to the temperature during melting and vaporization?
   The temperature stays constant at the melting point and boiling point, respectively.

7. Circle the letter next to the process that releases the most heat.
   a. Melting of 1 mol of water at 0°C
   b. Freezing of 1 mol of water at 0°C
   c. Vaporization of 1 mol of water at 100°C
   d. Condensation of 1 mol of water at 100°C

Look at Table 17.3 on page 522 to help you answer Questions 8 and 9.

8. How many of the 6 substances listed have a higher molar heat of vaporization than water? Which one(s)? 1; ethanol

9. It takes 3.16 kJ of energy to convert 1 mol of methanol molecules in the solid state to 1 mol of methanol molecules in the liquid state at the normal melting point.
Heat of Solution (pages 525–526)

10. The heat change caused by dissolution of one mole of a substance is the molar heat of solution.

11. How does a cold pack containing water and ammonium nitrate work?

When activated, the cold pack allows water and ammonium nitrate to mix, producing an endothermic reaction. As heat is absorbed in the reaction, the temperature of the pack falls.

Reading Skill Practice

Writing a summary can help you remember the information you have read. When you write a summary, write only the most important points. Write a summary for each of the five types of heat changes described on pages 520–526. Your summary should be much shorter than these six pages of text. Do your work on another sheet of paper.

Students should describe briefly heat of fusion and solidification, heat of vaporization and condensation, and heat of solution.

SECTION 17.4 CALCULATING HEATS OF REACTION (pages 527–532)

This section explains how Hess’s law of heat summation and standard heats of formation may be applied to find enthalpy changes for a series of chemical and physical processes.

Hess’s Law (pages 527–529)

1. For reactions that occur in a series of steps, Hess’s law of heat summation says that if you add the thermochemical equations for each step to give a final equation for the reaction, you may also add the heats of reaction for each step to give the final heat of reaction.

2. Is the following sentence true or false? Graphite is a more stable form of elemental carbon than diamond at 25°C, so diamond will slowly change to graphite over an extremely long period of time. __________ true

3. Look at Figures 17.13 and 17.14 on pages 528 and 529. According to Hess’s law, the enthalpy change from diamond to carbon dioxide can be expressed as the sum of what three enthalpy changes?

   a. diamond to graphite (−1.9 kJ)

   b. graphite to carbon monoxide (−110.5 kJ)

   c. carbon monoxide to carbon dioxide (−283.0 kJ)
CHAPTER 17, Thermochemistry (continued)

Standard Heats of Formation (pages 530–532)

4. The change in enthalpy that accompanies the formation of one mole of a compound from its elements with all substances in their standard states at 25°C and 101.3 kPa is called the __________________ standard heat of formation.

5. Is the following sentence true or false? Chemists have set the standard heat of formation of free elements, including elements that occur in nature as diatomic molecules, at zero. __________ true

6. Complete the enthalpy diagram below by finding the heat of formation when hydrogen and oxygen gases combine to form hydrogen peroxide at 25°C. Use the data in Table 17.4 on page 530 and the equation \( \Delta H_f^0 = \Delta H_f^0 \text{(products)} - \Delta H_f^0 \text{(reactants)} \) to find the answer.

\[ H_2(g) + O_2(g) \quad \Delta H_f^0 = -187.8 \text{ kJ/mol} \]

\[ H_2O_2(l) \]

7. Look at Table 17.4. Methane burns to form carbon dioxide and water vapor.

\[ \text{CH}_4(g) + 2O_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g) \]

a. Will the heat of this reaction be positive or negative? How do you know?

It will be negative; the heats of formation for carbon dioxide and water vapor are much less than zero. The heat of formation of methane is much closer to zero.

b. How does your experience confirm that your answer to Question 7a is reasonable?

The burning of fuels such as methane gives off heat. Exothermic reactions have negative heats of reaction.
GUIDED PRACTICE PROBLEM 3 (page 510)

3. When 435 J of heat is added to 3.4 g of olive oil at 21°C, the temperature increases to 85°C. What is the specific heat of the olive oil?

Analyze

a. What is the formula for calculating specific heat? \( C = \frac{q}{m \times \Delta T} \)

b. What are the knowns and the unknown in this problem?

Knowns:
- \( m = 3.4 \text{ g} \)
- \( q = 435 \text{ J} \)
- \( \Delta T = (85°C - 21°C) = 64°C \)

Unknown: \( C_{\text{olive oil}} \)

Calculate

c. Substitute the known values into the equation for specific heat and solve.

\[
C_{\text{olive oil}} = \frac{435 \text{ J}}{3.4 \text{ g} \times 64°C} = 2.0 \text{ J/(g°C)}
\]

Evaluate

d. Explain why you think your answer is reasonable. Think about the time it takes to fry foods in olive oil versus the time it takes to cook foods in boiling water.

Because the specific heat of olive oil is lower than the specific heat of water, olive oil can reach a higher temperature than water when the same amount of energy is added to equal masses of each. This property makes olive oil good for cooking foods quickly because olive oil heats up more quickly than water under the same conditions.

e. Are the units in your answer correct? How do you know?

Yes, because specific heat is expressed in J/(g°C), or cal/(g°C).
CHAPTER 17, Thermochemistry (continued)

GUIDED PRACTICE PROBLEM 12 (page 513)

12. When 50.0 mL of water containing 0.50 mol HCl at 22.5°C is mixed with
50.0 mL of water containing 0.50 mol NaOH at 22.5°C in a calorimeter, the
temperature of the solution increased to 26.0°C. How much heat (in kJ) was
released by this reaction?

a. Calculate the final volume of the water.

\[ V_{\text{final}} = 50.0 \text{ mL} + 50.0 \text{ mL} = 100.0 \text{ mL} \]

b. Calculate the total mass of the water, using the density of water.

\[ m = 100.0 \text{ mL} \times \frac{1.00 \text{ g}}{\text{mL}} = 100. \text{ g} \]

c. Calculate \( \Delta T \).

\[ \Delta T = 26.0 \, ^\circ \text{C} - 22.5 \, ^\circ \text{C} = 3.5 \, ^\circ \text{C} \]

d. Substitute the known quantities into the equation for changes in enthalpy (\( \Delta H \)).

\[ \Delta H = (100. \text{ g}) \times (4.18 \text{ J/(g} \cdot ^\circ \text{C}) \times 3.5 \, ^\circ \text{C} \]

e. Solve.

\[ 1500 \text{ J} \]

f. Convert joules to kilojoules (kJ) and round to three significant figures.

\[ 1500 \text{ J} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 1.5 \text{ kJ} \]

EXTRA PRACTICE (similar to Practice Problem 14, page 516)

14. When carbon disulfide is formed from its elements, heat is absorbed.
Calculate the amount of heat (in kJ) absorbed when 8.53 g of carbon disulfide
is formed.

\[ \text{C(s) + 2S(s) \rightarrow CS}_2(l) \quad \Delta H = 89.3 \text{ kJ} \]

\[ 8.53 \text{ g } \text{CS}_2 \times \frac{89.3 \text{ kJ}}{1 \text{ mol } \text{CS}_2} \times \frac{1 \text{ mol } \text{CS}_2}{76.2 \text{ g } \text{CS}_2} = 10.0 \text{ kJ} \]

GUIDED PRACTICE PROBLEM 22 (page 521)

22. How many grams of ice at 0°C could be melted by the addition of 0.400 kJ
of heat?

a. Write the conversion factors from \( \Delta H_{\text{fus}} \) and the molar mass of ice.

\[ \frac{1 \text{ mol ice}}{6.01 \text{ kJ}} \quad \frac{18.0 \text{ g ice}}{1 \text{ mol ice}} \]

b. Multiply the known heat change by the conversion factors.

\[ 0.400 \text{ kJ} \times \frac{1 \text{ mol ice}}{6.01 \text{ kJ}} \times \frac{18.0 \text{ g ice}}{1 \text{ mol ice}} = 1.20 \text{ g ice} \]

EXTRA PRACTICE (similar to Practice Problem 23, page 524)

23. How much heat (in kJ) is absorbed when 88.45 g H_2O(l) at 100°C and 101.3 kPa
is converted to steam at 100°C? Express your answer in kJ.

\[ 88.45 \text{ g } \text{H}_2\text{O} \times \frac{1 \text{ mol } \text{H}_2\text{O}}{18.0 \text{ g } \text{H}_2\text{O}} \times \frac{40.7 \text{ kJ}}{1 \text{ mol } \text{H}_2\text{O}} = 200 \text{ kJ} \]

192 Guided Reading and Study Workbook