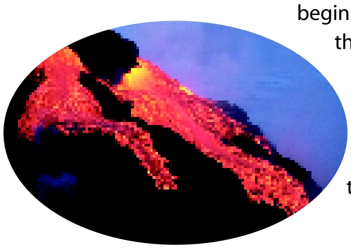
17.1 The Flow of Energy—Heat and Work

Connecting to Your World

Lava flowing out of an erupting volcano is very hot. Its temperature ranges from 550°C to 1400°C. As lava flows down the side of a volcano, it loses heat and begins to cool slowly. In some instances, the lava may flow into the ocean, where it cools more rapidly. In this section, you will learn about heat flow and why some substances cool down or heat up more quickly than others.



Guide for Reading

Key Concepts

- In what direction does heat flow?
- What happens in endothermic and exothermic processes?
- In what units is heat flow measured?
- On what two factors does the heat capacity of an object depend?

Vocabulary

thermochemistry
chemical potential energy
heat
system
surroundings
law of conservation of energy
endothermic process
exothermic process
heat capacity
specific heat

Reading Strategy

Building Vocabulary As you read the section, write a definition of each vocabulary term in your own words.

Energy Transformations

Energy is the capacity for doing work or supplying heat. Unlike matter, energy has neither mass nor volume. Energy is detected only because of its effects—for example, the motion of the race car in Figure 17.1.

Thermochemistry is the study of energy changes that occur during chemical reactions and changes in state. Every substance has a certain amount of energy stored inside it. The energy stored in the chemical bonds of a substance is called **chemical potential energy.** The kinds of atoms and their arrangement in the substance determine the amount of energy stored in the substance.

During a chemical reaction, a substance is transformed into another substance with a different amount of chemical potential energy. When you buy gasoline, you are actually buying the stored potential energy it contains. The controlled explosions of the gasoline in a car's engine transform the potential energy into useful work, which can be used to propel the car. At the same time, however, heat is also produced, making the car's engine extremely hot. Energy changes occur as either heat transfer or work, or a combination of both.

Heat, represented by *q*, is energy that transfers from one object to another because of a temperature difference between them. One of the effects of adding heat to an object is an increase in its temperature. It is the radiant heat of the sun's rays that makes a summer day hot. In this example, the air is the object that absorbs heat and increases in temperature. **Heat always flows from a warmer object to a cooler object.** 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.

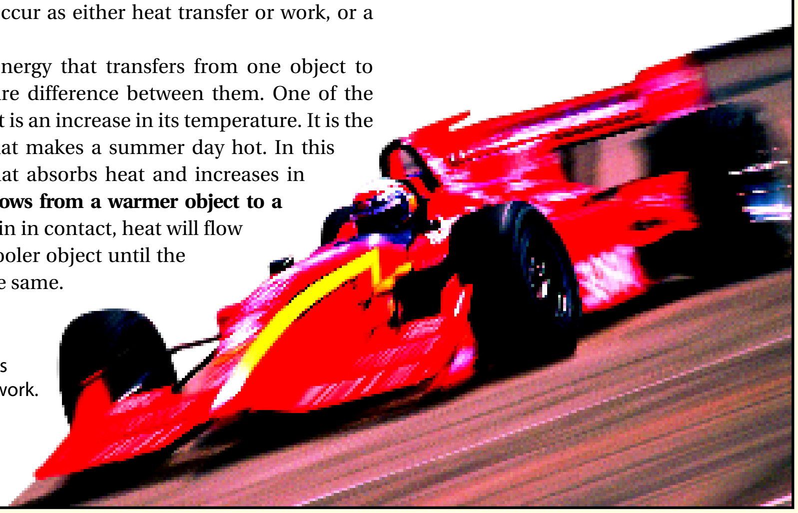


Figure 17.1 When fuel is burned in a car engine, chemical potential energy is released and is used to do work.

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 17.1
- **Core Teaching Resources,** Section 17.1 Review
- **Transparencies,** T180–T182
- **Laboratory Manual,** Lab 34

Technology

- **Interactive Textbook with ChemASAP,** Problem-Solving 17.2, 17.4, Assessment 17.1
- **Go Online,** Section 17.1

17.1

1 FOCUS

Objectives

17.1.1 Explain how energy, heat, and work are related.

17.1.2 Classify processes as either exothermic or endothermic.

17.1.3 Identify the units used to measure heat transfer.

17.1.4 Distinguish between heat capacity and specific heat.

Guide for Reading

Build Vocabulary L2

Paraphrase Ask students to write a definition in their own words for each vocabulary term, and then write a complete sentence with the term.

Reading Strategy L2

Use Prior Knowledge To assess whether students know the difference between temperature and energy, ask, **What does a thermometer measure?** *(average kinetic energy)* **Does a thermometer measure heat?** *(no)*

2 INSTRUCT

Connecting to Your World

Ask, **What happens to the heat in lava once it flows out of a volcano?** *(The heat is released.)* **Why does lava cool more quickly in water than on land?** *(Water has a greater capacity to absorb heat than does air; the temperature difference between the lava and water may be greater than between the lava and the air.)*

Energy Transformations

Use Visuals L1

Figure 17.1 Have students study the photograph of the race car. Ask, **What work is done as the chemical potential energy of the fuel is released?** *(The race car moves around the track.)* **In addition to work, what other type of energy change occurs as the fuel is burned?** *(heat is released)*

Exothermic and Endothermic Processes

Discuss L2

Discuss with students the distinction between kinetic and potential energy. Kinetic energy is the energy associated with an object because of its motion. Potential energy is the energy associated with an object because of its position in a field of force or due to its particular chemical composition. Explain that the potential energy of a reactant or a product in a chemical reaction is determined by the strengths of the attractive and repulsive forces between atoms. In a chemical reaction, atoms are rearranged into new groupings that have different relative potential energies. The change in potential energy is either the result of absorption of energy from the surroundings (endothermic reaction) or the release of energy to the surroundings (exothermic reaction).

TEACHER Demo

An Endothermic Reaction L2

Purpose Students will observe an endothermic reaction between two solids.

Materials barium hydroxide octahydrate, ammonium chloride, 250-mL Erlenmeyer flask with stopper

Safety Barium salts are poisonous if ingested. Inhalation of concentrated ammonia vapors can be dangerous. Perform this demo in a fume hood or a well-ventilated room. Disposal: Flush the solution down the drain with excess water.

Procedure Mix 32 g of barium hydroxide octahydrate ($Ba(OH)_2{\cdot}8H_2O$) with 11 g of ammonium chloride (NH_4Cl) in a 250-mL Erlenmeyer flask fitted with a stopper. Swirl to mix.

Expected Outcome The flask becomes extremely cold. Place the flask on a wet piece of wood and the flask will freeze to the wood.

(Reference: *Chemical Demonstrations* by Bassam Z. Shakhashiri, The University Press, 1983)

Word *Origins*

Exothermic comes from the Greek words *exo,* meaning "outside of," and *therme,* meaning "heat." **Based on the characteristics of endothermic reactions, what do you think the Greek prefix *endo-* means?**

Exothermic and Endothermic Processes

Chemical reactions and changes in physical state generally involve either the release or the absorption of heat. In studying energy changes, you can define a **system** as the part of the universe on which you focus your attention. The **surroundings** include everything else in the universe. In thermochemical experiments, you can consider the region in the immediate vicinity of the system as the surroundings. Together, the system and its surroundings make up the universe. A major goal of thermochemistry is to examine the flow of heat between the system and its surroundings. The **law of conservation of energy** states that in any chemical or physical process, energy is neither created nor destroyed. If the energy of the system decreases during that process, the energy of the surroundings must increase by the same amount so that the total energy of the universe remains unchanged.

In thermochemical calculations, the direction of the heat flow is given from the point of view of the system. An **endothermic process** is one that absorbs heat from the surroundings. **In an endothermic process, the system gains heat as the surroundings cool down.** In Figure 17.2a, the system (the person) gains heat from its surroundings (the fire). Heat flowing into a system from its surroundings is defined as positive; q has a positive value. An **exothermic process** is one that releases heat to its surroundings. **In an exothermic process, the system loses heat as the surroundings heat up.** In Figure 17.2b, the system (the body) loses heat to the surroundings (the perspiration on the skin, and the air). Heat flowing out of a system into its surroundings is defined as negative; q has a negative value because the system is losing heat.

Checkpoint ***What does the law of conservation of energy state?***

Figure 17.2 Heat flow is defined from the point of view of the system. **a** In an endothermic process, heat flows into the system from the surroundings. **b** In an exothermic process, heat flows from the system to the surroundings. In both cases, energy is conserved.
Interpreting Diagrams ***In which process does q have a negative value?***

Word *Origins* L2

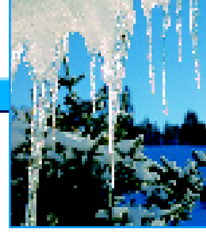
The Greek prefix *endo*-means "within." Some examples of words that use this prefix are *endoskeleton*, *endomorph*, and *endoderm*.

Differentiated Instruction

Less Proficient Readers L1

Have students write definitions for each of the key terms in this chapter. Special attention should be given to those terms that are defined by mathematical relationships. Example calculations showing how to apply the formulas should be included in their notes.

CONCEPTUAL PROBLEM 17.1



Recognizing Exothermic and Endothermic Processes

On a sunny winter day, the snow on a rooftop begins to melt. As the meltwater drips from the roof, it refreezes into icicles. Describe the direction of heat flow as the water freezes. Is this process endothermic or exothermic?

1 Analyze ***Identify the relevant concepts.***

Heat always flows from a warmer object to a cooler object. An endothermic process absorbs heat from the surroundings. An exothermic process releases heat to the surroundings.

2 Solve ***Apply concepts to this situation.***

In order for water to freeze, its temperature must decrease. So heat must flow out of the water (the system). Because heat is released from the system to the surroundings (the air), the process is exothermic.

Practice Problems

1. A container of melted paraffin wax is allowed to stand at room temperature until the wax solidifies. What is the direction of heat flow as the liquid wax solidifies? Is the process exothermic or endothermic?

2. When solid barium hydroxide octahydrate ($Ba(OH)_2 \cdot 8H_2O$) is mixed in a beaker with solid ammonium thiocyanate (NH_4SCN), a reaction occurs. The beaker quickly becomes very cold. Is the reaction exothermic or endothermic?

Interactive Textbook

Problem-Solving 17.2 Solve Problem 2 with the help of an interactive guided tutorial.

with ChemASAP

Units for Measuring Heat Flow

Describing the amount of heat flow requires units different than those used to describe temperature. **Heat flow is measured in two common units, the calorie and the joule.**

You have probably heard of someone exercising to "burn calories." During exercise your body breaks down sugars and fats into carbon dioxide and water, and this process releases heat. Although there is not an actual fire burning the sugars and fats within your body, chemical reactions accomplish the same result. In breaking down 10 g of sugar, for example, your body releases a certain amount of heat. The same amount of heat would be released if 10 g of sugar were completely burned in a fire.

A calorie (cal) is defined as the quantity of heat needed to raise the temperature of 1 g of pure water 1°C. The word *calorie* is written with a small c except when referring to the energy contained in food. The dietary Calorie, written with a capital C, always refers to the energy in food. One dietary Calorie is actually equal to one kilocalorie, or 1000 calories.

$$1 \text{ Calorie} = 1 \text{ kilocalorie} = 1000 \text{ calories}$$

The statement "10 g of sugar has 41 Calories" means that 10 g of sugar releases 41 kilocalories of heat when completely burned.

The joule is the SI unit of energy. One joule of heat raises the temperature of 1 g of pure water 0.2390°C. You can convert between calories and joules using the following relationships.

$$1 \text{ J} = 0.2390 \text{ cal} \qquad 4.184 \text{ J} = 1 \text{ cal}$$

CONCEPTUAL PROBLEM 17.1

Answers

1. Heat flows from the system (paraffin) to the surroundings (air). The process is exothermic.
2. Since the beaker becomes cold, heat is absorbed by the system (chemicals within the beaker) from the surroundings (beaker and surrounding air). The process is endothermic.

Practice Problems Plus L2

Chapter 17 Assessment problem 47 is related to Conceptual Problem 17.1.

Units for Measuring Heat Flow

Discuss L2

Make sure students understand the terms introduced in this section and how to convert from one to another. Students may have difficulty with the distinction between *calorie* and *Calorie* because everyday usage of the terms is often not accurate. The distinction between *heat capacity* and *specific heat* can be hard to remember because the terms are so closely related and sound so similar. Tell students to remember that *specific* heats of different materials can be compared because the quantity of matter involved (1 g) is *specified.*

Facts and Figures

Significant Figures

Point out that the concept of significant figures applies only to measured quantities. Students may wonder why an estimated digit can be considered significant. Tell them a significant figure is one that is known to be reasonably reliable. A careful estimate fits this criterion. On the chalkboard, illustrate different examples—such as a liquid in a graduated cylinder or beaker—and discuss where the estimated digit can occur. Go over the rules for determining which digits are significant and give examples of each. Stress that zeros that serve only as placeholders are not significant. For example, the numbers 3200 and 0.0032 both have 2 significant figures.

Answers to...

Figure 17.2 In the process shown in Figure 17.2b, the system loses heat to its surroundings, so q is negative.

Checkpoint The law of conservation of energy states that in any chemical or physical process, energy is neither created nor destroyed.

Heat Capacity and Specific Heat

Use Visuals L1

Table 17.1 Have students study Table 17.1. Ask, **Which has a higher specific heat capacity—water or steam?** *(water)* **What factors do you think affect the specific heat of each substance?** *(Specific heat is affected by the amount of heat and the change in temperature.)*

Go Online NSTA SCILINKS

Download a worksheet on **Specific Heat** for students to complete, and find additional teacher support from NSTA SciLinks.

CLASS Activity

Heat Transfer L2

Purpose Students will compare heat transfer of different materials.

Materials sheet metal (13 cm × 18 cm), Styrofoam™ (13 cm × 18 cm), wood (40 cm × 20 cm), glue

Procedure Glue a 13 cm × 18 cm piece of sheet metal and a 13 cm × 18 cm piece of Styrofoam™ to a piece of wood that is about 40 cm × 20 cm. Pass the wood around the classroom, and ask students to put their hands on each of the three surfaces and describe the temperature of each.

Expected Outcome Usually students indicate that the metal feels the coldest and the Styrofoam™ feels the same temperature as their hands. Explain that all of the surfaces are colder than their hand, and that heat is being transferred from their hand to those surfaces. Metals conduct heat away from the hand more efficiently than Styrofoam™, so they feel colder than Styrofoam™.

Go Online NSTA SCILINKS

For: Links on specific heat
Visit: www.SciLinks.org
Web Code: cdn-1171

Heat Capacity and Specific Heat

The amount of heat needed to increase the temperature of an object exactly 1°C is the **heat capacity** of that object. **The heat capacity of an object depends on both its mass and its chemical composition.** The greater the mass of the object, the greater its heat capacity. One of the massive steel girders in Figure 17.3, for example, requires much more heat to raise its temperature 1°C than a small steel nail does. Similarly, a cup of water has a much greater heat capacity than a drop of water.

Different substances with the same mass may have different heat capacities. On a sunny day, a 20-kg puddle of water may be cool, while a nearby 20-kg iron sewer cover may be too hot to touch. This situation illustrates how different heat capacities affect the temperature of objects. Assuming that both the water and the iron absorb the same amount of radiant energy from the sun, the temperature of the water changes less than the temperature of the iron because the specific heat capacity of water is larger.

The specific heat capacity, or simply the **specific heat,** of a substance is the amount of heat it takes to raise the temperature of 1 g of the substance 1°C. Table 17.1 gives specific heats for some common substances. Water has a very high specific heat compared with the other substances in the table. You can see from the table that one calorie of heat raises the temperature of 1 g of water 1°C. Metals, however, have low specific heats. One calorie of heat raises the temperature of 1 g of iron 9°C. So water has a specific heat nine times that of iron. Heat affects the temperature of objects with a high specific heat much less than the temperature of those with a low specific heat.

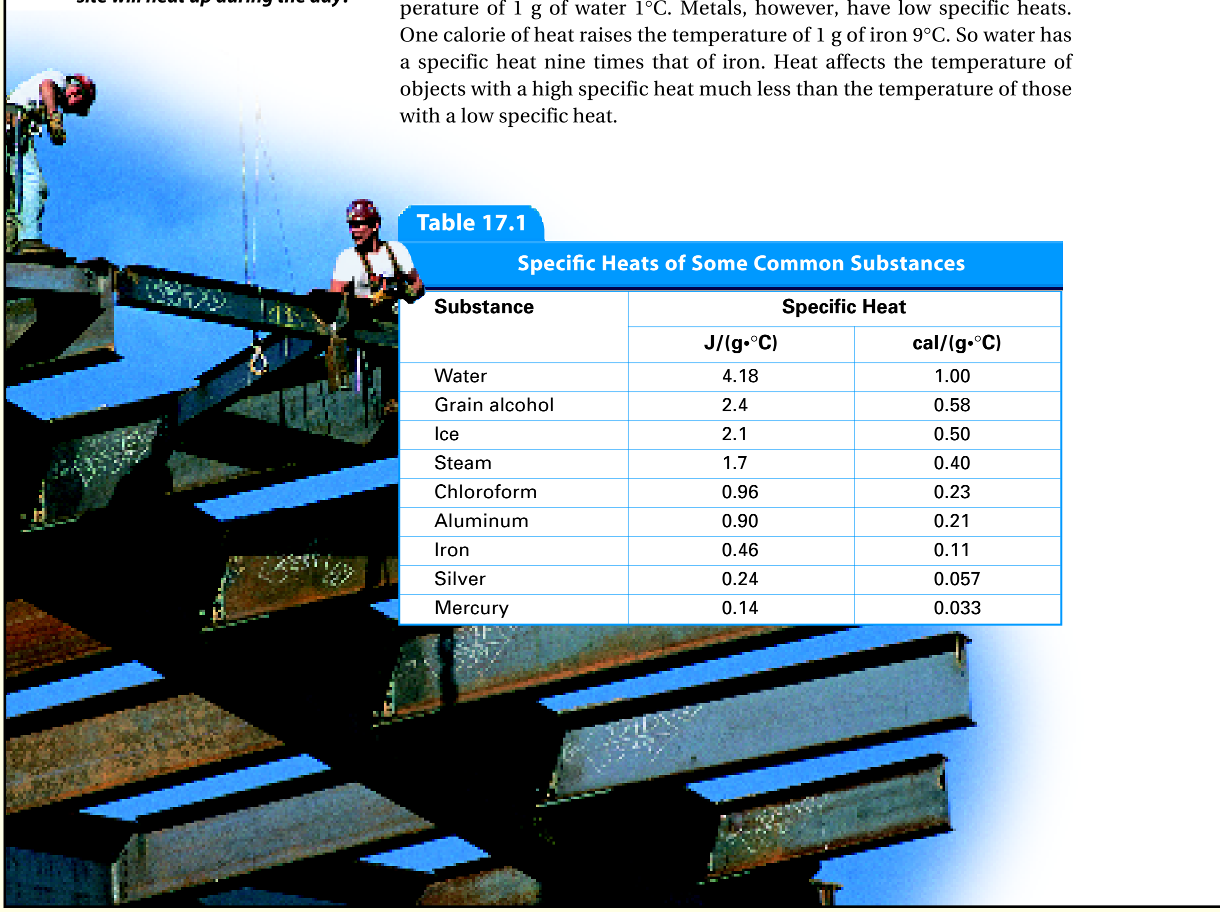


Figure 17.3 A massive steel girder has a higher heat capacity than a steel nail. **Inferring** ***What factors affect how quickly the different areas of a construction site will heat up during the day?***

Table 17.1

Specific Heats of Some Common Substances

Substance	Specific Heat	
	J/(g•°C)	cal/(g•°C)
Water	4.18	1.00
Grain alcohol	2.4	0.58
Ice	2.1	0.50
Steam	1.7	0.40
Chloroform	0.96	0.23
Aluminum	0.90	0.21
Iron	0.46	0.11
Silver	0.24	0.057
Mercury	0.14	0.033

Figure 17.4 Water releases a lot of heat as it cools. **a** During freezing weather, farmers protect citrus crops by spraying them with water. The ice that forms has a protective effect as long as its temperature does not drop below 0°C. **b** Because it is mostly water, the filling of a hot apple pie is much more likely to burn your tongue than the crust.

Just as it takes a lot of heat to raise the temperature of water, water also releases a lot of heat as it cools. Water in lakes and oceans absorbs heat from the air on hot days and releases it back into the air on cool days. This property of water is responsible for moderate climates in coastal areas. Figure 17.4 illustrates two other common effects associated with the high specific heat of water. The orange trees in Figure 17.4a have been sprayed with water to protect the fruit from frost damage during icy weather. As the water freezes, it releases heat, which helps prevent the fruit from freezing. In Figure 17.4b, the label on a box of apple pie warns that the "filling is hot." When a freshly baked apple pie comes out of the oven, both the filling and crust are at the same temperature. However, the filling, which is mostly water, has a higher specific heat than the crust. In order to cool down, the filling must give off a lot of heat. This is why you have to be careful not to burn your tongue when eating hot apple pie.

To calculate the specific heat (C) of a substance, you divide the heat input by the temperature change times the mass of the substance.

$$C = \frac{q}{m \times \Delta T} = \frac{\text{heat (joules or calories)}}{\text{mass (g)} \times \text{change in temperature (°C)}}$$

In the equation above, q is heat and m is mass. The symbol ΔT (read "delta T") represents the change in temperature. ΔT is calculated from the equation $\Delta T = T_f - T_i$, where T_f is the final temperature and T_i is the initial temperature. As you can see from the equation, specific heat may be expressed in terms of joules or calories. Therefore, the units of specific heat are either J/(g·°C) or cal/(g·°C).

Checkpoint ***What is the relationship between specific heat and heat capacity?***

Thinking Critically L3

Show students a map of California and discuss the difference in temperature between a coastal city such as San Francisco and an inland city such as Fresno. Ask students to explain a remark once made by Mark Twain: "The coldest winter I ever spent was the summer I spent in San Francisco." *(The relatively high heat capacity of the large bodies of water near San Francisco help to moderate local temperatures. During summer, the ocean water warms slowly as it absorbs large amounts of heat from warm air masses. Onshore breezes off the cool water keep coastal land temperatures from rising to match those of inland areas. Condensation of water vapor in the air produces a cool fog, which probably enhanced Mark Twain's impression of the cool of San Francisco summers.)*

Use Visuals L1

Figure 17.4 Have students refer to Figure 17.4. Discuss how spraying fruit and flooding orchards with a few inches of water can keep the fruit from freezing. *(As water cools and freezes, it releases energy that can warm the air and protect the fruit.)*

Facts and Figures

Dietary Calories

Your proper caloric intake depends on your level of physical activity. In an eight-hour day at a desk, you burn about 800 Calories. This is about the number of Calories in two helpings of spaghetti. When exercising, however, you become a relative biochemical blast furnace. In vigorous activities such as running and jumping, you expend 7–10 Calories per minute, or 420–600 Calories per hour. At these rates, a runner who covers a 26-mile marathon course in 3 hours might expend 1800 Calories, or the equivalent of 4.5 helpings of spaghetti. Have students do research to compare the energy expended (in Calories per minute) during several types of sports related and non–sports related activities.

Answers to...

Checkpoint The specific heat is the heat capacity of an object divided by its mass in grams.

Sample Problem 17.1

Answers

3. 2.0 J/(g•°C)
4. 1.8 kJ

Practice Problems Plus L2

How much heat is required to raise the temperature of 400.0 g of silver 45°C? *(4.3×10^3 J)*

Math Handbook

For a math refresher and practice, direct students to algebraic equations, page R69.

3 ASSESS

Evaluate Understanding L2

Place an ice cube in a beaker of cool water. Have students discuss the flow of heat when the ice and water are the system and surroundings, respectively, and when the ice/water mixture and a 37°C room are the system and surroundings, respectively.

Reteach L1

Emphasize that substances vary in their response to an input of heat. A given amount of heat raises the temperature of some substances (such as metals) far more than others (such as nonmetals). Point out that specific heat is a property of a substance. It is a measure of the ability of a substance to store heat.

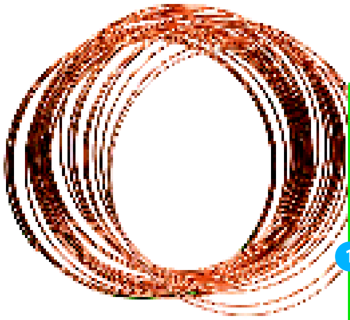
Writing Activity

The water has a higher heat capacity than the concrete. Thus, the sun's heat raises the temperature of the concrete more than that of the water.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 17.1.

with ChemASAP



SAMPLE PROBLEM 17.1

Calculating the Specific Heat of a Metal

The temperature of a 95.4-g piece of copper increases from 25.0°C to 48.0°C when the copper absorbs 849 J of heat. What is the specific heat of copper?

1 Analyze *List the knowns and the unknown.*

Knowns
- $m_{Cu} = 95.4 g$
- $\Delta T = (48.0°C - 25.0°C) = 23.0°C$
- $q = 849$ J

Unknown
- $C_{Cu} = ?$ J/(g·°C)

2 Calculate *Solve for the unknown.*

Use the known values and the definition of specific heat, $C = \frac{q}{m \times \Delta T}$, to calculate the unknown value C_{Cu}.

$$C_{Cu} = \frac{q}{m \times \Delta T} = \frac{849\ \text{J}}{95.4\ \text{g} \times 23.0°\text{C}} = 0.387\ \text{J/(g·°C)}$$

3 Evaluate *Does the result make sense?*

Water has a very high specific heat (4.18 J/(g·°C)). Metals, however, have low specific heats, so the calculated value of 0.387 J/(g·°C) seems reasonable.

Math Handbook

For help with algebraic equations, go to page R69.

Practice Problems

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?
4. How much heat is required to raise the temperature of 250.0 g of mercury 52°C?

Interactive Textbook

Problem-Solving 17.4 Solve Problem 4 with the help of an interactive guided tutorial.

with ChemASAP

17.1 Section Assessment

5. **Key Concept** In what direction does heat flow between two objects?
6. **Key Concept** How do endothermic processes differ from exothermic processes?
7. **Key Concept** What units are used to measure heat flow?
8. **Key Concept** On what factors does the heat capacity of an object depend?
9. Using calories, calculate how much heat 32.0 g of water absorbs when it is heated from 25.0°C to 80.0°C. How many joules is this?
10. A chunk of silver has a heat capacity of 42.8 J/°C and a mass of 181 g. Calculate the specific heat of silver.
11. How many kilojoules of heat are absorbed when 1.00 L of water is heated from 18°C to 85°C?

Writing Activity

Explanatory Paragraph Use the concept of heat capacity to explain why on a sunny day the concrete deck around an outdoor swimming pool becomes hot, while the water stays cool.

Interactive Textbook

Assessment 17.1 Test yourself on the concepts in Section 17.1.

with ChemASAP

Section 17.1 Assessment

5. Heat flows from the object of higher temperature to the object of lower temperature.
6. Endothermic processes absorb heat from the surroundings; exothermic processes release heat to the surroundings.
7. calories and joules
8. mass and chemical composition
9. 1.76×10^3 cal (1.76 kcal); 7.36×10^3 J (7.36 kJ)
10. 2.36×10^{-1} J/(g•°C)
11. 2.8×10^2 kJ